The Impact of Digital Transformation on Green Innovation: An Empirical Analysis Based on the Mediating Effect of ESG Performance

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Abstract: Driven by the "Dual Carbon" goals and sustainable development requirements, digital transformation has emerged as a core mechanism driving corporate value transition by enabling green innovation. This study investigates the pathways through which corporate digital transformation (DT) influences green technology innovation (GTI) via environmental, social, and governance (ESG) performance. Leveraging longitudinal datasets of SSE and SZSE mainboard-listed enterprises (2018-2023), we conduct regression analysis and mediation effect tests to examine the direct impact of DT on GTI and the mediating role of ESG performance. Key findings include:(1) DT significantly enhances GTI, where digital technologies improve resource utilization efficiency and accelerate green technology R&D;(2) DT positively impacts corporate ESG performance through enhancing environmental stewardship, reinforcing social accountability practices, and elevating governance integrity;(3) ESG performance acts as a partial mediator between DT and GTI, indicating that firms with advanced ESG management systems more effectively translate digital capabilities into green innovation advantages.

Keywords: Digital Transformation; ESG Performance; Green Innovation; Mediating Effect

1. Introduction

Amid escalating global climate change concerns and the push for sustainable development, green innovation has become a strategic imperative for enterprises seeking competitive advantage[1]. China's "Dual Carbon" policy framework enforces carbon quota constraints, compelling industrial transformation and upgrading. Meanwhile, digital technologies provide innovative solutions for sustainable corporate development, with DT playing an increasingly vital role in facilitating green innovation. Simultaneously, digital tools are reshaping the fundamental logic of ESG management: from intelligent carbon emission monitoring systems (environmental dimension) to decentralized decision-making mechanisms (governance dimension) and stakeholder value co-creation platforms (social dimension)[2]. However, systematic research on the interplay among DT, ESG performance, and GTI remains limited, particularly regarding whether ESG performance serves as a mediating mechanism in this process[3].

2. Theoretical Analysis and Research Hypotheses

2.1 Digital Transformation and Green Innovation

DT leverages a cluster of technologies, including intelligent manufacturing systems, process automation, and data-driven decision-making, leading to paradigm shifts in resource utilization and subsequently promoting GTI. Studies suggest that firms with stronger digital capabilities are more adept at developing and producing green products while minimizing environmental impact. Thus, we propose:

H1 ： Digital transformation is positively associated with green innovation.

2.2 Digital Transformation and ESG Performance

ESG performance systematically quantifies corporate sustainability across three dimensions:

Environmental (E): Digital technologies enhance resource efficiency, reduce carbon emissions, and optimize supply chain management, strengthening firms' environmental responsibility.

Social (S): Digital management systems improve

corporate social responsibility practices, workplace conditions, employee well-being, and stakeholder engagement.

Governance (G): DT enhances transparency, optimizes governance structures, reduces agency costs, and mitigates information asymmetry. Thus, we propose:

H2 ： Digital transformation is positively correlated with ESG performance.

2.3 The Mediating Role of ESG Performance

ESG performance not only reflects corporate sustainability efforts but may also serve as a key channel through which DT drives GTI. Robust ESG strategies foster green investments, optimize resource allocation, and promote green technology R&D. Moreover, digital technologies can enhance ESG outcomes through mechanisms such as smart manufacturing for carbon reduction and improved governance transparency. Hence, we propose:

H3: ESG performance mediates the relationship between digital transformation and green innovation.

3. Research Design

3.1 Data Sources

Spanning the years 2018 to 2023, this analysis leverages records of Chinese mainboard-listed entities in the Shanghai and Shenzhen equity markets, with raw data procured from the CSMAR and WIND financial platforms. Data were refined through the following steps:

Financial sector entities were excluded from the sample.

Entities marked with financial anomaly alerts (ST and *ST) were removed.

Eliminating firms with missing key financial data.

To address the influence of extreme values, variables were Winsorized at the 1st and 99th percentiles.

A total of 5,682 firm-year observations were retained. Data processing was conducted using Excel and STATA, with empirical analysis performed via SPSS 26.

Table 1. Variable Definition

Type	Name	Symbol	Definition
Dependent Variable	Green Innovation	GI	Ln(green invention patents + green utility model patents+1)
Independent Variable	Digital Transformation	DT	Ln(Digital transformation-related term frequency+1)
Mediating Variable	ESG Performance	ESG	Mean Value of the Huazheng ESG Rating Index
Control Variables	Firm size	Size	Ln(Total Assets)
	Operating profit growth rate	OPGR	[(Current Year Operating Profit − Previous Year Operating Profit) / Previous Year Operating Profit] × 100%
	Leverage Ratio	Lev	Total Liabilities / Total Assets
	Return on equity	ROE	Net Profit / Shareholders' Equity
	Equity concentration	Top1	The proportion of shares held by the largest shareholder
	Year	Year	dummy variable

3.2 Variable Definitions

3.2.1 Dependent variable

Green Innovation (GI):Measured by the number of independent green patents granted to firms, following WIPO's green patent classification[4].Patent counts were normalized via natural logarithms after adding unity to the sum of green invention and utility model patents, a method used to mitigate skewness and ensure cross-period comparability.

3.2.2 Independent variable

Digital Transformation (DT):Constructed based on Wu Fei et al. (2021), leveraging Python web crawling and natural language processing to extract firm-level DT indicators across AI,blockchain, cloud computing,and big data[5].The frequency of DT-related keywords is logged to create a standardized DT index.

3.2.3 Mediating variable

ESG Performance (ESG): Measured using the Huazheng ESG rating, which dynamically updates quarterly based on financial reports, public sentiment, and supply chain carbon tracking. Firms are scored on a 9-point scale (AAA=9, C=1), with annual averages computed.

3.2.4 Control variables

To strengthen the robustness of the empirical findings, drawing on relevant literature, this paper primarily selects variables from three aspects: firm basic attributes, financial indicators, and corporate governance[6]. Specifically, the

variables selected include firm size (Size), operating profit growth rate (OPGR), leverage(Lev), return on equity (ROE), and equity concentration (Top1). Additionally, to account for temporal effects, year dummy variables are introduced. Table 1 enumerates the critical parameters.

3.3 Empirical Model

To examine the relationship between corporate digital transformation and green innovation, while also investigating the mediating role of ESG performance, this study constructs the following empirical models based on the aforementioned analysis and hypotheses:

$$GI_{i,t} = \alpha_0 + \alpha_1 DT_{i,t} + \alpha_2 Control_{i,t} + \varepsilon_{i,t} \quad (1)$$

$$ESG_{i,t} = \beta_0 + \beta_1 DT_{i,t} + \beta_2 Control_{i,t} + \varepsilon_{i,t} (2)$$

$$GI_{i,t} = \gamma_0 + \gamma_1 DT_{i,t} + \gamma_2 ESG_{i,t} + \gamma_3 Control_{i,t} + \varepsilon_{i,t} (3)$$

Model (1) serves as a regression equation to examine the relationship between corporate digital transformation and green innovation, while Models (2) and (3) constitute the mediation effect testing equations. Here, subscript 'i' indexes individual firms and 't' corresponds to the time dimension (yearly intervals),while 'year' represents the fixed effects for time, and ε denoting the stochastic disturbance term. The rejection of $\beta_1 = 0$ in favor of $\beta_1 > 0$ provides empirical evidence for a constructive linkage between digital transformation and ESG performance[7]. If α_1 , β_1 , γ_1 are statistically significant and nonzero, this suggests that ESG performance functions as a transmission mechanism bridging digital transformation and green innovation.

Table 2. Descriptive Statistics

	N	Minimum	Maximum	Mean	Standard Deviation
GI	5682	0.000	3.738	0.394	0.800
DT	5682	0.000	5.328	1.788	1.411
ESG	5682	2.000	6.250	4.343	0.842
Size	5682	20.188	25.602	22.297	1.134
OPGR	5682	-0.383	1.208	0.150	0.257
Lev	5682	0.062	0.784	0.377	0.168
ROE	5682	-0.018	0.363	0.107	0.071
Top1	5682	0.089	0.687	0.313	0.130

4. Empirical Results

4.1 Descriptive Statistics

Table 2 summarizes the key statistical characteristics of the variables examined in this research. After sample selection and filtering, a total of 5,682 firm-year observations were included. The green innovation (GI) variable ranges from 0 (minimum) to 3.738 (maximum), clustered around a central tendency of 0.394, indicating a structural gap in green innovation efforts among market participants. The digital transformation (DT) variable exhibits from 0 to 5.328, averaging 1.788 with a dispersion of 1.411. The data reveal pronounced variations in the adoption of digital technologies among A-share listed firms in China, with an overall relatively low degree of digital adoption. The ESG metric (ESG) demonstrates a central tendency of 4.343 with a dispersion of 0.842, suggesting that corporate ESG performance remains relatively stable without excessive dispersion. However, notable variations persist across firms in terms of environmental responsibility, social commitment, and governance practices, highlighting considerable room for improvement in overall ESG performance.

4.2 Correlation Analysis

Applying Pearson's correlation coefficients, this research examines the pairwise relationships among key variables. As shown in Table 3, digital transformation exhibits demonstrates a statistically robust positive association with green innovation at the 1% significance level (r = 0.189**). Similarly, ESG performance is positively and significantly correlated with green innovation (r = 0.169**), while digital transformation also shows a significant positive association with ESG performance (r = 0.161**). These preliminary findings suggest that digital transformation contributes to the advancement of green innovation, and strong ESG performance further facilitates green innovation development[8]. Additionally, the VIF for all variables are close to 1 and remain well below the threshold of 10, confirming the absence of problematic linear interdependencies in the model.

Table 3. Correlation Analysis

	GI	DT	ESG	Size	OPGR	Lev	ROE	Top1
GI	1							
DT	0.189**	1						
ESG	0.169**	0.161**	1					

Size	0.161**	0.121**	0.151**	1				
OPGR	0.088**	-0.024	-0.005	0.050**	1			
Lev	0.158**	0.071**	-.046**	0.513**	0.136**	1		
ROE	0.087**	-.031*	0.102**	0.149**	0.367**	-0.002	1	
Top1	-.057**	-.087**	-0.019	0.027*	-0.005	0.001	0.112**	1

Note: * and ** denote significance at the 5% and 1% levels, respectively.

4.3 Regression Results Analysis

Table 4 presents the detailed empirical results.

Model (1) yields a coefficient estimate of 0.171 for α_1 (t = 13.226), reaching statistical significance at the 1% threshold. This supports Hypothesis H1, confirming that digital transformation is positively associated with green innovation.

For Model (2), β_1 attains a coefficient of 0.148 (t = 11.435), surpassing the 1% significance threshold. This validates Hypothesis H2, suggesting that corporate digital transformation has a significant positive impact on ESG performance.

In Model (3), γ_1 decreases to 0.151 (t = 10.317, $p < 0.01$) when ESG performance is included in the regression. Meanwhile, ESG performance exerts a statistically robust influence on green innovation outcomes. This result indicates that ESG performance accounts for part of the explanatory power of digital transformation, reducing its direct effect on green innovation. Therefore, Hypothesis H3 is supported, confirming that ESG performance serves as a mediating mechanism between digital transformation and green innovation.

Table 4. Regression Result Robustness of the Results is Systematically Verified through Alternative Variable Operationalizations and Subsample Analyses.

	Model(1)	Model(2)	Model(3)
ESG			0.135** (10.317)
DT	0.171** (13.226)	0.148** (11.435)	0.151** (11.649)
Size	0.079**	0.202**	0.052**
OPGR	0.049**	-0.022	0.052**
Lev	0.098**	-0.157**	0.120**
ROE	0.068**	0.086**	0.056**
Top1	-0.052**	-0.021	-0.049**
Observations	5682	5682	5682
Year effects	YES	YES	YES
F-value	75.306	72.146	41.528
R^2	0.074	0.071	0.093

Note: * and ** denote significance at the 5% and 1% levels, respectively.

4.4 Robustness Tests

4.4.1 Alternative measurement of the independent variable

In alignment with Zhao Chenyu et al. (2021)'s empirical strategy, the analysis refines the measurement of digital transformation by extracting relevant keywords from four dimensions: intelligent manufacturing, modern information systems, digital technology applications, and internet-based business models[9]. The total keyword frequency is then adjusted using a natural logarithm transformation to construct a new independent variable, NEWDT. As shown in Table 5, despite the change in measurement approach, the NEWDT estimator exhibits a sustained positive effect ($p < 0.01$), reinforcing the robustness of the primary analytical outcomes.

4.4.2 Alternative measurement of the mediating variable

In the primary analysis, ESG performance is measured using the nine-tier ESG evaluation system developed by Huazheng. As a robustness check, this study adopts an alternative ESG rating method from Wind ESG, constructing a new mediating variable, NEWESG. The regression results show that NEWESG's positive coefficient persists with statistical significance ($p < 0.01$), further validating the robustness of the original conclusions.

4.4.3 Adjusting the sample period

The COVID-19 pandemic from 2019 to 2021 may have introduced biases in the estimation results. To address this concern, this study removes observations from the 2019–2021 period and performs a cross-period robustness test. As presented in Table 5, even after modifying the sample range, digital transformation and ESG performance continue to exhibit a pronounced positive influence on green innovation, underscoring that the research conclusions remain stable over time[10].

Table 5. Robustness Tests

	Alternative Measurement of the Independent Variable	Alternative Measurement of the Mediating Variable	Adjusting the Sample Period

NEWDT	0.110** (8.498)		
NEWESG		0.158** (12.133)	
DT			0.145** (7.803)
ESG			0.110** (5.819)
Control variables	YES	YES	YES
Observations	5682	5682	5682
Year effects	YES	YES	YES
F-value	71.212	87.240	41.528
R^2	0.081	0.097	0.093

Note: * and ** denote significance at the 5% and 1% levels, respectively, with t values in parentheses.

5. Research Conclusions and Recommendations

5.1 Research Conclusions

Leveraging a dataset of mainboard-listed firms in China's SSE and SZSE exchanges (2018-2023), this research systematically examines the dynamic interactions among digital transformation (DT), ESG performance (ESG), and green innovation (GI). Empirical validation is carried out using regression analysis and mediation effect models. The principal outcomes of this research can be distilled into the following points:

First, digital transformation has a statistically robust beneficial impact on green innovation. Regression analysis indicates that corporate investment in and progress with digital transformation effectively enhance green innovation. Specifically, the adoption of digital technologies such as artificial intelligence, the Internet of Things, big data, and cloud computing not only optimizes production processes and improves resource utilization but also facilitates breakthroughs in energy-saving and emission-reduction technologies. These results highlight that firms actively implementing digital strategies can significantly enhance their capabilities in green technological innovation.

Second, digital transformation substantially improves ESG performance. The findings reveal that digital technologies play a pivotal role in environmental management, social responsibility fulfillment, and corporate governance. Specifically, digital transformation fosters a more transparent and efficient governance structure, mitigates information asymmetry, and enhances decision-making efficiency. In terms of environmental management, digital tools can significantly reduce pollutant emissions and improve resource efficiency. Additionally, digital technologies facilitate stronger engagement with stakeholders, thereby improving corporate social responsibility initiatives.

Finally, ESG performance serves as a key transmission mechanism between digital transformation and green innovation. The results indicate that digital transformation not only directly fosters green innovation but also does so indirectly through improvements in ESG performance. This suggests that firms with superior ESG management can more effectively harness digital technologies for green innovation, enhance the development of environmentally friendly products, optimize the sustainability of supply chains, and attract greater policy support and investor confidence. Therefore, firms should not only advance their digital transformation efforts but also strengthen ESG governance to maximize their green innovation potential.

In summary, this study not only validates the symbiotic relationship binding digital transformation, ESG performance, and green innovation but also provides a comprehensive examination of the mediating role of ESG performance in this relationship. These findings offer robust theoretical support for corporate green innovation initiatives while also providing empirical evidence for policymakers in shaping regulations in this domain.

5.2 Managerial Recommendations

Empirical insights yield actionable frameworks across three stakeholder domains: corporate practice, government policy, and investor engagement. These frameworks aim to promote the integrated development of digital transformation, ESG management, and green innovation.

5.2.1 Corporate level: accelerating digital transformation and establishing a green innovation system

First, firms should intensify investment in digital technologies to strengthen their digital capabilities. Leveraging advanced technologies such as artificial intelligence, blockchain, and big data analytics can significantly enhance production efficiency and minimize resource wastage, thereby boosting green innovation. For

instance, manufacturing enterprises can utilize smart manufacturing technologies to optimize production processes and reduce carbon emissions, while logistics companies can implement digital management tools to lower energy consumption and enhance operational efficiency.

Second, companies should integrate digital transformation with ESG governance by aligning technological advancements with environmental management, social responsibility, and corporate governance enhancement. Firms can utilize digital tools to improve supply chain transparency, enhance carbon footprint management, and advance sustainability goals. Moreover, it is crucial to develop a data-driven ESG monitoring system to ensure that corporate digital upgrades align with environmental and social responsibility requirements.

Finally, firms should foster organizational adaptability and cultivate a green innovation culture. Executives should embed sustainability objectives into corporate strategic planning and encourage R&D teams to explore green technological innovations. Additionally, promoting employee participation in ESG governance can strengthen internal sustainability awareness and drive broader corporate engagement in green initiatives.

5.2.2 Government level: strengthening policy frameworks to guide the synergistic development of digitalization and green innovation

The government should play an active role in promoting corporate digital transformation and green innovation by establishing comprehensive policy frameworks.

First, policymakers should enhance financial and policy support for digital-driven green innovation, including the introduction of dedicated funding programs and tax incentives to encourage corporate investment in digital and green technologies. For instance, firms utilizing low-carbon technologies and smart manufacturing solutions could receive financial subsidies to accelerate their digital and green transition.

Second, regulatory authorities should reinforce ESG disclosure standards to enhance market transparency. Governments should develop a standardized ESG reporting framework that provides clear guidelines for corporate disclosures. Firms should be required to regularly disclose their ESG performance, including environmental impact, social responsibility initiatives, and governance structures. Strengthening ESG disclosure requirements will boost investor confidence and improve market recognition of corporate sustainability efforts.

Finally, governments should advance digital infrastructure development to facilitate corporate digital transformation. Expediting the deployment of 5G networks, industrial internet, and other digital infrastructure will provide firms with efficient and stable technological support. Additionally, governments can encourage collaboration between technology firms and traditional industries to co-develop digital solutions tailored for green innovation.

5.2.3 Investor and financial institution level: promoting green finance and encouraging sustainable investment

Investors and financial institutions serve as key enablers of corporate green innovation.

First, investors should incorporate ESG factors into their investment decision-making and prioritize firms that demonstrate strong ESG performance. Research suggests that sound ESG management enhances long-term corporate value and reduces operational risks. Therefore, investors should consider ESG performance as a key evaluation criterion when selecting investment targets and actively engage with firms to improve their ESG governance.

Second, financial institutions should foster innovation in green financial products and expand financing channels for sustainable development. Lending entities could launch green transition bonds with ESG performance triggers, specifically targeting investments in smart manufacturing upgrades and renewable energy integration.

Furthermore, collaboration between governments and financial institutions can facilitate the establishment of green investment funds or sustainability bonds to promote corporate investment in green technologies and sustainable business practices.

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