Environment, Social and Governance; Vol.3, No.1; 2026
E-ISSN: 3006-3973 P-ISSN：3006-3965
DOI: https://doi.org/10.70267/ esg2026.v3n1.1024
Published by: Zeus Press

How Does ESG Performance Drive Firms' Green Transformation under China's "Dual Carbon" Goals? Empirical Evidence from A-share Listed Companies

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Abstract

Under the background of the "dual carbon" goals and high-quality development, corporate green transformation has become a key pathway to promote sustainable economic development. This study aims to systematically examine whether and how corporate ESG performance drives green technological innovation. Using data from Chinese A-share listed companies from 2009 to 2023, a two-way fixed effects model is constructed and validated through various robustness and endogeneity tests. The empirical results show that ESG performance significantly promotes green technological innovation, and this conclusion remains robust after replacing variable measures, adjusting time windows, and controlling for high-dimensional fixed effects. Mechanism analysis reveals that ESG performance primarily drives green innovation indirectly through two channels: increasing R&D investment and alleviating financing constraints. Furthermore, heterogeneity analysis indicates that this promoting effect is more pronounced in state-owned enterprises and firms with female executives. The findings provide empirical evidence and policy implications for improving ESG governance systems and advancing corporate green transformation.

Keywords

ESG performance, green innovation, dual carbon goals, R&D investment, financing constraints

1. Introduction

1.1 Research Background

Under the backdrop of the "dual carbon" goals and high-quality development, green and low-carbon transformation has become a crucial direction for adjusting China's economic structure and shifting its development mode. As the core entities of China's economic growth, A-share listed companies are not only key drivers of economic expansion but also major players in high-carbon-emission industries such as steel, chemicals, and power. Their green transformation performance directly impacts the achievement of the national "dual carbon" strategic objectives. In this process, Environmental, Social, and Governance (ESG) performance has increasingly emerged as an important indicator for measuring firms' sustainable development capabilities. How to promote corporate green technological innovation by enhancing ESG performance has

become a core issue of common concern in both theoretical research and policy practice. Although the ESG concept has been widely adopted in international capital markets, academic views on its impact on corporate green innovation remain markedly divided. On one hand, from a traditional economic perspective, ESG investments and disclosures may increase compliance and governance costs, exerting a "crowding-out effect" on green R&D. On the other hand, based on stakeholder theory, strong ESG performance helps mitigate information asymmetry, improve financing environments, and secure external resource support, thereby generating an "innovation compensation effect." In the Chinese context, influenced by institutional environments, policy orientations, and corporate ownership structures, the mechanisms through which ESG affects green innovation may exhibit distinct characteristics compared to Western countries, and relevant empirical evidence still requires further validation.

1.2 Literature Review

A substantial body of research based on panel data and robust econometric methods consistently shows that improvements in corporate ESG performance generally significantly promote green innovation activities. These effects are primarily manifested in increases in green patent applications, invention patent outputs, and patent citation counts. Such conclusions have been widely validated in samples of Chinese A-share listed companies as well as in international studies [1-4]. Existing research further indicates that the promoting role of ESG on green innovation operates mainly through channels such as alleviating financing constraints, optimizing the allocation of green R&D resources, strengthening corporate governance and managerial environmental awareness, attracting innovative human capital, and enhancing investment efficiency and government-enterprise relations [5-8].

At the same time, the literature commonly finds that the innovation effects of ESG exhibit significant contextual dependency and heterogeneity. On one hand, the strength of ESG's impact on green innovation varies with the choice of innovation indicators, sample periods, and econometric methods. Some studies suggest that ESG is more effective in increasing the quantity of green innovation, while its influence on high-value or technologically frontier invention patents is relatively limited, and may even be insignificant in certain industries or firm types [9, 10]. On the other hand, nonlinear relationships are increasingly being uncovered: at lower ESG levels, resource reallocation may suppress innovation inputs, whereas at higher ESG levels, firms are more likely to incorporate green innovation into long-term strategic objectives [11]. In addition, discrepancies in ESG ratings and insufficient disclosure quality may induce "greenwashing" behavior, thereby weakening ESG's role in driving substantive green technological progress [12, 13].

Further heterogeneity analyses reveal systematic differences in the efficiency of ESG-to-green-innovation conversion across institutional and firm characteristics. State-owned enterprises, benefiting from policy support and public resources, are more likely to convert ESG performance into tangible green technological outputs, whereas non-state-owned enterprises rely more heavily on market incentives and financing conditions for their innovation responses to ESG [14, 15]. Firm size also plays a significant moderating role: large enterprises, with their resource reserves and R&D capabilities, are better positioned to achieve high-quality green invention patent outputs, while SMEs' ESG actions tend to exhibit weaker or symbolic characteristics [16]. Moreover, industry pollution intensity, regional institutional environments, and regulatory strictness further shape variations in the ESG-green innovation relationship [4, 17, 18], underscoring the critical role of external institutional foundations in this linkage.

In summary, building on existing research that has confirmed ESG performance's contribution to promoting corporate green innovation, this paper further systematically examines the strength of this effect, its underlying mechanisms, and transmission pathways. Grounded in resource-based theory and the "dual carbon" strategic context, and using data from Chinese A-share listed companies, this study incorporates heterogeneity analyses based on state-owned versus non-state-owned enterprises and the presence of female executives, thereby enriching the theoretical interpretation and practical implications of the ESG-green innovation relationship in emerging market contexts.

2. Theoretical Analysis and Research Hypotheses

In the context of the "dual carbon" goals and high-quality development, corporate green innovation has become a crucial pathway to achieving sustainable competitive advantages. ESG performance, as a

comprehensive indicator measuring firms' environmental responsibility, social responsibility, and governance level, not only reflects the degree of emphasis placed on sustainable development but also profoundly shapes firms' innovation decision-making behavior by influencing resource allocation, governance efficiency, and external evaluations. Drawing primarily on resource-based theory, this paper systematically analyzes the internal logic through which corporate ESG performance influences green innovation.

2.1 ESG Performance and Corporate Green Innovation

Existing research conducted across different countries and institutional contexts generally finds that improvements in corporate ESG performance significantly promote green patent outputs and green technological innovation. However, this relationship exhibits clear heterogeneity influenced by firm characteristics, industry attributes, and external institutional environments. Based on resource-based theory, strong ESG performance enhances firms' reputation and legitimacy, enabling them to access critical resources, alleviate financing constraints, and improve governance structures. This suppresses short-term opportunistic behavior and strengthens long-term strategic orientation. These mechanisms collectively bolster the resource base, organizational capabilities, and strategic motivation for firms to engage in green innovation, providing theoretical support for ESG's role in driving green innovation. Accordingly, the following hypothesis is proposed:

H1: Corporate ESG performance positively influences firms' green innovation capabilities.

2.2 ESG Performance, R&D Investment, and Green Innovation

Resource-based theory posits that firms' competitive advantages stem from the acquisition and efficient transformation of key resources, with R&D investment serving as the core vehicle for converting resources into innovation outputs. Strong ESG performance improves firms' reputation, legitimacy, and governance quality, thereby enhancing financing environments and reinforcing long-term strategic orientation. This strengthens resource acquisition capabilities and optimizes the allocation of R&D resources, directing investments toward green technological domains. Consequently, R&D investment plays a significant mediating role between ESG performance and corporate green innovation. Based on the above analysis, the following hypothesis is proposed:

H2: Corporate ESG performance promotes green innovation by increasing R&D investment.

2.3 ESG Performance, Financing Constraints, and Green Innovation

Strong ESG performance enhances information transparency and institutional legitimacy, thereby mitigating information asymmetry between firms and capital providers and reducing adverse selection and moral hazard risks. In China's policy-guided institutional environment, firms with high ESG performance are more likely to obtain policy-oriented financial support, government subsidies, and green credit resources, effectively alleviating financing constraints. The reduction in financing constraints not only expands the scale of disposable funds available to firms but also strengthens their capacity to bear the uncertainty associated with green innovation, providing critical assurance for sustained green technological R&D and low-carbon transformation. Therefore, this paper argues that financing constraints play an important mediating role between ESG performance and corporate green innovation, and proposes the following hypothesis:

H3: Corporate ESG performance promotes green innovation by alleviating financing constraints.

3. Research Design

3.1 Sample Selection and Data Sources

This paper uses data from Chinese A-share listed companies from 2009 to 2023 as the sample and applies the following processing steps: (1) exclusion of ST and *ST companies; (2) exclusion of companies with missing or abnormal data; (3) exclusion of financial industry companies; (4) to prevent the influence of extreme values on the results, continuous firm-level variables are winsorized at the 1% and 99% levels.

After the above processing, a final sample of 40,334 observations is obtained. Green patent data are sourced from the CSMAR database. Corporate ESG performance data are obtained from the Huazheng ESG Rating Database, using the annual comprehensive ESG score provided as the measure of firms' ESG performance. Other firm financial data are all sourced from the CSMAR database.

3.2 Model Specification and Variable Definitions

3.2.1 Model Specification

The following multivariate regression model is constructed to examine the impact of corporate ESG performance on green innovation:

$$GI_{i,t}=\alpha_0+\alpha_1 ESG_{i,t}+\sum Controls + YearFE + FirmFE+\varepsilon_{i,t} \quad (1)$$

where *i* denotes the firm and *t* denotes the year; the dependent variable *GI* represents green innovation; *ESG* is the core explanatory variable; *Controls* represents the set of control variables; *YearFE* denotes year fixed effects; *FirmFE* denotes firm fixed effects; and ε is the residual term. If corporate ESG performance has a significant positive effect on green innovation (i.e., Hypothesis H1 holds), then α_1 should be significantly positive. To enhance the robustness of statistical inferences, robust standard errors are used in the regression models.

3.2.2 Variable Definitions

(1) Dependent Variable

Green Innovation (GI). Following existing studies, domestic research primarily measures firms' innovation capabilities using the number of patent applications, granted patents, or citations received. This paper selects the number of green patent applications (rather than granted patents) as the indicator for the following reasons: (1) green patent applications have relatively high thresholds and can therefore reflect firms' green innovation efforts to a certain extent; (2) the authorization process for green patents is lengthy, so using application numbers better captures timely and accurate green innovation activities in the current year. The dependent variable is constructed as the natural logarithm of (total green patent applications + 1) to measure firms' level of green innovation.

(2) Explanatory Variable

Corporate ESG Performance (ESG). The ESG concept aligns with sustainable development principles, and corresponding ESG performance evaluation systems exist. However, in China, the securities market lacks a unified evaluation system for listed companies' ESG performance, necessitating reliance on third-party rating agencies. The Huazheng ESG rating system fully draws on international ESG frameworks while incorporating Chinese national conditions, constructing a top-down four-level indicator system for comprehensive evaluation of listed companies. It employs semantic analysis, natural language processing (NLP), and other intelligent algorithms to assign values to firms' ESG performance. Therefore, this paper uses the comprehensive ESG score from Huazheng as the data source. This score is on a 100-point scale; higher scores indicate better overall performance across the environmental, social, and governance dimensions.

(3) Control Variables

Drawing on studies by Fang Xianming et al.[19], Cai Qingfeng et al. [20], and others, the following firm-level control variables are included: firm size (SIZE), return on assets (ROA), leverage ratio (LEV), revenue growth rate (GROWTH), cash flow (CFLOW = net cash flow from operating activities / total assets), firm age (LNAGE), shareholding proportion of the largest shareholder (TOP1), and government subsidies (SUBSIDY). Table 1 provides detailed variable descriptions.

Table 1: Variable Definitions

Variable Type	Variable Name	Variable Symbol	Calculation Method	Unit
Independent Variable	ESG Performance	ESG	Huazheng ESG Comprehensive Score	-

Dependent Variable	Green Innovation	GI	Natural logarithm of (total green patent applications + 1)	Units
Mediating Variables	Financing Constraints	WW	(Whited & Wu, 2006)[21]	-
	R&D Expenditure Amount	R&D	RDSpendSum	CNY
Control Variables	Firm Size	SIZE	Ln (total assets)	-
	Profitability Indicator	ROA	Return on assets (net profit / total assets)	%
	Risk Indicator	LEV	Leverage ratio (total liabilities / total assets)	%
	Growth Indicator	GROWTH	Operating revenue growth rate	%
	Cash Flow Ratio	CFLOW	Cash flow = net cash flow from operating activities / total assets	%
	Firm Age	INAGE	Ln (Year - listing year)	-
	Ownership Structure	TOP1	Ownership concentration - shareholding proportion of the largest shareholder	%
	Fiscal Subsidy Variable	SUBSIDY	Government subsidies as a proportion of total assets	%

4. Descriptive Statistics

To standardize variable scales and improve the readability of results, this paper applies linear scale transformations to certain variables: the green innovation indicator is constructed by adding one to the number of green patent applications, taking the natural logarithm, and scaling proportionally; ownership concentration is standardized as a percentage. These transformations do not alter the relative relationships among variables or the estimation conclusions. Table 2 presents the results of the descriptive statistical analysis:

Table 2: Descriptive Statistical Analysis

	count	mean	sd	min	p50	max
GI	40334	35.797	76.15335	0.000	0.000	329.584
ESG	40334	73.386	4.750901	58.340	73.557	83.931
SIZE	40334	22.217	1.28256	19.987	22.012	26.240
ROA	40334	0.038	.0603946	-0.225	0.038	0.202
LEV	40334	0.417	.2065822	0.051	0.407	0.908
GROWTH	40334	0.002	.0037199	-0.005	0.001	0.023
CFLOW	40334	0.049	.0682204	-0.154	0.048	0.244
lNAGE	40334	2.043	.9234538	0.000	2.197	3.367
TOP1	40334	0.343	.1489203	0.086	0.321	0.746
SUBSIDY	40334	0.005	.0049267	0.000	0.003	0.028

5. VIF Multicollinearity Test

Table 3 presents the VIF test results:

Table 3: VIF Test

Variable	VIF
SIZE	1.75
ROA	1.59
LEV	1.69
GROWTH	1.10
CFLOW	1.24
LNAGE	1.42
TOP1	1.08
SUBSIDY	1.06

Mean VIF	1.35

All explanatory variables have VIF values below 2, with the maximum value of 1.75 for SIZE and the minimum value of 1.06 for Subsidy. The average VIF is 1.35. Overall, the model exhibits no significant multicollinearity issues, and the regression results

6. Empirical Analysis

6.1 Baseline Regression

Table 4 presents the baseline regression results. In columns (3) and (4), the coefficients of ESG are 1.155 and 0.376, respectively, both passing the 1% significance level test. The regression results indicate that, after controlling for firm-specific characteristics and industry-year trends, ESG performance continues to exert a significant positive driving effect on corporate green innovation. Specifically, firms' active investments in environmental responsibility, social responsibility, and internal governance can provide better resource support and reputational assurance for green technological R&D, thereby enhancing their green innovation output levels. This result strongly supports Hypothesis 1 proposed in this paper.

Table 4: Baseline Regression

	GI	GI	GI	GI
ESG	2.041***	0.390***	1.155***	0.376***
	(25.775)	(4.298)	(13.862)	(4.122)
SIZE			14.237***	3.306***
			(37.636)	(3.542)
ROA			28.837***	8.597
			(3.772)	(1.388)
LEV			17.436***	5.336
			(7.558)	(1.557)
GROWTH			-15.968	-101.127
			(-0.154)	(-1.488)
CFLOW			-17.396***	-11.026**
			(-2.910)	(-2.371)
LNAGE			-10.109***	1.302
			(-21.352)	(1.189)
TOP1			-22.158***	-9.560
			(-8.664)	(-1.601)
SUBSIDY			1101.754***	240.988***
			(14.395)	(3.351)
_cons	-113.950***	7.167	-349.645***	-67.590***
	(-19.573)	(1.076)	(-42.164)	(-3.163)
Firm_FE	NO	YES	NO	YES
Year_FE	NO	YES	NO	YES
N	40334	40334	40334	40334
r2_a	0.016	0.590	0.067	0.590
F	664.373	18.473	322.741	6.016

t statistics in parentheses $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.2 Robustness Tests

6.2.1 Changing the Measurement of Key Variables

To test the robustness of the baseline regression results, this paper further verifies the relationship between ESG performance and corporate green technological innovation by replacing the measurement methods of both the core explanatory variable and the dependent variable. Specifically, for the dependent variable, while the previous analysis used the total number of green patent applications to measure green technological

innovation, this section employs the number of green invention patent applications (GI2) and the number of green utility model patent applications (GI3) as alternative indicators to distinguish between high-quality green innovation and relatively incremental green innovation. For the explanatory variable, the continuous Huazheng ESG comprehensive score is replaced with the discrete Huazheng ESG rating indicator (ESG_Rating), assigned values from 1 to 9 levels, to examine whether the impact of different ESG rating levels on green innovation remains consistent.

Table 5 reports the regression results of the above robustness tests. The results show that when using the number of green invention patent applications (GI2) and the number of green utility model patent applications (GI3) as dependent variables, the regression coefficients of the ESG comprehensive score are 0.002 and 0.004, respectively, both significantly positive at the 1% level. This indicates that improvements in ESG performance significantly promote firms' green technological innovation activities across different types. These findings suggest that both high-technological-content green invention innovations and primarily improvement-oriented green utility model innovations increase significantly with improvements in corporate ESG performance, thereby verifying the robustness of the baseline regression conclusions.

Furthermore, when replacing the ESG comprehensive score with the ESG rating indicator and re-estimating with the total number of green patent applications (GI) as the dependent variable, the estimated coefficient of ESG_Rating is 1.471 and significantly positive at the 1% level. This indicates that higher ESG rating levels are associated with higher levels of green innovation output. This result further corroborates the positive promoting effect of ESG performance on green innovation from the discrete rating dimension, demonstrating that the conclusions of this paper are not dependent on a single method of constructing ESG indicators.

In summary, by simultaneously replacing the measurement indicators for green innovation and ESG performance, the empirical results continue to show that ESG performance has a significant and robust positive impact on corporate green technological innovation, further enhancing the credibility of the research conclusions.

Table 5: Robustness Test Results (Part 1)

	GI2	GI3	GI
ESG	0.002***	0.004***	-
	(3.227)	(4.472)	-
ESG_Rating	-	-	1.471***
	-	-	(3.610)
SIZE	0.029***	0.027***	3.397***
	(3.900)	(3.080)	(3.640)
ROA	0.076	0.081	8.880
	(1.507)	(1.613)	(1.432)
LEV	0.054**	0.026	5.044
	(1.973)	(0.895)	(1.471)
GROWTH	-1.053**	-1.346**	-105.268
	(-1.969)	(-2.428)	(-1.550)
CFLOW	-0.064*	-0.075*	-11.087**
	(-1.707)	(-1.949)	(-2.384)
LNAGE	0.012	0.015	1.222
	(1.418)	(1.471)	(1.116)
TOP1	-0.053	-0.095*	-9.539
	(-1.128)	(-1.731)	(-1.596)
SUBSIDY	2.143***	1.395**	241.066***
	(3.823)	(2.278)	(3.352)
_cons	-0.619***	-0.634***	-47.903**
	(-3.643)	(-3.107)	(-2.338)
Firm_FE	YES	YES	YES
Year_FE	YES	YES	YES
N	40334	35628	40334
r2_a	0.559	0.616	0.590
F	5.971	5.530	5.602

*t statistics in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

6.2.2 Replacing the Econometric Model-Tobit Method

Given the obvious left-censoring feature of the corporate green technological innovation variable at zero, using ordinary linear regression methods may lead to biased parameter estimates. To address this, this paper further introduces the Tobit model to re-estimate the relationship between corporate ESG performance and green technological innovation, better handling the statistical inference issues caused by censored data and thereby testing the robustness of the baseline regression conclusions.

Table 6 presents the regression results of the Tobit model. The results show that under different model specifications, the regression coefficients of corporate ESG performance (ESG) are all significantly positive and significant at the 1% statistical level. This indicates that after accounting for the censored nature of the green innovation variable and adjusting the econometric method, the promoting effect of ESG performance on corporate green technological innovation remains robust. This conclusion is highly consistent with the previous empirical results based on the fixed effects model, further validating the core research hypothesis that "improvements in corporate ESG performance can significantly promote green technological innovation."

From the perspective of control variables, variables such as firm size, leverage, and government subsidies also show significant effects in most models, indicating that firms' resource endowments and external support continue to play important roles in the green innovation process. Overall, the Tobit regression results demonstrate that the aforementioned empirical conclusions do not undergo substantial changes due to the replacement of the econometric model, further enhancing the credibility and robustness of the research findings.

Table 6: Robustness Test Results (Part 2)

	GI	GI	GI
ESG	4.886***	5.812***	5.812***
	(14.459)	(17.814)	(17.654)
SIZE	47.676***	47.531***	47.531***
	(31.265)	(31.226)	(31.529)
ROA	147.819***	75.430**	75.430**
	(4.564)	(2.383)	(2.467)
LEV	69.082***	60.847***	60.847***
	(7.210)	(6.387)	(6.504)
GROWTH	205.803	-910.084**	-910.084**
	(0.480)	(-2.135)	(-2.264)
CFLOW	-92.561***	-80.780***	-80.780***
	(-3.774)	(-3.350)	(-3.470)
LNAGE	-42.356***	-40.007***	-40.007***
	(-21.983)	(-21.402)	(-22.460)
TOP1	-90.642***	-96.271***	-96.271***
	(-8.881)	(-9.550)	(-9.490)
SUBSIDY	4706.147***	3832.765***	3832.765***
	(15.745)	(13.176)	(14.154)
_cons	-1514.629***	-1600.477***	-1600.477***
	(-43.447)	(-45.338)	(-46.773)
/			
var(e.GI1)	49254.937***	44121.728***	44121.728***
	(57.293)	(57.819)	(81.355)
Observations	40334	40334	40334
Log likelihood	-76595.109	-75057.830	-75057.830

*t statistics in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

6.2.3 Replacing the Time Window

To further test the robustness of the research conclusions across different periods, this paper conducts robustness analysis by adjusting the sample time windows, changing the baseline sample period from 2009-2023 to the sub-periods of 2013-2023 and 2009-2019, respectively.

The selection of these time windows has clear research motivations. On one hand, 2013 is widely regarded as an important turning point when China's environmental governance and green development policies were significantly strengthened, after which environmental regulation intensity increased markedly and green

finance and ESG concepts became increasingly institutionalized. Limiting the sample to 2013-2023 helps examine whether the impact of corporate ESG performance on green technological innovation remains valid in a more mature institutional environment with stronger environmental policy constraints and ESG disclosure. On the other hand, after 2019, corporate operations and innovation activities were jointly affected by the COVID-19 pandemic, macroeconomic fluctuations, and policy responses, potentially introducing periodic disturbances to firms' green innovation behavior. Adjusting the sample to 2009-2019 helps exclude interference from unconventional shocks such as the pandemic and tests whether the conclusions are driven by specific extreme events.

The regression results in Table 7 indicate that in both alternative time windows (2013-2023 and 2009-2019), the coefficients of corporate ESG performance on green technological innovation remain significantly positive, with signs and significance levels highly consistent with the baseline regression results. This suggests that the earlier conclusion-"corporate ESG performance can significantly promote green technological innovation"-is not dependent on a specific institutional environment or exogenous shock in any particular period but exhibits strong robustness and generalizability across different time contexts.

Table 7: Robustness Test Results (Part 3)

	GI	GI
	2009-2019	2013-2023
ESG	0.533***	0.275***
	(4.771)	(2.880)
SIZE	3.674***	2.861***
	(3.244)	(2.770)
ROA	6.915	9.921
	(0.861)	(1.528)
LEV	4.360	3.755
	(1.051)	(0.969)
GROWTH	-228.337***	-37.318
	(-3.053)	(-0.474)
CFLOW	-5.549	-11.143**
	(-1.026)	(-2.107)
LNAGE	4.700***	1.226
	(3.029)	(0.950)
TOP1	-12.096	-8.613
	(-1.583)	(-1.262)
SUBSIDY	289.490***	245.556***
	(3.471)	(2.964)
_cons	-91.722***	-48.527**
	(-3.447)	(-2.086)
Observations	23975	33969

*t statistics in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

6.3 Endogeneity Tests

Given the potential influence of omitted variables and reverse causality between corporate ESG performance and green technological innovation, this paper conducts multiple endogeneity tests to verify the robustness of the baseline conclusions. First, to control for time-varying unobservable shocks at the industry level, industry-year interaction fixed effects are added to the baseline model. To mitigate the potential issue of green innovation reversely affecting ESG ratings, lagged one-period and lagged two-period ESG performance variables are used as explanatory variables in the regressions. The results in columns (3) and (4) show that the signs and significance levels of the lagged ESG variables remain consistent with the baseline regression, indicating that the research conclusions are unlikely to be driven by reverse causality.

Overall, the above results demonstrate that after sufficiently controlling for high-dimensional fixed effects and addressing potential endogeneity issues, the promoting effect of corporate ESG performance on green technological innovation remains robust.

Table 8: Endogeneity Test Results

	GI	GI	GI	GI
	(1)	(2)	(3)	(4)
ESG	0.321***	0.388***	0.393***	0.315***
	(3.498)	(4.000)	(4.169)	(3.199)
SIZE	4.107***	4.664***	3.189***	2.857***
	(4.302)	(4.145)	(3.168)	(2.687)
ROA	7.191	7.359	8.310	8.942
	(1.171)	(1.110)	(1.263)	(1.329)
LEV	4.129	4.920	5.176	2.813
	(1.214)	(1.308)	(1.408)	(0.711)
GROWTH	-148.816**	-117.183	-86.251	-73.129
	(-2.129)	(-1.566)	(-1.163)	(-0.932)
CFLOW	-7.969*	-12.415**	-7.223	-5.154
	(-1.723)	(-2.421)	(-1.423)	(-0.962)
LNAGE	1.937*	1.946	-4.228**	-6.193**
	(1.685)	(1.534)	(-2.290)	(-2.347)
TOP1	-6.680	-10.478	-15.733**	-17.125**
	(-1.097)	(-1.500)	(-2.496)	(-2.541)
SUBSIDY	213.164***	227.886***	255.082***	260.263***
	(2.962)	(2.777)	(3.272)	(3.042)
_cons	-82.990***	-98.004***	-51.541**	-31.689
	(-3.759)	(-3.854)	(-2.230)	(-1.262)
Industry_Year_FE	YES	NO	--	--
City_Year_FE	NO	YES	--	--
N	40325	38033	35331	30873
r2_a	0.602	0.607	0.597	0.603

*t statistics in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

6.4 Heterogeneity Analysis

6.4.1 Ownership Nature: State-Owned vs. Non-State-Owned Enterprises

Considering differences in ownership structure, the sample is divided into state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs) to test the impact of ESG performance on green innovation across different ownership types. Table 9 shows the influence of ownership nature on the regression results:

Table 9: Heterogeneity by Ownership Nature

	GI	GI
	SOEs	non-SOEs
ESG	0.611**	0.343***
	(2.257)	(3.496)
Firm_FE	YES	YES
Year_FE	YES	YES
N	4319	32263
r2_a	0.676	0.627

*t statistics in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

In the SOE subsample, the coefficient of ESG performance on green technological innovation is significantly positive at the 5% significance level, indicating that improvements in ESG performance effectively promote green patent outputs in SOEs. In contrast, in the non-SOE subsample, the regression coefficient of ESG performance is also positive but with relatively lower significance and smaller magnitude, suggesting that the conversion effect from ESG to green innovation is weaker in non-SOEs.

These differences indicate that ownership nature plays an important moderating role in the process through which ESG influences green innovation. Compared to non-SOEs, SOEs typically bear more explicit environmental governance responsibilities and enjoy institutional advantages in policy support, resource access, and financing constraints, making it easier for them to translate ESG improvements into tangible green technological innovation outcomes. Non-SOEs' ESG investments rely more on market incentives and external

financing conditions, resulting in more cautious green innovation responses under resource constraints and uncertainty.

6.4.2 Presence of Female Executives

To further examine the moderating role of management characteristics in the process through which ESG performance influences corporate green innovation, this paper divides the sample into groups based on whether firms have female executives and estimates the impact of ESG performance on green technological innovation separately in the "with female executives" and "without female executives" subsamples. The regression results are shown in Table 10.

Table 10: Female Executives

	GI	GI
	With Female Executives	Without Female Executives
ESG	0.390***	0.249
	(3.673)	(1.447)
Firm FE	YES	YES
Year FE	YES	YES
N	27033	12866
r2 a	0.615	0.599

*t statistics in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

The results indicate that in the subsample with female executives, the regression coefficient of ESG performance on green technological innovation is significantly positive at a high significance level, suggesting that in contexts where female executives participate in corporate governance, improvements in ESG performance can more effectively translate into green patent outputs. In contrast, in the subsample without female executives, the impact of ESG performance on green innovation remains positive but with relatively weaker significance and estimated magnitude; in some models, it does not reach conventional significance levels.

These results suggest that the presence of female executives strengthens the effect of ESG performance on the conversion to green technological innovation to some extent. On one hand, female executives typically exhibit stronger risk aversion and long-term orientation, placing greater emphasis on firms' environmental responsibilities and sustainable development goals, which helps promote the substantive implementation of ESG concepts internally. On the other hand, gender-diverse management teams can improve decision quality and internal monitoring mechanisms, reducing the crowding-out effect of short-term performance pressures on green R&D investments and thereby enhancing the conversion efficiency from ESG investments to green innovation outputs.

Overall, the presence of female executives significantly influences the marginal effects of ESG on green innovation. This finding further reveals the managerial contextual dependency of the ESG–green innovation relationship and provides supplementary evidence from the perspectives of corporate governance and top management characteristics.

6.5 Mechanism Tests

6.5.1 Increasing R&D Investment

To further reveal the internal mechanisms through which corporate ESG performance influences green technological innovation, this paper conducts mediating effect analysis from the perspective of R&D investment, examining whether ESG performance promotes green technological innovation by increasing firms' R&D expenditure. The relevant regression results are shown in Table 11.

The results indicate that in the regression with R&D expenditure as the dependent variable, the coefficient of corporate ESG performance is significantly positive, suggesting that improvements in ESG performance significantly increase firms' resource allocation to R&D activities. This finding shows that firms with higher ESG performance are more inclined to increase sustained investments in technological R&D, laying a resource foundation for green technological innovation. Furthermore, when both ESG performance and R&D expenditure are included in the model for green technological innovation, the effect of R&D expenditure on green innovation is significantly positive, while the coefficient of ESG performance is somewhat attenuated

compared to the baseline regression but remains significant. This indicates that R&D investment plays a partial mediating role between ESG performance and green technological innovation.

These results suggest that ESG performance does not merely influence corporate green innovation through external reputation or institutional constraints but does so by affecting internal resource allocation decisions-particularly by increasing R&D investment intensity-thereby driving green technological innovation outputs. From the perspective of resource-based theory, strong ESG performance helps firms acquire and integrate key innovation resources and enhance long-term R&D investment capabilities. From the stakeholder theory perspective, improved ESG performance strengthens trust relationships with governments, financial institutions, and investors, alleviating financing constraints and providing more stable financial support for R&D activities. The increase in R&D investment further improves firms' exploratory capabilities and innovation output efficiency in the green technology domain, constituting an important transmission pathway for ESG's influence on green innovation.

Table 11: R&D Expenditure Amount

	GI	RDSpendSum	GI
ESG	0.383***	6536979.859***	0.332***
	(4.110)	(4.321)	(3.590)
R&D			0.000***
			(5.488)
SIZE	3.416***	73182510.864***	2.846***
	(3.590)	(3.070)	(2.967)
ROA	8.702	78826447.235	8.087
	(1.386)	(1.509)	(1.296)
LEV	5.388	-6.093e+07*	5.863*
	(1.550)	(-1.894)	(1.688)
GROWTH	-111.915	8.218e+08	-118.322*
	(-1.624)	(1.108)	(-1.725)
CFLOW	-11.628**	-1.167e+07	-11.537**
	(-2.440)	(-0.203)	(-2.433)
LNAGE	1.327	6815055.557	1.274
	(1.192)	(0.271)	(1.149)
TOP1	-9.750	-8.603e+07	-9.079
	(-1.611)	(-0.775)	(-1.503)
SUBSIDY	247.577***	1.228e+09*	238.007***
	(3.409)	(1.917)	(3.288)
_cons	-70.103***	-1.894e+09***	-55.338**
	(-3.211)	(-4.365)	(-2.519)
N	40334	40334	40334
r2_a	0.596	0.557	0.600
F	6.083	11.905	7.979

*t statistics in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

6.5.2 Alleviating Financing Constraints

Building on the previous analysis that ESG performance promotes green technological innovation by increasing R&D investment, this paper further examines another potential transmission mechanism from the perspective of financing constraints. Financing constraints are considered a key external limiting factor for firms in conducting green technological innovation, particularly given the large investment scale, long payback periods, and high uncertainty risks associated with green R&D.

The results in Table 12 show that in the regression with the financing constraint indicator as the dependent variable, the coefficient of corporate ESG performance is significantly negative. This indicates that strong ESG performance helps improve firms' information disclosure quality and external reputation, enhancing the confidence of financial institutions and investors in firms' long-term development capabilities, thereby reducing financing costs and expanding financing availability. Furthermore, when both ESG performance and financing constraints are included in the green technological innovation regression model, the effect of financing constraints on green innovation is significantly negative, while the coefficient of ESG performance is somewhat reduced compared to the baseline model but remains significant. This suggests that financing

constraints play a partial mediating role between ESG performance and green technological innovation. In other words, ESG performance not only directly promotes corporate green technological innovation but also indirectly enhances green innovation outputs by alleviating financing constraints.

In summary, alleviating financing constraints is one of the important mechanisms through which ESG performance promotes corporate green technological innovation. This finding further deepens the understanding of the internal logic of the ESG–green innovation relationship and provides strong mechanism-level support for the earlier conclusions.

Table 12: Financing Constraints

	GI	WW	GI
ESG	0.416***	-0.000***	0.418***
	(4.348)	(-5.564)	(3.808)
WW			-27.378**
			(-2.384)
SIZE	3.436***	-0.051***	1.581
	(3.878)	(-97.562)	(1.316)
ROA	1.417	-0.076***	6.807
	(1.032)	(-8.479)	(1.425)
LEV	2.868	0.032***	3.009
	(1.104)	(13.423)	(0.766)
GROWTH	0.006***	-3.500***	-95.815**
	(4.314)	(-3461519.320)	(-2.384)
CFLOW	-7.926**	-0.097***	-15.997***
	(-2.150)	(-25.758)	(-3.198)
LNAGE	1.391	0.005***	0.716
	(1.223)	(6.334)	(0.544)
TOP1	-9.542	-0.018***	-9.466
	(-1.565)	(-5.574)	(-1.397)
SUBSIDY	0.187***	-0.001***	0.174***
	(4.077)	(-30.245)	(4.314)
_cons	-70.245***	0.132***	-55.257**
	(-3.358)	(11.591)	(-2.264)
N	40334	34406	34406
r2_a	0.610	1.000	0.611
F	8.270	1.685e+12	.

t statistics in parentheses $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

7. Conclusions

This paper uses data from Chinese A-share listed companies from 2009 to 2023 as the sample to systematically examine the impact of corporate ESG performance on green technological innovation and its underlying mechanisms. The findings indicate that improvements in ESG performance significantly promote firms' green innovation outputs, and this conclusion remains robust under various robustness and endogeneity tests. Mechanism analysis reveals that ESG primarily drives green innovation indirectly through two pathways: expanding the scale of R&D investment and alleviating financing constraints. On one hand, strong ESG performance improves the external financing environment and reduces financing costs, providing stable financial support for high-risk, long-cycle green R&D activities. On the other hand, ESG practices help optimize resource allocation and strengthen managerial environmental responsibility awareness, thereby directing R&D resources toward green and low-carbon technological domains.

Based on the above conclusions, this paper offers the following policy implications: First, firms should incorporate ESG construction and information disclosure into their long-term development strategies, treating them as important resources for securing sustained competitive advantages and supporting green innovation. Second, governments should improve ESG disclosure and evaluation systems and amplify the guiding effect of ESG on green innovation through policy instruments such as green finance, fiscal subsidies, and tax incentives. Third, financial institutions should deeply integrate ESG indicators into risk assessment and

resource allocation decisions, channeling capital toward firms with high potential for green innovation and jointly advancing the economy toward high-quality, low-carbon, and sustainable development.

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Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgment

This paper is an output of the science project.

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