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The Impact of Corporate Digital Transformation on Green Technology Innovation

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Abstract. This research is based on two key needs—national climate strategy and corporate sustainable development—and does an empirical study on how digital transformation affects corporate green technology innovation. It uses a complete set of data on Chinese listed firms, with coverage from 2000 to 2023, and also examines the mediating role of ESG ratings along with how the effect shifts based on a firm's property rights structure and scale. The findings of this study show three main results: first, digital transformation has a clear positive effect on green technology innovation, and this effect is proven reliable; second, analysis of its mechanism finds that improved ESG ratings act as a partial mediator in this relationship; third, the effect is heterogeneous—it is stronger in large-scale firms than in SMEs, and brings far greater benefits to non-state-owned enterprises than to state-owned ones. This study also provides valuable empirical evidence and policy recommendations, which help promote better synergy between corporate digitalization and green innovation and in turn support the achievement of China's "Dual Carbon" goals.

Keywords: Digital Transformation, Green Technology Innovation, Digital Economy, ESG

1. Introduction

Green technology has become of key importance—it now stands as a decisive front in global competition for the new industrial revolution and technological advancement. According to the Third Plenary Session of the 20th CPC Central Committee, promoting green and low-carbon development is a key objective for deepening comprehensive reforms and advancing Chinese-style modernization. Green technological innovation is a special type of innovation. It combines environmental sustainability with a core focus on advancement, and it has a dual impact. On one hand, it greatly boosts energy efficiency and improves environmental performance by streamlining production processes. This optimization leads directly to energy conservation and emission reductions, and eases the ecological impact of industrial activity. On the other hand, it helps enterprises break through the limits of conventional products and develop uniquely differentiated green product lines. This speeds up the overall technological innovation cycle. This process not only strengthens a firm's independent innovation but also boosts its green competitiveness—it also provides critical support for achieving a balanced synergy between economic growth and environmental protection. Corporate green technology innovation needs to be promoted. This way, pollution can be better controlled at its source and treated at the end-of-pipe. The green and low-

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carbon transformation and green socioeconomic development will help with this. Carbon emissions can then be reduced continuously. This provides crucial momentum and technological support for achieving the carbon peak and carbon neutrality goals [1].

Simultaneously, global digital wave has permeated critical enterprise functions—production, services, and green R&D innovation—spawning diverse new models and business formats. Digitalization's pivotal role in driving corporate transformation and green innovation has become increasingly evident. Given China's current low-quality green patent landscape, digital development offers favorable factor inputs, robust environmental support, and rare new opportunities for expanding the quantity of corporate green technological innovation. The integration of enterprises and digital technologies which center on big data and artificial intelligence has fundamentally transformed traditional innovation models while reconfiguring the combination of innovation factors. As an emerging factor of production, data-driven digital economies have become vital engines for advancing high-quality economic development [2], elevating innovation levels [3,4], advancing total factor productivity [5], and empowering urban carbon reduction [6].

Digitalization, as a crucial micro-level manifestation of data as a factor, forms a deep connection with corporate green technological innovation under the "carbon peak and carbon neutrality" strategy through enterprise digital transformation—the core vehicle for industrial digitalization. This paper uses listed companies as research samples, incorporating corporate ESG as a mediating variable and enterprise development capabilities as a moderating variable. Through empirical analysis, it aims to systematically clarify what the causal impact of digital transformation on green technology innovation is, how ESG mediates this relationship, and to what extent it is moderated by enterprise development capability.

2. Theoretical analysis and research hypotheses

2.1. Impact of digital transformation on green technology innovation

In the data-driven economy era, corporate digital transformation is a key driver for green technological innovation, and this enabling effect shows mainly in three areas: knowledge acquisition, innovation paradigm restructuring, and strategic transformation. Digital technologies first reshape innovation ecosystems by breaking down knowledge barriers—they’ve become vital tools for enterprises to explore new knowledge and spark innovative thinking, offering plenty of information resources and communication channels to help with breakthroughs in green technology innovation, and employees can use these technologies to break through geographical limits, exchange ideas and knowledge in real time, and speed up the spread and implementation of green innovation concepts inside organizations. Digital tools second expand traditional innovation theory in a dynamic way; based on Schumpeter's innovation theory, innovation covers five areas: "new products, new technologies, new markets, new raw materials, and new organizational structures," and digital transformation has sped up the development of these innovation elements, pushed for updates to corporate R&D processes, and let enterprises integrate and optimize internal and external R&D resources more effectively. Building digital capabilities finally has become a strategic key for dealing with the challenges of "carbon peaking and carbon neutrality"—when facing global carbon neutrality and peak carbon challenges, enterprises must take green development as their core strategy and integrate sustainable development principles into all production and operational processes, and in this journey, digital transformation serves as a vital force driving green technological innovation [7].

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To conclude, the essay proposes Hypothesis 1: Transforming corporate digitalization can boost the innovation of green technology.

2.2. Mediating effects of ESG

Digital transformation improves corporate ESG performance through two pathways. On one hand, it eases information asymmetry by stopping managers from lowering transparency, weakening disclosure quality, or engaging in "greenwashing" to maximize short-term profits—these practices mislead investors, harm corporate reputation, and create compliance risks, and digital transformation solves this dilemma by making information disclosure more accurate and timely. On the other hand, digital transformation boosts management and decision-making efficiency, and this impact extends to core operational areas like production, procurement, and marketing: in manufacturing, intelligent automation systems, big data analytics, and IoT devices increase output while cutting energy consumption and raw material waste; in supply chain management, digital tools break down information silos, so companies use supply chain software and big data analytics to quickly grasp market and supplier conditions, and they use predictive analytics to anticipate supply-demand fluctuations, optimize inventory, and make procurement more transparent and supply chain collaboration more efficient; on the demand side, artificial intelligence collects and analyzes customer behavior data, purchasing preferences, and consumption trends to target specific groups accurately. Overall, digital transformation helps enterprises build value co-creation networks with various stakeholders, which in turn helps them fulfill social responsibilities more efficiently and drives improvements in ESG performance.

Research [8,9] shows that green technology innovation focuses on environmental sustainability. It helps save energy, cut emissions, and boost economic benefits through innovations in technology, products, and services. Better ESG ratings drive green technology innovation in two ways. One way is reducing conflicts between shareholders and management by easing agency problems. Companies set clear ESG goals and incentive mechanisms. They create transparent green development strategies that align management’s actions with shareholders' long-term interests. Better ESG ratings also help identify environmental and social risks. This pushes managers to prioritize sustainable development and long-term returns over short-term profits, speeding up the rollout of green technological innovations. Another way is easing financing constraints by reshaping capital market risk pricing mechanisms. This breaks the "financing-innovation" deadlock for green technology innovation. Green technological innovation requires long R&D cycles and large capital investment. It also comes with high uncertainty about returns. This makes external investors cautious, leaving companies facing difficulties in getting external funding. The challenge is especially big in early R&D stages. Companies struggle to secure enough money and find it hard to achieve stable market returns, making financial support critical. A strong ESG rating shows a company’s commitment to sustainable development and social responsibility. It earns more trust from financial institutions. This lets companies get lower interest rates, access more financing channels, and secure substantial capital support. It effectively eases financing constraints and drives real improvements in green technology innovation.

Therefore, the essay proposes Hypothesis 2: Transforming corporate digitalization can enhance substantive innovation of green technology by improving its ESG ratings.

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3. Model construction

3.1. Model construction

1. To effectively discern how corporate digital transformation impacts green technological innovation, the specific specification of the econometric model established in this paper is presented in Equation (1):

$$Y_{ijt} = \beta_0 + \beta_1 Dig_{ijt} + \beta_2 CONTROL_{ijt} + \lambda_j + \mu_t + \xi_{ijt} \tag{1}$$

$$M_{it} = \alpha_0 + \alpha_1 Dig_{it} + \beta CONTROL_{it} + y_i + \tau_t + \varepsilon_{it} \tag{2}$$

$$GTI_{it} = \alpha_0 + \alpha_1 Dig_{it} + \alpha_2 M_{it} + \beta CONTROL_{it} + \gamma_i + \tau_t + \varepsilon_{it} \tag{3}$$

Here subscripts i, j, and t represent firm, industry, and year respectively; Y_{ijt} denotes the dependent variable; β_0 is the constant term; Dig_{ijt} is the core explanatory variable representing the digital transformation level of firm i in industry j during year t; $CONTROL_{ijt}$ represents the control variable; ξ_{ijt} denotes the random error term; λ_j indicates the industry fixed effect; μ_t represents the year fixed effect.

3.2. Selection of variables

3.2.1. Explanatory variable: digital transformation

Drawing on studies such as [10] and [11], this paper employs text analysis of corporate annual reports. Corporate digital transformation is measured by the natural logarithm of one plus the processed frequency of relevant keywords which are obtained from the AKRD database in CNRDS for the period 2000–2023.

3.2.2. Dependent variable: green technological innovation

Resource input and utilization efficiency ultimately manifest in technological innovation. Patent applications, representing innovation outputs, provide a more accurate gauge of an innovator's technical capabilities. Following the research of [12], this study utilizes relevant data on green patent applications of listed companies in CNRDS. Green technological innovation is measured by the natural logarithm of one plus the sum of the number of green invention patents and green utility model patents.

3.2.3. Mediating variable: corporate ESG

Corporate ESG performance is measured by the annual average of the HuaZheng ESG rating. The rating system comprises nine grades which are assigned values from 9 (for AAA) down to 1 (for C).

3.2.4. Control variables

The selection of control variables is informed by prior scholarly work on green technological innovation. The model accounts for Board (logarithm of independent director numbers), TOP1

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(logarithm of the top shareholder's stake), Lev (total leverage ratio), Size (logarithm of total assets), Age (logarithm of company age), and Roe (return on equity).

3.3. Data sources and descriptive statistics

The dataset for this analysis comprises A-share listed companies in China from 2000 to 2023. Data regarding digital transformation and green technology innovation were procured from CNRDS, ESG ratings from Wind, and the control variables from CSMAR. A multi-step data cleaning procedure was implemented, which included the exclusion of ST/*ST firms, financial sector entities, and records with missing essential data. Additionally, to reduce the potential bias from extreme values, a winsorization at the 1st and 99th percentiles was performed on all continuous variables.

Table 1 presents descriptive statistics showing key features of the variables. Green technology innovation has a mean of 0.370, a median of 0, and a maximum of 3.690. This shows only a few firms lead in this area while most have weak or no related capabilities. Digital transformation also shows right-skewness—its mean is higher than the median. This means only a small number of firms have high digitalization levels, most firms remain at lower levels.

Table 1. Descriptive statistics for each variable

Variable	Observed Value	Mean	Standard	Min	Median	Max
TOP1	31848	3.460	0.460	2.220	3.500	4.320
Board	31848	1.220	0.240	0.690	1.100	1.950
Growth	31550	0.140	0.220	-0.250	0.0900	1.210
Roe	31720	0.0700	0.110	-0.560	0.0700	0.320
Age	31848	2.120	0.780	0.690	2.200	3.370
Size	31848	22.27	1.320	19.96	22.07	26.37
DIGA	31848	1.450	1.430	0	1.100	5.200
Lev	31848	0.420	0.200	0.0600	0.420	0.870
ESG	31848	73.67	4.660	59.66	73.79	84.22
GTI	31829	0.370	0.780	0	0	3.690

4. Empirical analysis

4.1. Benchmark regression results

The benchmark regression results, as presented in Column (1) of Table 2, show that the coefficient of DIG is statistically significant at the 1% level. These results suggest that digital transformation exerts a positive impact on green collaborative innovation. Compared to firms that have not undergone digital transformation, those that have exhibit more active green collaborative innovation activities. Thus, Hypothesis 1 is validated.

Table 2. Robustness and heterogeneity tests

	(1)	(2)	(3)
	GTI	GTI	GTI
DIGA	0.0480***	0.0440***	0.0453***
DIGB	(0.00394)		(0.00420)

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Table 2. (continued)

		(0.00453)	
TOP1	-0.0200**	-0.0218**	-0.0201**
	(0.00955)	(0.00955)	(0.0101)
Board	0.0513***	0.0504***	0.0600***
	(0.0174)	(0.0174)	(0.0183)
Roe	0.00715***	0.00709***	0.00660**
	(0.00267)	(0.00268)	(0.00269)
Age	-0.0855***	-0.0827***	-0.0850***
	(0.00659)	(0.00661)	(0.00821)
Size	0.150***	0.150***	0.151***
	(0.00452)	(0.00454)	(0.00481)
Lev	0.142***	0.139***	0.141***
	(0.0264)	(0.0264)	(0.0286)
		(0.0670)	(0.0691)
Dual			0.0114
			(0.0108)
Cash			0.225***
			(0.0503)
Year/ IND	Yes	Yes	Yes
_cons	-2.924***	-2.992***	-3.007***
	(0.0998)	(0.0996)	(0.106)
N	31718	31718	28342
R^2	0.185	0.183	0.188
adj. R^2	0.182	0.181	0.185

Note: Values in parentheses indicate t-values. *, **, and *** denote significance levels of 10%, 5%, and 1%, respectively. The same applies below.

4.2. Robustness tests

To verify the reliability of the estimation results, this study employs the following two methods for robustness tests, as shown in Columns (2) and (3) of Table 2: First, the measurement approach for the explanatory variable is altered. An alternative taxonomy comprising four dimensions—digital technology application, internet business models, smart manufacturing, and modern information systems—is adopted to replace the initial structure that included artificial intelligence, big data, cloud computing, blockchain and digital technology application. These are aggregated to form a proxy variable (DIGA) for digital transformation. The test results remain consistent with the benchmark regression ones.

Next, additional control variables were added to reduce bias caused by omitted variables, such as dual roles (Dua) and cash flow level (cash). The results still matched the benchmark regression.

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4.3. Heterogeneity test

4.3.1. Heterogeneity in firm ownership attributes

The sample is divided by ownership into state-owned and non-state-owned enterprises. This is to assess how the impact of digital transformation on green innovation volume might vary between the two groups. The results in Columns (1) and (2) of Table 3 show both subgroups have a positive and significant effect from digital transformation. But a comparative analysis finds this effect is much stronger in non-state-owned enterprises. This situation is different from the conventional view that "the resource advantages of SOEs make it easier to amplify the dividends of digitalization." The main reasons are these. Non-state-owned enterprises face fiercer market competition, so they have a more urgent need for digital transformation. They also have shorter decision-making chains and more flexible organizational structures—this lets them quickly turn digital technologies into green innovation capacity and shorten the "input-output" cycle. On the other hand, non-state-owned enterprises have limited resources, so they tend to align digital resources precisely with green R&D to use them efficiently. State-owned enterprises, though, have to balance multiple objectives. This disperses their resource focus on green innovation to some extent. What's more, non-SOEs are more sensitive to market demand. Digital transformation lets them adjust R&D directions quickly, which boosts innovation efficiency. So the operational characteristics of non-SOEs make them better able to use digital transformation to advance green technology innovation. This provides a basis for making differentiated policies.

Table 3. Heterogeneity in

	(1)	(2)	(3)	(4)
	GTI	GTI	GTI	GTI
DIGA	0.0475***	0.0477***	0.0469***	0.0463***
	(0.00764)	(0.00454)	(0.00640)	(0.00457)
TOP1	-0.0962***	-0.0103	0.115***	-0.0136
	(0.0181)	(0.0115)	(0.0272)	(0.0208)
Board	0.0828***	-0.00873	-0.0148	-0.0285**
	(0.0291)	(0.0216)	(0.0151)	(0.0116)
Roe	0.0126	0.00641**	0.0701	0.230***
	(0.00880)	(0.00270)	(0.0435)	(0.0306)
Age	-0.0767***	-0.124***	0.200***	0.117***
	(0.0134)	(0.00859)	(0.00780)	(0.00991)
Size	0.164***	0.138***	-0.114***	-0.0714***
	(0.00695)	(0.00636)	(0.0113)	(0.00770)
Lev	-0.0911**	0.247***	0.00881**	0.00534
	(0.0457)	(0.0326)	(0.00406)	(0.00330)
Year	Yes	Yes	Yes	Yes
IND	Yes	Yes	Yes	Yes
_cons	-2.898***	-2.664***	-4.214***	-2.108***
	(0.156)	(0.145)	(0.182)	(0.210)

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Table 3. (continued)

N	11774	19820	15955	15763
R^2	0.247	0.171	0.217	0.150
adj. R^2	0.241	0.167	0.212	0.145

4.3.2. Heterogeneity in firm size

This study measures firm size by using the logarithm of total assets and divides the sample into large firms and small and medium-sized enterprises (SMEs) based on the median firm size for grouped regressions. Data from Columns (3) and (4) in Table 3 demonstrate that the coefficient of digital transformation is larger for large firms than for SMEs. This outcome stems from two factors: larger firms possess more sophisticated technological systems and face fiercer competition, compelling them to pursue green technological innovation to enhance overall patent output. Smaller firms, conversely, lag in technological development, encounter milder market competition, and demonstrate relatively weaker green technological innovation capabilities.

4.4. Mediating effect test

To examine whether corporate ESG plays a mediating role in the relationship between digital transformation and green technology innovation, this study establishes a mediation model as specified in Equations (2) and (3), where M_{it} represents corporate ESG.

A mediation test was conducted to examine the role of ESG, with results detailed in Table 4. The analysis establishes that digital transformation significantly improves corporate ESG performance (Column 1). Moreover, even after controlling for ESG, the direct effect of digital transformation on green innovation is still positive, while ESG itself also shows a discernible positive impact. These findings collectively substantiate that ESG serves as a partial mediator, thereby providing empirical support for Hypothesis 2.

Table 4. Mediating effect test results

	(1)	(2)
	ESG	GTI
DIGA	0.222***	0.0451***
	(0.0238)	(0.00393)
TOP1	0.216***	-0.0228**
	(0.0578)	(0.00952)
Board	0.288***	0.0475***
	(0.105)	(0.0173)
Roe	0.0226	0.00685**
	(0.0162)	(0.00267)
Age	-0.751***	-0.0756***
	(0.0399)	(0.00660)
Size	1.357***	0.132***
	(0.0273)	(0.00468)
Lev	-4.827***	0.206***

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Table 4. (continued)

	(0.160)	(0.0267)
	(0.443)	(0.0729)
ESG		0.0132***
		(0.000927)
Year/IND	Yes	Yes
_cons	47.03***	-3.543***
	(0.604)	(0.109)
N	31720	31718
R^2	0.144	0.190
adj. R^2	0.141	0.187

5. Conclusion

5.1. Key findings

The sample is divided by ownership into state-owned and non-state-owned enterprises. This operation aims to assess how the impact of digital transformation on green innovation volume might vary between these two groups.

The results in Columns (1) and (2) of Table 3 show both subgroups have a positive and significant effect from digital transformation. But a comparative analysis finds this effect is much stronger in non-state-owned enterprises. This outcome differs from the conventional view that “the resource advantages of SOEs make it easier to amplify the dividends of digitalization.”

The main reasons for this difference are as follows. Non-state-owned enterprises face fiercer market competition, so they have a more urgent need for digital transformation. They also have shorter decision-making chains and more flexible organizational structures—this lets them quickly turn digital technologies into green innovation capacity and shorten the “input-output” cycle. Meanwhile, non-state-owned enterprises have limited resources, so they tend to align digital resources precisely with green R&D to achieve efficient utilization. State-owned enterprises, though, must balance multiple objectives, which disperses their resource focus on green innovation to some extent. Additionally, non-SOEs are more sensitive to market demand; digital transformation enables them to adjust R&D directions quickly, which further boosts innovation efficiency. These operational characteristics of non-SOEs make them better able to leverage digital transformation to advance green technology innovation, providing a basis for formulating differentiated policies.

5.2. Research implications

Based on these findings, advancing digital transformation to empower corporate green technological innovation and support the "dual carbon" goals needs efforts from multiple dimensions.

At the governmental level, it is essential to build a policy framework that integrates digitalization and green innovation, with guidance from the "dual carbon" objectives. For enterprise ownership structure differences, priority must be given to the innovation potential of non-state-owned enterprises (NSOEs)—specialized subsidies and technical service platforms can reduce their digital transformation costs, while state-owned enterprises (SOEs) should be guided to learn from NSOEs' transformation flexibility, optimize internal decision-making mechanisms, and boost synergistic efficiency between digital transformation and green innovation. For enterprise scale differences,

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small and medium-sized enterprises (SMEs) should get more financial subsidies and technical guidance to lower their transformation barriers. Enterprises must enhance information capabilities to improve innovation performance—they should make full use of digital technologies to streamline information exchange channels, including using digital communication technologies to reduce vertical information barriers between top-down and bottom-up flows, ensuring accurate delivery of management's strategic intent [13]. Governments also need to refine ESG assessment mechanisms, clarify ESG disclosure standards, and gradually implement mandatory ESG reporting systems to push enterprises to adopt standardized green innovation practices through external oversight; at the same time, set up routine audit mechanisms for green innovation subsidies, strengthen legal frameworks and intellectual property protection systems in the digital economy, and strictly crack down on green technology infringement.

At the corporate level, on the one hand, non-state-owned enterprises (non-SOEs) should leverage their flexibility to increase investments in digital transformation, deeply integrating digital technologies into the entire green R&D and production processes. Enhancing their ESG ratings will further strengthen their market competitiveness. On the other hand, state-owned enterprises (SOEs) need to optimize internal management processes, improve the efficiency of transformation-related decision-making, and strengthen technical exchanges and cooperation with non-SOEs. Furthermore, large firms and small and medium-sized enterprises (SMEs) should engage in industrial chain collaboration to achieve complementary sharing of digital resources and green innovation resources. Ultimately, this will foster a development paradigm characterized by "complementary advantages between SOEs and non-SOEs, and collaboration between large and small firms."

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