Applied Statistical Modelling and Reliability Assessment of Digital Transformation Effects on Sustainable Business Model Performance: Panel Data Evidence from China's Manufacturing Sector

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Abstract

This paper examines how digital transformation affects sustainable business model performance in Chinese listed manufacturing firms from 2019 to 2023. A composite measurement system is built for digital maturity, green business practices, green finance, and sustainable performance. Reliability testing, descriptive statistics, Pearson correlations, two-way fixed-effects panel regression, robustness checks, mediation and moderation models, Sobel and Bootstrap tests, and structural equation modelling are jointly employed. The results show a positive association between digital transformation and sustainable business model performance ($\beta = 0.369$, $p < 0.01$). Green business practices partially mediate this relationship and explain 30.89% of

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the total effect, while green financial support strengthens the link (interaction $\beta = 0.087$, $p < 0.05$). The findings provide statistically reliable evidence that digital capability, green operations, and external finance jointly improve sustainable business outcomes.

Keywords: Applied statistical modelling, reliability assessment, panel data analysis, structural equation modelling, mediation-moderation analysis, measurement validity, digital transformation, sustainable business model performance, green finance.

1 Introduction

The rapid expansion of the digital economy has made enterprise transformation increasingly dependent on measurable data capability, statistical evaluation, and evidence-based management. Digital transformation [1, 2], supported by cloud computing, big data, artificial intelligence, and information infrastructure, reshapes production systems, operating routines, and organisational coordination. At the same time, carbon-neutrality targets [3, 4] and green development policies require firms to report reliable performance across environmental, social, and economic dimensions. Sustainable business models [5, 6] therefore raise a statistical issue as well as a managerial one: the effect of digital maturity on sustainable performance must be measured, tested, and verified under heterogeneous enterprise conditions. Although existing studies have examined individual technologies or single performance indicators, fewer papers evaluate measurement reliability, the mediating role of green business practices, and the moderating role of green financial support within a unified empirical design. This paper responds to that gap by constructing a digital maturity scale covering technology platforms, data governance, organisational change, and strategic planning, and by testing its direct, mediated, and moderated effects on sustainable business model performance.

Green business practices form a credible transmission channel through which digital capability is converted into observable sustainable outcomes. These practices include green design, green supply chain management, cleaner production, environmental monitoring, and circular-economy activities. Prior research suggests that digital technologies [7, 8] can improve resource allocation and environmental traceability, but technology expenditure by itself does not automatically generate stable sustainability gains. The effectiveness of green practices is likely to depend on organisational capability, financing constraints, and external incentives. Green financial instruments [9, 10], including green bonds and ESG-oriented funds, can lower financing barriers, improve environmental disclosure, and support low-carbon projects through risk-pricing mechanisms. Yet the statistical interaction between digital transformation and green financial support remains insufficiently tested with longitudinal enterprise data. This study therefore treats green business practices as a mediator and green financial support intensity as a moderator, enabling the empirical analysis to identify both the transmission path and the boundary condition of the digitalisation-performance relationship.

Accordingly, the research gap is twofold. First, previous work has not sufficiently examined whether measurements of digital transformation, green practices, and sustainable performance are reliable enough for multivariate statistical inference. Second, evidence remains limited on whether green finance changes the strength of the effect of digital maturity on sustainable business model performance. The rationale of this study is to provide an applied statistical framework that links construct reliability, panel-data identification, mediation-moderation testing, and SEM validation. Its originality lies in treating the digital-green-finance mechanism not only as a conceptual managerial relationship, but also as a statistically testable reliability problem in enterprise sustainability assessment. Drawing on dynamic capability theory and stakeholder theory, this paper proposes the following hypotheses to examine how digital technology, green practice, and financial support jointly influence sustainable performance.

Research Hypothesis

- **H1:** The higher the level of digital transformation, the better the performance of the enterprise's sustainable business model.
- **H2:** Green business practices mediate the relationship between the level of digital transformation and sustainable business model performance.
- **H3:** The higher the intensity of financial support for green investment, the stronger the positive impact of the level of digital transformation on the performance of sustainable business models.

2 Related Work

Digital transformation has become an important driver of enterprise competitiveness and sustainable development. Scholars generally define and measure it across technological, organisational, and strategic dimensions, including IT infrastructure construction [11, 12], data governance, digital strategic planning, and coordination across business units. A higher level of digital maturity [13, 14] may improve operating efficiency, innovation capacity, environmental monitoring, and resource optimisation, thereby affecting carbon reduction, social responsibility, and economic returns. For readers of reliability and statistical studies, however, the central issue is not only whether digital transformation matters, but whether its effect can be measured reliably and statistically identified. Existing studies often rely on regression analysis [19, 20] or structural equation modelling [21, 22], yet many do not combine measurement reliability, mediation analysis, moderation testing, and robustness checks within the same empirical design. This methodological fragmentation leaves room for a more systematic examination of the pathways linking digital maturity to sustainable business performance.

Green business practices are widely regarded as an operational pathway for sustainable development, covering green product design [23, 24], cleaner production, green supply chain management, and circular-economy models. Digital technologies [25, 26] can support these practices by improving energy management through data analytics, strengthening traceability through platform systems, and improving environmental information disclosure [27, 28]. At the same time, green finance [29, 30] provides external resources that may alter the strength of the digitalisation-performance relationship. Although prior studies have begun to discuss these links, cross-sectional evidence and single-equation models often limit the reliability of their conclusions. A panel-data design with fixed effects, subsample analysis, Bootstrap inference, and SEM-based validation can provide a more dependable statistical basis for assessing whether green finance and green business practices jointly shape sustainable business model performance.

Against this background, the present study positions sustainable business model performance as an applied statistical outcome rather than a purely strategic label. It links construct-level reliability testing with longitudinal regression and SEM-based validation, which helps clarify whether the observed digitalisation effect is stable across measurement choices, enterprise scales, and model specifications. This emphasis on measurement reliability, robustness, and interpretable inference is consistent with the methodological scope of reliability and statistical studies.

3 Methods

3.1 Sample Source and Index Measurement

The sample consists of manufacturing companies listed on the Shanghai and Shenzhen Stock Exchanges and observed over the five-year period from 2019 to 2023. The digital transformation level (DTL) and green business practices (GBP) are measured using a self-compiled questionnaire developed with reference to existing scales. The questionnaire covers IT infrastructure, data governance, organisational coordination, digital strategy, green production, and green supply chain practices, and it uses a five-point Likert scale. Green investment financial support intensity (IFSI) and sustainable business model performance (SBMP) are obtained from the Wind database and corporate annual reports. IFSI is measured as the ratio of annual green bond issuance to total financing. SBMP is constructed as a standardised triple-bottom-line composite index covering environmental, social, and economic performance. This measurement design combines perceptual scale information with objective financial and sustainability indicators, thereby improving the empirical basis for applied statistical modelling.

Control variables include firm size (FS, measured by the natural logarithm of total assets), capital structure (CS, measured by the debt-to-asset ratio), and firm age (FA, measured by years since registration). These variables are extracted from the Wind and CSMAR databases. During preprocessing, observations with more than 15% missing information are removed, and remaining missing values are treated through multiple imputation. Continuous variables are standardised using Z-scores to reduce scale effects and improve comparability across indicators. The final dataset covers 36 manufacturing sub-industries and 412 listed firms, generating 1,020 firm-year observations for the panel regression and SEM analyses. This panel structure supports reliability assessment, multivariate inference, and robustness testing without altering the original data source or measurement logic.

The variables are selected as shown in Table 1.

Reliability and validity testing is used to assess whether the multi-item scales provide stable and internally consistent measurements of the intended latent constructs. Cronbach's alpha evaluates internal consistency, composite reliability (CR) assesses construct reliability, and average variance extracted (AVE) examines convergent validity. Discriminant validity is assessed by comparing each construct's AVE with its squared correlations with other constructs. These procedures are central to the journal's statistical orientation

Table 1 Variable selection

Variable Types	Variable Name	Measuring Indicators
Independent variable (X)	Level of digital transformation	– Likert 5-point scale, multi-dimensional items (IT infrastructure, data governance, organizational collaboration, digital strategy, etc.) average score
Mediator Variable (M)	Green Business Practices	– Likert 5-level scale, covering green production, green supply chain, green marketing, circular economy practice, etc., taking the average score
Adjusted variable (W)	Intensity of financial support for green investment	– Annual green bond issuance as a percentage of total financing
Dependent variable (Y)	Sustainable business model performance	– Triple bottom line composite index: • Environmental performance (carbon reduction rate) • Social performance (CSR score) • Economic performance (green revenue growth rate)
Control variables	Enterprise scale	– Natural logarithm of total assets
	Capital Structure	– Debt-to-asset ratio
	Years of Establishment	– Years of establishment of the company (business registration information)

Table 2 Reliability and validity test results

Concept	Cronbach's α	Composite Reliability CR	Average Variance Extraction AVE
Level of digital transformation	0.876	0.901	0.652
Green Business Practices	0.892	0.915	0.682
Sustainable business model performance	0.835	0.872	0.601

because unreliable measurement would introduce random error and weaken subsequent regression, mediation, and SEM-based inference. The reliability and validity test results are reported in Table 2.

Table 2 shows that the Cronbach's alpha values of the three major constructs are all above 0.8, indicating satisfactory internal consistency. The CR values exceed 0.87, which further confirms construct reliability. The AVE values are all above 0.60, showing that the observed items explain a sufficient proportion of variance in their respective latent variables. In addition, the AVE values are higher than the squared correlations between constructs,

Table 3 Descriptive statistics

Variable	N	Mean	Standard Deviation	Minimum	Maximum
Level of digital transformation	412	3.21	0.57	1.80	4.75
Green Business Practices	412	3.34	0.61	1.67	4.83
Intensity of financial support for green investment	412	0.12	0.09	0.00	0.45
Sustainable business model performance	412	0.00	1.00	−1.85	2.37
Enterprise scale	412	22.10	0.94	20.35	24.56
Capital Structure	412	0.52	0.18	0.10	0.85
Years of Establishment	412	15.20	7.30	1	45

suggesting acceptable discriminant validity. Overall, the measurement model satisfies common reliability and validity requirements and is suitable for subsequent fixed-effects regression, mediation analysis, and SEM estimation.

Descriptive statistics are used to summarise the central tendency, dispersion, and range of the sample variables. This step is not merely descriptive; it functions as statistical quality control by showing whether the variables contain implausible values, excessive dispersion, or distributional patterns that may affect regression and SEM assumptions. The descriptive statistics are shown in Table 3.

As shown in Table 3, the mean DTL value is 3.21 with a standard deviation of 0.57, indicating that the digital transformation level of the sample firms is generally above the midpoint and moderately dispersed. GBP has a mean of 3.34 and a standard deviation of 0.61, suggesting that green practices are implemented to a reasonable degree but still vary across firms. The mean IFSI is 0.12, showing that green financial instruments account for a relatively small share of total financing and that access to such instruments is uneven. Because SBMP is standardized, its mean is 0 and its standard deviation is 1, which is appropriate for model estimation. For the control variables, firm size is relatively concentrated, capital structure indicates moderate leverage, and firm age shows meaningful variation. Overall, the dataset does not display obvious extreme values and is suitable for multivariate statistical analysis.

Pearson correlation analysis is conducted to examine the initial linear relationships among variables and to provide a preliminary check before multivariate model estimation. The results are shown in Table 4.

Table 4 reports a significant positive correlation between DTL and SBMP ($r = 0.47$, $p < 0.01$), which is consistent with the expected direction of

Table 4 Correlation analysis

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DTL	1						
GBP	0.53***	1					
	(0.000)						
IFSI	0.36***	0.42***	1				
	(0.000)	(0.000)					
SBMP	0.47***	0.51***	0.39***	1			
	(0.000)	(0.000)	(0.000)				
FS	0.29**	0.24**	0.18**	0.31***	1		
	(0.014)	(0.028)	(0.037)	(0.009)			
CS	−0.18**	−0.15*	−0.13	−0.22**	0.06	1	
	(0.030)	(0.086)	(0.112)	(0.017)	(0.212)		
FA	0.21**	0.18**	0.17**	0.20**	0.08	−0.10	1
	(0.01)	(0.022)	(0.045)	(0.031)	(0.136)	(0.158)	

Note: ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$. The correlation coefficient r is above the table cell, and the significance level is below. Weak correlation: 0.00–0.30; moderate correlation 0.30-0.50; strong correlation: 0.50–1.00.

H1. GBP is significantly correlated with both DTL ($r = 0.53$, $p < 0.01$) and SBMP ($r = 0.51$, $p < 0.01$), providing preliminary support for the proposed mediating path. IFSI is also positively correlated with SBMP ($r = 0.39$, $p < 0.01$), suggesting that green financial support may contribute to sustainable performance and may also condition the digitalization effect. Among the control variables, firm size is positively related to SBMP, while capital structure is negatively related to SBMP. These correlations justify the inclusion of control variables and the use of fixed-effects estimation to reduce omitted-variable bias.

3.2 Statistical Modelling and Data Analysis

A two-way fixed-effects panel model is used to estimate the direct association between digital transformation and sustainable business model performance while controlling for firm-specific and year-specific unobserved heterogeneity:

$$SBMP_{\mathrm{it}} = \alpha_0 + \alpha_1 DTL_{it} + \sum \beta_k Control_{kit} + \mu_i + \lambda_t + \epsilon_{it} \qquad (1)$$

In Formula (1), i denotes the firm, t denotes the year, alpha_i represents firm fixed effects, lambda_t represents year fixed effects, X_it denotes the control variables (FS, CS, and FA), and epsilon_it is the disturbance term.

The two-way fixed-effects specification controls for unobservable firm-level characteristics that are stable over time and for annual macroeconomic shocks affecting all firms. This setting improves the reliability of statistical inference by reducing omitted-variable bias and by distinguishing the effect of digital transformation from time-invariant enterprise heterogeneity and common year-level fluctuations.

The mediation effect is examined using the Baron and Kenny three-step procedure, supplemented by Sobel testing and Bootstrap confidence intervals. The three-step procedure clarifies whether DTL affects SBMP directly, whether DTL affects the mediator GBP, and whether GBP remains significant when both DTL and GBP are included in the outcome model. The additional Sobel and Bootstrap tests strengthen the reliability of indirect-effect inference and reduce dependence on a single testing criterion.

Step 1: Regression of independent variables on dependent variables
Step 2: Regression of independent variables on mediating variables

$$GBP_{\mathrm{it}} = \gamma_0 + \gamma_1 DTL_{it} + \sum \beta_k Control_{kit} + \mu_i + \lambda_t + \eta_{it} \tag{2}$$

Step 3: Independent variables and mediating variables are regressed on the dependent variable

$$\begin{aligned} SBMP_{it} = \delta_0 + \delta_1 DTL_{it} + \delta_2 GBP_{it} \\ + \sum \beta_k Control_{kit} + \mu_i + \lambda_t + \zeta_{it} \end{aligned} \tag{3}$$

To test the moderating role of green finance, the interaction term between IFSI and DTL is introduced into the fixed-effects model:

$$\begin{aligned} SBMP_{it} = \theta_0 + \theta_1 DTL_{it} + \theta_2 IFSI_{it} + \theta_3 (DTL_{it} \times IFSI_{it}) \\ + \sum \beta_k Control_{kit} + \mu_i + \lambda_t + \nu_{it} \end{aligned} \tag{4}$$

4 Empirical Results and Statistical Reliability Checks

4.1 Benchmark Regression Results

The benchmark regression results are shown in Table 5.

The benchmark results in Table 5 show that DTL has a significant positive effect on SBMP. In Model (1), without control variables, the coefficient is 0.412 ($p < 0.01$) with a standard error of 0.061. Firms with

Table 5 Benchmark regression results

Dependent variable: SBMP	(1)	(2)
DTL	0.412***	0.369***
	(0.061)	(0.058)
FS		0.085**
		(0.039)
CS		−0.021
		(0.027)
FA		0.014
		(0.011)
N	1020	1020
R^2	0.311	0.384
Individual fixed effects	Included	Included
Year fixed effects	Included	Included

Note: ***p < 0.01, **p < 0.05, *p < 0.10. Column (1) does not include control variables. Column (2) includes control variables. The regression coefficient is above each cell, with a significant asterisk on the right and the standard error below.

stronger digital transformation capabilities therefore tend to report higher sustainable business model performance. The result is statistically significant and practically meaningful because the dependent variable combines environmental, social, and economic performance after standardisation. This finding supports H1 and suggests that digital infrastructure, data governance, organisational coordination, and strategic integration are associated with measurable improvements in sustainable performance.

After firm size, capital structure, and firm age are added in Model (2), DTL remains significantly positive (coefficient = 0.369, $p < 0.01$; standard error = 0.058). Firm size is also positive and significant, implying that larger firms may have stronger resources for sustainability-oriented transformation. Capital structure and firm age are not statistically significant in this specification. The R-squared value increases from 0.311 to 0.384 after adding controls, indicating improved explanatory power. More importantly, the stability of the DTL coefficient across specifications suggests that the main finding is not driven by basic firm characteristics.

The two-way fixed-effects model strengthens the reliability of the benchmark conclusion by controlling for firm-specific unobservable characteristics and year-level shocks. Under this setting, the positive relationship between DTL and SBMP remains statistically significant, supporting the interpretation that digital transformation is a stable predictor of sustainable business model performance. From an applied statistical perspective, this result provides a consistent baseline for the subsequent robustness, mediation, moderation, and SEM analyses.

4.2 Robustness Test

To examine the robustness of the benchmark result, this study replaces the original DTL variable with enterprise information technology investment intensity (ITII). ITII is measured as the proportion of annual information-technology-related expenditure in operating income. Compared with the broader DTL scale, ITII captures the financial investment dimension of digitalisation. If the estimated effect remains significant under this alternative operational definition, the conclusion that digital transformation improves SBMP can be regarded as more statistically reliable.

The regression analysis results of variable substitution are:

The alternative-variable regression results are reported in Table 6. In Model (1), ITII has a significant positive effect on SBMP (coefficient = 0.282, $p < 0.01$), indicating that greater investment in information technology is associated with better sustainable business model performance. This finding supports the benchmark result from an investment-based

Table 6 Regression analysis results of variable substitution

Dependent Variable: SBMP	(1)	(2)
ITI	0.282***	0.245***
	(0.069)	(0.064)
FS		0.137**
		(0.057)
CS		−0.089
		(0.062)
FA		0.076*
		(0.045)
N	1020	1020
R^2	0.211	0.317
Individual fixed effects	Included	Included
Year fixed effects	Included	Included

Note: ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$. Column (1) does not include control variables. Column (2) includes control variables. The regression coefficient is above each cell, with a significant asterisk on the right and the standard error below.

Table 7 Regression analysis results after dividing the enterprise size

Dependent Variable: SBMP	(1)	(2)	(3)	(4)
DTL	0.426***	0.385***	0.198*	0.164*
	(0.077)	(0.069)	(0.101)	(0.096)
FS		0.132**		0.089
		(0.057)		(0.061)
CS		−0.058		−0.093
		(0.049)		(0.063)
FA		0.029		0.017
		(0.024)		(0.022)
N	510	510	510	510
R2	0.327	0.392	0.148	0.191
Individual fixed effects	Included	Included	Included	Included
Year fixed effects	Included	Included	Included	Included

Note: ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$. Columns (1) and (2) are respectively large and medium-sized enterprises without and with control variables. Columns (3) and (4) are respectively small enterprises without and with control variables. The regression coefficient is above each cell, the significance asterisk is on the right, and the standard error is below.

measurement perspective and suggests that digital resource allocation contributes to sustainability through process optimisation, resource coordination, and data-driven management.

After control variables are added in Model (2), the ITII coefficient remains positive and significant (coefficient = 0.245, $p < 0.01$). Firm size and firm age also show positive effects, while capital structure remains statistically insignificant. The consistent direction and significance of ITII under both specifications indicate that the main effect is not sensitive to the choice of digitalisation measure. This robustness test strengthens H1 and improves the statistical reliability of the empirical conclusion.

Sub-sample analysis is further used to test whether the digitalisation effect differs across firm sizes. Large and medium-sized enterprises and small enterprises may differ in resource allocation, technology absorption, organisational structure, and policy responsiveness. Separate regression analysis identifies heterogeneity, clarifies the applicability boundary of the main result, and improves the practical interpretability of the statistical findings.

The regression analysis results after dividing the enterprise size are shown in Table 7.

The sub-sample results in Table 7 show clear heterogeneity by enterprise size. For large and medium-sized enterprises, DTL has a strongly significant positive effect on SBMP in both the model without controls and the model with controls (coefficients = 0.426 and 0.385, respectively). The relatively higher R-squared values also indicate better model fit in this group. These findings suggest that larger firms are more capable of translating digital tools into green performance, social responsibility, and economic outcomes because they usually have stronger resource integration capacity and more mature organisational systems.

For small enterprises, the DTL coefficients remain positive but are weaker and only significant at the 10% level (0.198 and 0.164). This pattern indicates that digital transformation still contributes to sustainable performance among smaller firms, although the effect is less stable and more constrained by resource limitations. From a statistical perspective, the result confirms the general direction of the main effect while showing that firm size changes the strength and reliability of the estimated relationship. Policy support and external financing may therefore be particularly important for small enterprises seeking to convert digital investment into sustainable outcomes.

4.3 Moderating Effect

Introducing the interaction term between IFSI and DTL allows the study to test whether green financial support changes the strength of the digitalisation-performance relationship. This moderation analysis evaluates the boundary condition of the main effect and helps determine whether external green finance improves the effectiveness and reliability of digital transformation in supporting sustainable business models.

The results of the moderation effect are shown in Table 8.

Table 8 reports the moderation results. The interaction term DTL $\times$ IFSI is positive and significant in both specifications (0.098, $p < 0.05$; 0.087, $p < 0.05$), indicating that green financial support strengthens the positive relationship between digital transformation and SBMP. In other words, firms with stronger access to green financing are better able to convert digital capability into sustainable performance. The main effects of DTL and IFSI are also statistically significant, confirming that both internal digital capability and external financial support contribute to sustainable outcomes.

After control variables are included, the coefficients of DTL, IFSI, and the interaction term remain stable, which supports the robustness of the moderation effect. The increase in R-squared from 0.314 to 0.368 indicates that adding control variables and the interaction term improves model explanation. These findings support H3 and show that green finance operates as a

Table 8 Moderating effect results

Dependent Variable: SBMP	(1)	(2)
DTL	0.282***	0.257***
	(0.061)	(0.058)
IFSI	0.146**	0.131**
	(0.065)	(0.063)
DTL× IFSI	0.098**	0.087**
	(0.043)	(0.041)
FS		0.073*
		(0.038)
CS		−0.042
		(0.033)
FA		0.012
		(0.021)
N	1020	1020
R^2	0.314	0.368
Individual fixed effects	Included	Included
Year fixed effects	Included	Included

Note: ***p < 0.01, **p < 0.05, *p < 0.10. Column (1) does not include control variables. Column (2) includes control variables. The regression coefficient is above each cell, with a significant asterisk on the right and the standard error below.

statistically significant external condition under which digital transformation produces stronger sustainable performance.

4.4 Mediation Effect

The regression results of the mediation effect are shown in Table 9.

The mediation analysis follows the Baron and Kenny three-step approach, and the results in Table 9 support the mediating role of GBP between DTL and SBMP. In the first step, DTL significantly predicts SBMP (0.369, $p < 0.01$). In the second step, DTL significantly predicts GBP (0.287, $p < 0.01$). In the third step, when DTL and GBP are entered together, GBP remains significant (0.428, $p < 0.01$), while the DTL coefficient decreases from 0.369 to 0.246 but remains significant. This pattern indicates partial mediation rather than full mediation.

The mediation result suggests that digital transformation affects sustainable business model performance through both a direct channel and an indirect channel via green business practices. Digitally mature firms

Table 9 Mediation effect regression

Variable	(1) Dependent Variable: SBMP	(2) Dependent Variable: GBP	(3) Dependent Variable: SBMP
DTL	0.369***	0.287***	0.246***
	(0.058)	(0.055)	(0.061)
GBP			0.428***
			(0.069)
FS	0.085**	0.062*	0.064*
	(0.039)	(0.037)	(0.036)
CS	−0.021	−0.018	−0.020
	(0.027)	(0.025)	(0.026)
FA	0.014	0.012	0.013
	(0.011)	(0.010)	(0.011)
N	1020	1020	1020
R^2	0.384	0.336	0.419
Individual fixed effects	Included	Included	Included
Year fixed effects	Included	Included	Included

Note: ***p < 0.01, **p < 0.05, *p < 0.10. Columns (1), (2), and (3) correspond to the first, second, and third steps of Baron & Kenny's three-step method, respectively.

Table 10 Sobel test and Bootstrap confidence interval

Mediation Effect Test	Total Effect	Direct Effect	Indirect Effects	Intermediary Ratio
	0.369	0.255	0.114	30.89%
Sobel test	Z value = 3.21		P value = 0.0013	
Bootstrap 95% CI	[0.065, 0.179]			

may improve resource monitoring, process coordination, and environmental information transparency, making green practices more substantive and measurable. The increase in R-squared from 0.384 to 0.419 after adding GBP further shows that the mediator improves model explanatory power. Therefore, H2 is supported: green business practices serve as a statistically meaningful bridge between digital capability and sustainable performance.

The Sobel test and Bootstrap method are further used to verify the significance and robustness of the mediating effect. The Sobel test evaluates whether the indirect effect differs significantly from zero, while the Bootstrap procedure estimates the confidence interval of the indirect effect through repeated sampling and therefore provides a more distribution-free reliability check.

The Sobel test and Bootstrap confidence interval are shown in Table 10.

As shown in Table 10, the Sobel test produces a Z value of 3.21 and a p value of 0.0013, indicating that the indirect effect is statistically significant. The Bootstrap test, based on 5,000 resamples, yields a 95% confidence interval of [0.065, 0.179], which does not include zero. These two results jointly confirm the reliability of the mediating path from DTL to SBMP through GBP.

The total effect is 0.369, the direct effect is 0.255, and the indirect effect is 0.114. The indirect path accounts for 30.89% of the total effect, meaning that approximately one-third of the digitalisation effect operates through green business practices. This proportion is substantively meaningful while still leaving a direct effect of DTL on SBMP. The result highlights the combined importance of technological capability and green operational practice in explaining sustainable performance.

The SEM results are shown in Table 11.

The goodness of fit indicators are shown in Table 12.

The SEM results indicate that the overall model fit is satisfactory: chi-square/df = 1.96, RMSEA = 0.044, CFI = 0.962, TLI = 0.954, and SRMR = 0.039. All indicators meet commonly accepted thresholds, supporting the reliability of the path estimation. The SEM analysis further confirms the partial mediating role of GBP between DTL and SBMP and is consistent with the fixed-effects regression results. Taken together, the regression, Sobel, Bootstrap, and SEM evidence provides a coherent statistical basis for H2 and strengthens the credibility of the proposed digital-green-finance mechanism.

Table 11 SEM results

Path	Standardized Coefficient	Standard Error	p-value
DTL → GBP	0.295***	0.041	<0.001
GBP → SBMP	0.432***	0.058	<0.001
DTL → GBP → SBMP	0.178**	0.063	0.004

Table 12 Goodness of fit index

Index	Value	Recommended Standards
χ^2/df	1.96	<3
RMSEA	0.044	<0.08
CFI	0.962	>0.90
TLI	0.954	>0.90
SRMR	0.039	<0.08

5 Discussion

5.1 Theoretical Contribution and Mechanism Explanation

This study contributes to applied statistics, reliability assessment, and data analytics by showing how digital transformation, green business practices, and green finance can be examined through an integrated empirical framework. The paper is not limited to a conceptual discussion of sustainable transformation; it evaluates measurement reliability, estimates panel regression models, tests mediation and moderation effects, and validates the mechanism through SEM. The novelty of the study lies in combining scale reliability assessment, fixed-effects identification, robustness testing, and SEM validation to examine a digital-green-finance mechanism in enterprise sustainability performance. In theoretical terms, the findings extend dynamic capability theory by showing that digitally enabled information processing and resource reconfiguration can be converted into sustainable performance through measurable green practices. The stakeholder perspective is also extended by identifying green financial support as an external condition that strengthens the performance effect of digital transformation.

At the mechanism level, the results reveal a dual-path effect. Digital transformation directly improves SBMP by enhancing data governance, operational efficiency, environmental monitoring, and organisational coordination. It also indirectly improves SBMP by supporting green business practices that translate digital capability into specific low-carbon and sustainability-oriented actions. Green financial support further amplifies this process by reducing financing constraints and providing external incentives for digital-green projects. The combined evidence from regression, robustness testing, mediation analysis, moderation analysis, and SEM provides a statistically grounded explanation of how technology, management, and finance jointly influence sustainable business model performance.

The applied value of the study lies in the fact that its modelling strategy can be reproduced by researchers and practitioners who need to evaluate sustainability performance with imperfect enterprise data. The integrated design also avoids relying on a single regression coefficient: the main relationship is checked through alternative measurement, enterprise-size heterogeneity, mediation, moderation, Bootstrap inference, and SEM fit. This structure strengthens the credibility of the findings and makes the empirical contribution more transparent for applied statistical research.

5.2 Policy Implications

The findings suggest that enterprises should build integrated digital-green platforms in which data governance, resource optimisation, environmental monitoring, and sustainability evaluation are managed within the same information system. Investment in cloud computing, the Internet of Things, and big data analytics should be connected with measurable indicators such as carbon reduction, resource efficiency, green revenue growth, and CSR performance. Enterprises should also strengthen green business practices so that digital investment is translated into quantifiable environmental and social value rather than remaining a purely technical upgrade.

Government agencies and regulators should improve the green finance policy system and design differentiated green bonds, carbon-credit financing products, green credit schemes, and ESG investment tools for firms of different sizes and industries. These instruments can reduce financing costs for digital-green transformation and improve the statistical traceability of environmental outcomes. At the same time, regional digital infrastructure, environmental data-sharing platforms, and third-party ESG evaluation standards should be strengthened to improve the quality and comparability of sustainability data.

A long-term green financial ecosystem also requires standardised disclosure rules, cross-departmental collaboration, and more transparent evaluation mechanisms. Supporting small and medium-sized enterprises is particularly important because the sub-sample results show weaker and less stable digitalisation effects for this group. Policy tools such as tax incentives, subsidies, risk compensation, and targeted credit can help smaller firms overcome resource constraints and improve the reliability of their digital and sustainable transformation outcomes.

5.3 Strengths, Limitations and Future Research

The main strength of this study is its integrated statistical design. The analysis combines scale reliability testing, fixed-effects panel regression, robustness checks, mediation-moderation analysis, Sobel testing, Bootstrap confidence intervals, and SEM validation within one empirical framework. This design provides a more reliable assessment than a single-equation model and makes the mechanism between digital transformation, green practices, green finance, and sustainable performance easier to verify.

The study also has limitations. First, the sample is limited to listed manufacturing firms in China, so the estimated relationships may not fully represent unlisted firms, service industries, or cross-country settings. Second, the observation window covers 2019–2023, which is sufficient for panel estimation but still relatively short for capturing long-term digital and green transformation effects. Third, the DTL and GBP measures partly rely on questionnaire-based indicators, which may contain subjective response bias despite satisfactory reliability and validity results. Fourth, the modelling design identifies robust statistical associations, but stronger causal evidence would require quasi-experimental designs, instrumental variables, or longer dynamic panels.

Future research may extend the dataset to more regions and industries, compare listed and unlisted enterprises, and examine whether the mechanism changes across ownership types, technology intensity, and regulatory environments. Additional work could also incorporate dynamic panel models, Bayesian estimation, causal machine learning, or multi-level modelling to test the persistence, uncertainty, and causal robustness of the digital-green-finance mechanism. These next steps would further strengthen the reliability and external validity of statistical evidence in sustainable business model research.

6 Conclusion

This study provides applied statistical evidence that digital transformation improves sustainable business model performance both directly and indirectly through green business practices. Green financial support further strengthens this relationship. By combining measurement reliability testing, descriptive statistics, correlation analysis, fixed-effects panel regression, robustness testing, sub-sample analysis, mediation-moderation modelling, Sobel testing, Bootstrap confidence intervals, and SEM, the paper offers a statistically robust framework for evaluating the digital-green-finance mechanism in Chinese manufacturing enterprises. The study contributes to reliability and statistical research by showing how composite measurement, model reliability, and multivariate inference can be used to examine sustainability-related enterprise performance. The results also have applied value for managers and policymakers because they identify the conditions under which digital capability is more likely to become sustainable performance. Future research should extend the design to additional industries, cross-regional and cross-country samples, longer panel periods, and alternative statistical methods such as Bayesian estimation, causal inference, and dynamic panel modelling.

Compliance with Ethical Standards

Disclosure of Potential Conflicts of InterestThe authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Research Involving Human Participants and/or Animals

This research involving human participants was conducted in accordance with the ethical standards established by the institutional research committee and with the 1964 Helsinki declaration and its later amendments. In the case of animal research, all procedures were carried out in compliance with relevant guidelines and laws.

Informed Consent

Informed consent was obtained from all individual participants included in the study, and any personal data has been anonymized to protect privacy.

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