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Corporate Digital Transformation and Green Innovation: The Mediating Mechanism of ESG Performance

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Abstract. Under China's "dual-carbon" strategy and the growth of the digital economy, digital transformation together with green innovation has become a pivotal driver of sustainable development. The research relies on panel data collected from companies listed on China's A-share market between 2015 and 2023 to empirically examine the relationship among enterprise digitalization, ESG performance, and green innovation, placing particular attention on ESG's transmission pathway. The results demonstrate that digital transformation represents a pivotal factor in boosting enterprises' ability to pursue green innovation, while ESG performance functions as a partial mediator, transmitting and reinforcing the positive effects of digitalization. Further tests demonstrate that the facilitating role of digital transformation is more accentuated in private corporations, highlighting the varying effects of corporate ownership configuration. By integrating digitalization with ESG governance, this research enriches the understanding of how digital capabilities foster sustainable innovation and provides actionable insights for policymakers and corporate managers. Overall, the findings contribute to both academic debates on digital economy and sustainability, and practical efforts to achieve green transition under carbon neutrality goals.

Keywords: Digital Transformation, Green Innovation, ESG.

1. Introduction

Amid the "dual-carbon" initiative and the quest for premium growth, green innovation has emerged as a crucial engine for advancing modern industrial system construction and achieving sustainable growth in China. Year after year, China has claimed the throne as the global leader in green patent submissions, with figures from WIPO revealing that in 2022, the nation accounted for a massive 31.2% of the global total. Nevertheless, the proportion of high-quality and original green technologies remains insufficient. At the firm level in particular, mismatches between green innovation inputs and outputs, as well as a lack of endogenous motivation, remain pronounced. This suggests that relying solely on traditional "command-and-control" environmental regulation is insufficient to unlock firms' potential for green innovation, underscoring the urgent need for complementary market mechanisms that combine both incentives and guidance.

In this context, the corporate green transition is increasingly driven by the digital economy, which is now widely acknowledged as a crucial force. According to statistics published by China's Academy of ICT, the value created by China's digital industries amounted to RMB 54 trillion,

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representing 43% relative to GDP. The digital economy contributes to more efficient resource distribution, greater openness of information, the reduction of income disparities, and the stimulation of innovation and entrepreneurial activity [1,2]; furthermore, it exerts a subtle influence on firms' green behavior through improvements in governance structures and the optimization of decision-making mechanisms. Compared with traditional policy instruments, digital empowerment provides technical, systemic, and platform-based endogenous support for green innovation. However, given the high risk, uncertainty, and externalities associated with green innovation, technological resources alone are insufficient; its realization still depends on firms' strategic orientation and incentive mechanisms.

Although prior studies have examined how digitalization influences corporate development by improving managerial efficiency, optimizing resource allocation, strengthening information processing and decision-making, and promoting supply chain collaboration and innovation activities [3], and ESG ratings have also been demonstrated to be crucial in enhancing governance quality, reinforcing social responsibility, and motivating sustainable strategies [4], systematic research on the "Digitalization–ESG–Green Innovation" transmission mechanism remains scarce. Existing literature has not fully addressed whether corporate digitalization indirectly promotes green innovation by improving ESG performance, nor whether ESG acts as a mediator in this transmission chain. In this context, the research utilizes a comprehensive panel dataset encompassing 31,638 observations across various firm-year dimensions for A-share listed entities ranging from 2015 to 2023. This allows for the construction of a mediation effect model, which meticulously investigates the intricate ties between corporate digitalization, ESG performance (environmental, social, and governance), and the advancement of green technology. This article enriches intersectional literature by exploring the digital economy's role in green development, presenting empirical evidence to support firms in adopting effective sustainable practices for a more environmentally conscious future.

2. Theoretical framework and hypotheses

2.1. Digital transformation and green innovation

Within the context of the "dual-carbon" strategy, digital transformation is progressively emerging as a vital area of emphasis in firms' development strategies. Based on the RBV framework, firms gain strategic advantages through scarce and hard-to-imitate resources and capabilities. As a strategic resource, digital technologies can support green innovation through information processing, resource integration, and process optimization, thereby enabling firms to sustain competitiveness under carbon reduction and green development constraints.

From an internal perspective, digital transformation facilitates green innovation through improvements in production systems, together with mechanisms for scientific research as well as technological development. The integration of big data, IoT, and AI allows companies to track energy consumption and carbon emissions in real time, promoting sustainability, embedding environmental governance into production processes and forming a data-driven closed loop for green R&D [5,6]. Meanwhile, digital technologies facilitate cross-departmental and inter-firm knowledge flows, reducing the costs of information transfer and technological diffusion, which allows firms to integrate internal and external green technology resources and accelerate the development of green innovation capabilities. Through digital platforms, firms can achieve low-carbon technology sharing, construct knowledge graphs, and enable cross-domain technology transfer, thereby broadening the knowledge boundaries of green innovation and boosting innovation-related research effectiveness and innovation quality [7,8].

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From an external perspective, digital transformation enhances firms' ability to perceive and adapt to regulatory and institutional environments, providing institutional support and policy incentives for green innovation. By leveraging digital tools, firms can improve their responsiveness to environmental regulations and enhance ESG performance, thereby enabling green technology development under institutional constraints and policy incentives. Furthermore, by constructing policy knowledge graphs and implementing data-driven compliance monitoring mechanisms, firms can better match subsidies and incentive policies for green innovation, thus reducing policy risks and resource acquisition costs, and providing stronger external safeguards for green innovation [9].

In summary, digital transformation may act as a key driver of green innovation through the dual pathways of internal resource integration and production optimization, as well as external policy adaptation and institutional alignment. Accordingly, we advance the following hypothesis:

H1: Digital transformation notably fosters green innovation.

2.2. Mediating role of ESG

Digitalization provides enterprises with new pathways for resource integration, information sharing, and management optimization. However, whether this technological potential can be transformed into substantive green innovation outcomes depends on the extent to which firms embed the concept of sustainable development into their strategic practices. ESG performance serves as the critical intermediary in this transformation process.

On the one hand, firms enhance the accuracy of gathering, evaluating, and reporting ESG-related indicators through enterprise digitalization initiatives.. This facilitates measurable improvements in environmental management, social responsibility fulfillment, and governance structure optimization. Such advancements not only enhance a firm's ESG rating but also strengthen external oversight and the trust of stakeholders in its green commitments. On the other hand, strong ESG performance can generate policy incentives, gain recognition from capital markets, and improve brand reputation [10,11], thereby providing enterprises with greater resources and stronger market momentum for advancing green innovation.

Accordingly, ESG functions as a "bridge" between digitalization and green innovation: while digitalization provides the enabling conditions, ESG translates them into sustainable innovation outcomes. Accordingly, we advance the following hypothesis:

H2: ESG acts as an intermediary in how digital transformation affects green innovation.

3. Model specification

3.1. Sample selection and data sources

The analysis is based on a dataset of Chinese A-share companies covering the period 2015–2023. The research dataset derives from the CSMAR database, China Securities Index Co., company annual reports, and statistical yearbooks. After excluding ST and financial firms, removing missing data, and winsorizing the top and bottom 1% of values, the resulting dataset includes 31,638 observations at the firm–year level.

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3.2. Variable definitions

3.2.1. Dependent variable: green innovation

Green innovation is quantified based on the volume of eco-innovation patents submitted by enterprises [12]. To improve the stability and comparability of the data, this measure is transformed by taking the natural logarithm.

3.2.2. Independent variable: digital transformation

As an information carrier that integrates both retrospective and prospective functions, the annual report provides textual evidence of a firm's digital transformation. Specifically, to capture the scope for enterprise digitalization, we compile a dictionary of relevant keywords and calculate their occurrence in annual reports [13]. This variable is standardized based on the yearly count of pertinent keywords appearing in each firm's annual report.

3.2.3. Mediating variable: ESG rating

Following prior studies, we employ ESG rating data from Huazheng ESG (China Securities Index) as a proxy [14]. The rating system evaluates listed firms' ESG performance using a nine-level scale ranging from C to AAA, corresponding to numerical scores from one to nine, with greater scores reflecting superior ESG performance.

3.2.4. Control variable

Building on previous research, we incorporate several firm- and governance-level control variables. All variables are described in detail in Table 1.

Table 1. Variable definitions

Category	Symbol	Variable Name	Definition
Dependent variable	Patent	Green Innovation	Captured by the quantity of green patent applications.
Independent variable	Digital	Digital Transformation	Calculated as digital intangible assets divided by total intangible assets.
Mediating variable	ESG	ESG Performance	Huazheng ESG rating score, ranging from 1 to 9.
Control variables	Size	Firm Size	The log-transformed total assets measured at year-end
	ROA	Profitability	Measured by net income relative to total assets.
	Leverage	Leverage Ratio	The share of a firm's assets represented by its liabilities.
	Growth	Growth	Defined as the increase in operating revenue relative to its value in the preceding year.
	Age	Duration since firm founding	Logarithm of (listing age + 1)

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Table 1. (continued)

Board	Board Size	Log-transformed total board size
Indep	Independent Directors	The proportion of independent directors relative to the total number of board members.
Dual	CEO Duality	Equals 1 when the CEO is concurrently the board chair, otherwise 0
Year	Year Fixed Effects	Year dummy variables controlling for time trends.
Industry	Industry Fixed Effects	Industry dummies based on CSRC industry classification codes.

3.3. Model specification

For analyzing the effect of corporate digital transformation on green innovation, the empirical model is constructed as follows:

$$Patent_{i,t} = \delta_0 + \delta_1 Digital_{i,t} + \beta Controls_{i,t} + Year + Ind + \varepsilon_{i,t} \quad (1)$$

To evaluate the intermediary function of ESG performance, we further estimate the following models:

$$ESG_{i,t} = \alpha_0 + \alpha_1 Digital_{i,t} + \alpha' Controls_{i,t} + Year + Ind + \varepsilon_{i,t} \quad (2)$$

$$Patent_{i,t} = \delta_0 + \delta_1 Digital_{i,t} + \delta_2 ESG_{i,t} + \beta Controls_{i,t} + Year + Ind + \varepsilon_{i,t} \quad (3)$$

4. Empirical analysis

4.1. Descriptive statistics

Table 2 reports summary statistics for the key variables. On average, green innovation (Patent) is 1.400, showing a standard deviation of 4.540 and a range of 33, suggesting that, despite a generally modest level of innovation among firms, there is considerable variation across different companies. On average, digital transformation (Digital) is 1.730, with a standard deviation of 1.420, while the maximum reaches 5.270, reflecting substantial cross-firm differences in digital transformation levels. The ESG score has an average of 4.160, a standard deviation of 1.010, implying that ESG performance for these enterprises lies at an above-average level.

Table 2. Descriptive statistics

Variable	N	Mean	SD	Min	p50	Max
Patent	31638	1.400	4.540	0	0	33
Digital	31637	1.730	1.420	0	1.610	5.270
ESG	31638	4.160	1.010	1	4	6
Size	31638	22.28	1.300	19.94	22.09	26.37
Leverage	31638	3.550	2.940	1.080	2.510	17.96
Growth	27679	0.150	0.380	-0.580	0.0900	2.240

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Table 2. (continued)

Age	31366	2.370	0.820	0	2.560	3.430
Board	31638	2.100	0.200	0	2.200	2.890
Indep	31638	0.380	0.0600	0	0.360	0.800
Dual	31638	0.310	0.460	0	0	1

Standard errors in parentheses

* p < 0.1, ** p < 0.05, *** p < 0.01

4.2. Baseline regression

Table 3 reports the baseline regression results assessing how digital transformation (Digital) influences green innovation (Patent). The coefficient for digital transformation is 0.150, attaining statistical significance at the 1% threshold. This finding implies that when digital transformation rises by one unit, green innovation correspondingly improves by 0.150 units, highlighting its crucial function in advancing enterprises' green innovative activities. Additionally for ESG, the estimated coefficient of 0.244 is statistically meaningful and passes the 1% significance test, which reflects that enterprises exhibiting superior ESG performance pursue green innovation more actively. One possible explanation is that enterprises with stronger ESG records tend to prioritize environmental protection as well as social responsibility, which in turn leads them to devote additional resources toward green R&D.

Overall, the adjusted $R^2$of 0.179 implies that the specification possesses a moderate explanatory power, capturing a meaningful share of the variation in green innovation., supporting the hypothesis that both digital transformation and ESG performance significantly enhance firms' green innovation.

4.3. Robustness test

Table 3 reports evidence from robustness assessments. We further assess the robustness of the baseline regression by employing another indicator of digital transformation (Digital_Zhang), formulated following the method proposed by Zhang Yongkun (reference omitted). Using the same model setup, Digital_Zhang shows a coefficient of 0.000750, which is positive and reaches significance at the 1% threshold in relation to Patent. This result verifies that the conclusion holds steady when different metrics are used to capture digital transformation.

Table 3. Baseline regression, robustness test

Variable	Baseline Regression (1)	Robustness Test (2)
	Patent	Digital_Zhang
Digital	0.150***	-
	(0.0240)	-
ESG	0.244***	-
	(0.0272)	-
Patent	-	0.000750***
	-	(0.000285)
Size	1.020***	-0.0194***

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Table 3. (continued)

	(0.0267)	(0.00125)
ROA	-	-0.0246
	-	(0.0192)
Leverage	-0.0193*	-0.00260***
	(0.0102)	(0.000495)
Growth	-0.261***	-0.000328
	(0.0696)	(0.00341)
Age	-0.358***	0.00316
	(0.0434)	(0.00197)
Board	0.786***	-0.0141*
	(0.169)	(0.00795)
Indep	2.402***	-0.0168
	(0.565)	(0.0267)
Dual	0.120**	-0.0000147
	(0.0595)	(0.00277)
SOE	0.284***	-
	(0.0688)	-
Ind	Yes	Yes
Year	Yes	Yes
N	27602	27603
R^2	0.182	0.257
adj. R2	0.179	0.255

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

4.4. Heterogeneity test

To examine how ownership structure shapes the mechanisms behind digital transformation, the dataset is divided into state-owned enterprises (coded as 1) and private firms (coded as 0), with separate regressions conducted for each category. Table 5 displays the empirical findings. Green innovation (Patent) shows a significantly positive effect on digital transformation (Digital) for both groups; nevertheless, non-SOEs exhibit a larger coefficient (0.0118, passes the 1% significance test), whereas SOEs show a smaller one (0.00729, likewise significant at 1%). The evidence suggests green innovation serves as a more powerful driver of digital transformation among non-SOEs. The adjusted R^2 values of 0.428 and 0.452, respectively, suggest that the models fit the data reasonably well.

Taken together, these findings highlight that ownership structure, as a key factor in internal governance and resource allocation, leads to heterogeneous effects on the digital transformation pathway, with the innovation-driving effect being more pronounced in non-SOEs.

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Table 4. Heterogeneity test

Variable	(1)	(2)
	Digital_Wu	Digital_Wu
Patent	0.00729***	0.0118***
	(0.00222)	(0.00204)
Size	0.158***	0.206***
	(0.0102)	(0.00895)
ROA	0.388*	-0.873***
	(0.202)	(0.119)
Leverage	-0.0265***	-0.00518*
	(0.00567)	(0.00300)
Growth	-0.0354	-0.00914
	(0.0291)	(0.0227)
Age	-0.0633***	-0.0175
	(0.0209)	(0.0131)
Board	-0.0404	0.170***
	(0.0675)	(0.0544)
Indep	-0.0765	0.363*
	(0.209)	(0.189)
Dual	0.0183	0.109***
	(0.0370)	(0.0166)
Ind	Yes	Yes
Year	Yes	Yes
N	8665	18937
R^2	0.434	0.454
adj. R^2	0.428	0.452

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

4.5. Mediation effect

This part empirically examines the role of ESG performance in bridging digital transformation with green-oriented innovation, thus uncovering the underlying transmission pathway. First, according to Model (2), the estimation shows a coefficient of 0.0125, indicating that greater digitalization of firms is associated with improved ESG outcomes. In addition, control variables such as company size and profitability are found to significantly impact ESG performance.

Second, Model (3) examines how digital transformation together with ESG performance shapes progress in green innovation. Findings reveal a clear and robust positive link connecting digital transformation with green innovation (coefficient = 0.00899, $p < 0.01$). Similarly, ESG performance is also found to exert a strong positive influence on green innovation (coefficient = 0.0414, p <

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0.01). Findings indicate ESG performance serves as an intermediary in the process through which digital transformation advances green innovation.

In summary, digital transformation exerts a direct influence on green innovation and also promotes it indirectly through improvements in ESG performance, indicating a partial mediation effect. These findings provide additional support for the pathway by which digital transformation enhances corporate green innovation.

Table 5. Mediation effect

Variable	(1)	(2)
	ESG	Digital_Wu
Patent	0.0125***	0.00899***
	(0.00131)	(0.00151)
Size	0.250***	0.166***
	(0.00575)	(0.00685)
ROA	2.737***	-0.670***
	(0.0883)	(0.103)
Leverage	0.0306***	-0.0109***
	(0.00228)	(0.00263)
Growth	-0.137***	0.00417
	(0.0157)	(0.0181)
Age	-0.237***	-0.0359***
	(0.00905)	(0.0105)
Board	0.171***	0.0362
	(0.0366)	(0.0421)
Indep	1.325***	-0.00628
	(0.123)	(0.142)
Dual	-0.00165	0.125***
	(0.0127)	(0.0147)
Ind	Yes	Yes
Year	Yes	Yes
N	27603	27602
R^2	0.200	0.445
adj. R^2	0.197	0.443

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

5. Conclusion and policy implications

Drawing on panel observations of Chinese A-share firms during 2015–2023, this research investigates the linkages among digital transformation, ESG performance, and green innovation. Multivariate regression and mediation-effect models are applied to systematically investigate the

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mechanisms linking digital transformation to green innovation, highlighting the mediating function of ESG. The core findings can be summarized as follows:

First, ESG performance serves as a key transmission channel through which digital transformation fosters green innovation. Empirical estimates indicate that progress in corporate digital upgrading exerts a notable positive influence on ESG performance, and superior ESG, in turn, further strengthen green innovation capacity, forming a "Digital Transformation → ESG → Green Innovation" mediation chain. This indicates digital upgrading goes beyond a technical enhancement, serving as a catalyst for improved governance and sustainability strategies.

Second, the mechanism exhibits ownership heterogeneity. Digitalization has a stronger beneficial effect on eco-innovation among non-SOEs relative to SOEs..

Drawing from the empirical evidence, the study offers a set of policy recommendations:

Promote the integration of digital transformation and ESG. Firms should embed ESG principles into their strategies and governance frameworks during the process of digital transformation. By leveraging digital technologies to enhance environmental management, social responsibility, and governance transparency, firms can achieve sustainable green innovation through the joint forces of technological upgrading and institutional optimization.

Implement differentiated policy guidance. When formulating green innovation policies, governments should pay particular attention to non-SOEs and heavily polluting industries. These entities often face greater transformation pressures but also possess higher innovation potential. Targeted measures such as digitalization subsidies and ESG-linked tax incentives can significantly enhance their green innovation capacity.

Build a green financing system in the digital era. It is essential to establish broader and more effective green financing channels that link firms' ESG performance to financing costs. Digital platforms can be utilized to foster collaboration among industry, academia, and research institutions, as well as to enhance supply-chain coordination. Such efforts can reduce innovation costs and market uncertainties, accelerating the process by which firms bring green innovations to market.

To conclude, the research not only uncovers the mechanisms linking firms' digital transformation, ESG performance, and green innovation, but also provides theoretical insights and policy recommendations to advance the superior development of enterprises along green, digital, and sustainable pathways.

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