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The Impact of ESG Performance on Corporate Green Innovation in Heavily Polluting Enterprises

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Abstract: *Under the "Dual Carbon" strategic goals, heavily polluting enterprises driven by environmental, social, and governance (ESG) principles to advance green innovation play a pivotal role in fostering green development and high-quality economic growth. This study employs a sample of Shanghai and Shenzhen A-share listed companies in heavily polluting industries from 2012 to 2022, empirically examining the impact of ESG performance on corporate green innovation. The result shows a significant positive relationship, confirmed by several robustness tests. Mechanism analysis reveals that ESG performance drives corporate digital transformation, thereby facilitating green technology innovation. Further heterogeneity analysis demonstrates that superior ESG performance significantly enhances green innovation levels in large-sized enterprises and non-high-tech industries within the heavily polluting sector. These findings provide empirical evidence to support green innovation initiatives in high-pollution firms and the formulation of adaptive government policies.*

Keywords: *ESG Principles, Green Innovation, Heavily Polluting Enterprises, Digital Transformation*

1. Introduction

In the context of the "dual carbon" strategic objectives, the ESG concept is gaining increasing attention for its role in disclosing and influencing corporate sustainable development and innovation. The ESG concept aligns closely with green, low-carbon, and sustainable development ideals, charting a path for enterprises to achieve sustainable and high-quality growth. Green technological innovation, combining both "green" and "technological innovation," echoes the sustainable development connotations measured by ESG ratings. Furthermore, given that the agglomeration and relocation of heavily polluting enterprises can impose significant negative externalities on the ecological environment, their transformation, upgrading, and development are critical to achieving the dual carbon goals. Therefore, it is imperative to conduct ESG scoring for these enterprises, quantify their ESG performance, and encourage them to improve across all ESG aspects while further promoting green innovation, thereby reducing overall societal resistance to sustainable development.

Existing research indicates that corporate ESG performance can significantly promote firm's green innovation [1]. In terms of mechanism testing, implementing tax incentives, enhancing corporate reputation and reducing equity financing costs, alleviating corporate financing constraints, and mitigating information asymmetry have all been confirmed as intermediary channels through which ESG performance affects corporate green innovative development [2-5]. Simultaneously, through moderation effect testing, it has been found that the degree of digital transformation, market competition intensity, and institutional environment can positively moderate the effect of ESG performance on firm-level sustainable innovation [4]. Some scholars have conducted empirical analysis after excluding high-pollution industries from the overall listed enterprise sample and still concluded that ESG performance has a positive promoting effect on corporate green innovation [6].

Subsequent research continues to expand in the fields of ESG performance or corporate green innovation. In research on ESG quantification systems, some scholars have constructed a rating divergence index by assigning values and weights to six ESG ratings (Huazheng, Wind, Menglang, FTSE Russell, Syntao Green Finance, and Bloomberg) and found that the greater the divergence in ESG ratings, the lower the efficiency of corporate green innovation [7]. This conclusion has been further verified in another study, which also shows that ESG rating divergence significantly exacerbates the green innovation bubble of enterprises [8]. According to some studies, boosting R&D investment can help a company improve its ESG performance, resulting in both more green innovations and higher-quality ones. [9-10]. Furthermore, several academics have operationalized "exploratory green innovation"

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through green invention patent filings, while using green utility model patents to quantify "exploitative green innovation." The relationship between these two forms is then assessed by calculating their proportional representation, providing a framework for analyzing corporate green innovative structures. The research reveals that corporate ESG assessment incentivizes firms to favor "exploratory green innovation" over "exploitative green innovation" by mitigating financing constraints, and government subsidies and digital transformation can strengthen this effect [11]. There is also research focusing on the sustainability of innovation, reflecting the degree of green innovation sustainability through the comparison of the count of green patent applications between the previous and subsequent periods, which confirms that corporate ESG responsibility accomplishment can significantly improve the sustainability of green innovation [12].

As the digital economy continues to evolve alongside advancing technologies, businesses now recognize digital transformation as an indispensable strategy to optimize information disclosure, streamline operations, and improve efficiency. However, limited research has examined the function of digital transformation within the ESG performance-green innovation nexus, especially in heavily polluting industries. Thus, this paper focuses on heavy-polluting industries and introduces digital transformation as a mediating factor to deepen the analysis of mechanistic pathways on ESG performance affecting green innovation. Through a series of empirical analyses, corresponding conclusions and implications are clarified to answer the following questions: Against the backdrop of China's rapidly growing ESG investment scale, can ESG performance of heavy-polluting enterprises genuinely influence their green technological innovation? Can digital transformation serve as an intermediary mechanism, and does this influence exhibit heterogeneity?

2. Research design

2.1 Sample selection and data sources

Given the lack of available data for certain high-pollution companies in 2023 and to more accurately capture shifts in economic and social conditions, heavily polluting firms listed on China's Shanghai and Shenzhen A-share markets between 2012 and 2022 are selected as dataset. The classification of heavily polluting industries follows the secondary industry categories specified in the 2012 revised *Industry Classification Guidelines for Listed Companies*, encompassing 15 specific industrial sectors such as B06 Coal Mining and Washing, C17 Textile Industry, and D44 Electricity, Heat Production and Supply [13]. Using the aforementioned industrial classifications, data samples of heavily polluting enterprises are selected as the research focus, undergoing a systematic screening procedure that including exclusion of listed companies in the financial sector, removal of firms subject to special treatment designations (ST, PT) and elimination of observations with substantial missing data. Following these data cleaning steps, the final dataset comprised 2,332 valid observations for analysis. Due to the different measurement standards and value ranges of variables, all variables are subjected to Min-Max Standardization to eliminate dimensional differences and avoid the impact of excessive numerical ranges of core variables on results.

The Huazheng ESG score data in this paper are obtained from the Wind database, green patent data from the China Research Data Services Platform (CNRDS), corporate annual report data from the official websites of the Shenzhen Stock Exchange and Shanghai Stock Exchange, and enterprise-level control variable data from the CSMAR Database.

2.2 Variable definition and description

For the explanatory variable, the Huazheng ESG Index is employed to measure corporate ESG performance. The Huazheng ESG evaluation system constructs an assessment framework from 3 dimensions: E (Environment), S (Society), and G (Governance). The comprehensive ESG score (ESG) is calculated through bottom-up weighted aggregation based on the indicator system to measure corporate ESG performance. The dependent variable, green technological innovation capability (GI), is measured by the count of green technology patents filed by listed companies. This indicator combines green invention and utility model patents to reflect novel technical solutions over the study period. Regarding the mediating variable, textual content is first extracted from the "MD&A" section of firms' annual reports as a data pool for subsequent keyword screening. Drawing on authoritative documents such as the *Special Action Plan for Digital Empowerment of Small and Medium-sized Enterprises*, *2020 Digital Transformation Trend Report*, and recent *Government Work Reports*, a specialized dictionary for digital

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transformation (Digit) is developed [14]. This involves systematically identifying 76 digital-related keywords, which are then categorized into 5 technological dimensions: artificial intelligence, big data, cloud computing, blockchain, and digital technology applications, to facilitate frequency analysis across the textual corpus. Additionally, to improve research precision, 4 corporate micro-level control variables are incorporated to capture the net impact of ESG performance on sustainable innovation: asset-liability ratio (Lev), return on total assets (ROA), book-to-market ratio (BM), and CEO duality (Dual). Detailed measurement methods for all variables are presented in Table.1.

Table 1 Variable definition and description

Type	Symbol	Variable Measurement
Explanatory Variable	ESG	Huazheng ESG Comprehensive Score
Dependent Variable	GI	LN (Corporate Green Technology Innovation Application Number + 1)
Mediating Variable	Digit	LN (The frequency sum of 76 digital transformation-related terms in the MD&A + 1)
Control Variables	Lev	Total Debt / Total Assets
	ROA	Net Profit / Total Assets
	BM	Shareholders' Equity / Market Value of the Company
	Dual	Whether the chairman and general manager are the same person, with a value of 1 indicating "Yes" and 0 indicating "No"

2.3 Model Specification

Model (1) is established to examine whether the ESG performance of heavily polluting enterprises can promote their green technological innovation capability. Considering that provinces where heavily polluting enterprises are located exhibit differences in economic levels, resource distribution, and environmental regulations, as well as the impacts of national policy shocks and macroeconomic cycles across different periods, a two-way fixed effects model for time and province is constructed. The symbol $CV_{i,t}$ signifies the set of control variables, ϑ_i and μ_t denote province and time fixed effects respectively, and $\varepsilon_{i,t}$ represents the error term.

$$GI_{i,t} = \alpha_0 + \alpha_1 ESG_{i,t} + \alpha_t CV_{i,t} + \vartheta_i + \mu_t + \varepsilon_{i,t} \quad (1)$$

The coefficient α_1 of ESG reflects the marginal effect of ESG performance on green innovation. If α_1 is significantly positive, the ESG performance of heavily polluting enterprises can promote their green innovation capability.

Models (2) and (3) are established to examine the mediating mechanism of digital transformation in the relationship between ESG performance of heavily polluting enterprises and their green technological innovation capability.

$$Digit_{i,t} = \gamma_0 + \gamma_1 ESG_{i,t} + \gamma_t CV_{i,t} + \vartheta_i + \mu_t + \varepsilon_{i,t} \quad (2)$$

$$GI_{i,t} = \beta_0 + \beta_1 ESG_{i,t} + \beta_2 Digit_{i,t} + \beta_t CV_{i,t} + \vartheta_i + \mu_t + \varepsilon_{i,t} \quad (3)$$

Model (2) is used to test the impact of ESG performance on digital transformation, while Model (3) is applied to examine the combined effects of digital transformation and ESG performance on enterprise green innovation.

Should the coefficient γ_1 in Model (2) and β_2 in Model (3) both exhibit statistically significant positive associations, this signifies the existence of a mediating effect exerted by digital transformation. If the coefficient β_1 in Model (3) is insignificant, a full mediating effect is indicated. If β_1 remains significantly positive but its estimated magnitude declines compared to Model (1), a partial mediating effect is indicated.

2.4 Descriptive Statistics

Table 2 presents the descriptive statistics for the raw data of key variables. The overall values of explanatory variable ESG performance are relatively high and concentrated, indicating that the ESG performance of China's high-pollution corporations has improved during recent years, but there remain certain individual differences. The dependent variable, corporate green innovation, exhibits considerable

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variability alongside a right-skewed distribution, suggesting that the performance of green innovative ability in China requires improvement. With regard to the mediating variable, notable disparities in digital transformation maturity exist among Chinese high-pollution firms.

Table 2 Variable statistics results

Variable	Observations	Mean	SD	Minimum	Maximum
ESG	2332	74.084	5.226	50.070	90.150
GI	2332	3.367	15.370	0.000	281.000
Digit	2332	1.290	3.501	0.000	41.000
Lev	2332	0.454	0.187	0.014	0.979
ROA	2332	0.037	0.054	-0.520	0.439
BM	2332	0.384	0.165	0.014	1.108
Dual	2332	0.177	0.381	0.000	1.000

3. Empirical results and analysis

3.1 Baseline regression

To validate the effect of ESG performance on green innovation in heavily polluting corporations, regression estimation is performed on Model (1) after data cleaning and standardization. Table 3 reports the test results. Column (1) presents results without control variables and fixed effects, Column (2) includes fixed effects but excludes control variables, and Column (3) incorporates both control variables and two-way fixed effects. Empirical results show that the regression coefficients of the explanatory variable ESG are significantly positive at the 1% significance level. These findings confirm that ESG strategies exerts a notable positive influence on the green technological innovation of high-pollution corporations, revealing that superior ESG performance significantly incentivizes such firms to participate in green technological advancement.

Table 3 Baseline regression

	(1)	(2)	(3)
Variable	GI	GI	GI
ESG	0.094***	0.090***	0.079***
	(3.46)	(3.17)	(2.85)
Lev			0.202***
			(9.36)
ROA			0.276***
			(4.59)
BM			0.164***
			(5.55)
Dual			-0.017**
			(-2.18)
Constant	0.047***	0.161***	-0.155***
	(2.84)	(5.39)	(-3.10)
Observations	2,332	2,332	2,332
R^2	0.005	0.087	0.121
Control Variables	NO	NO	YES
Time FE	NO	YES	YES
Province FE	NO	YES	YES

Note: The values in parentheses represent t-statistics.
*** indicates p<0.01, ** indicates p<0.05, * indicates p<0.1. The following tables are identical.

3.2 Robustness checks

First, the count of authorized green patents (GI') is utilized as the substituted dependent variable, owing to its enhanced authority and practical materiality in reflecting technological outcomes. As presented in Column (1) of Table 4, the coefficient of corporate ESG performance remains significantly positive at the 1% significance level, suggesting that research conclusion remains robust to alternative measurements of the dependent variable.

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Furthermore, to mitigate reverse causality, the regression model replaces the current-period explanatory variable (ESG) with its one-period lagged value (L_ESG). This specification enables an examination of how prior-year ESG condition influences contemporary green innovation capability. As presented in Column (2) of Table.4, the ESG coefficient remains a positive association at the 1% statistical significance standard, indicating that the promoting influence of ESG performance on green innovative advancement within heavily polluting sectors exhibits certain lag and persistence.

Additionally, this study shortens the sample time window and selects data from 2018 to 2022 for regression analysis. This period captures the dynamic changes in the ESG-related green development of heavily polluting listed firms driven by policies and specifically includes data from the pandemic-affected period. As shown in Column (3) of Table.4, ESG strategies significantly rises the quantity of green innovation applications by high-pollution corporations at the 1% standard. This implies that the favorable impact of ESG performance on their green technological innovation is not accidental but can withstand policy changes and complex economic scenarios.

Table 4 Robustness tests

Variable	(1) Substituting Dependent Variable GI'	(2) Explaining Variable Lagged One Period GI	(3) Shortened Time Window GI
ESG	0.215***		0.164***
	(9.18)		(3.93)
L_ESG		0.077***	
		(2.75)	
Lev	0.339***	0.204***	0.232***
	(15.68)	(9.23)	(6.84)
ROA	0.340***	0.269***	0.289***
	(6.17)	(4.39)	(3.95)
BM	0.152***	0.171***	0.145***
	(5.44)	(5.44)	(3.61)
Dual	-0.038***	-0.016*	-0.024**
	(-4.99)	(-1.93)	(-2.46)
Constant	-0.218***	-0.165***	-0.249***
	(-4.47)	(-3.29)	(-3.63)
Observations	2,332	2,120	1,060
R^2	0.362	0.124	0.154
Control Variables	YES	YES	YES
Time FE	YES	YES	YES
Province FE	YES	YES	YES

3.3 Mechanism identification test

To identify the mediating mechanism of digital transformation in the correlation between ESG performance and green innovation capability of high-pollution firms, the mediating effect of digital transformation is tested. Based on Model (1) introduced earlier, stepwise regression tests are further conducted using Models (2) and (3) [15]. Table 5 reports the test results, where Column (1) presents the baseline regression, showing that ESG performance has a positive impact on green innovation in heavily polluting enterprises. In Column (2), the coefficient of ESG is significantly positive at the 1% significance level, implying that ESG practices can promote digital transformation in these enterprises. In Column (3), the coefficient of digital transformation (Digit) is significantly positive at the 1% level. Concurrently, the ESG coefficient remains significant at the same level with a positive sign, though its magnitude is diminished relative to the baseline regression specification. This suggests that corporate digital transformation operates as a partial mediator in the association between ESG strategies and green innovation of high-pollution firms.

Overall, the ESG performance of high-pollution corporations enhances their green innovation capabilities through corporate digital transformation, illustrating the mediating role of digitalization in this causal relationship. In this process, when heavily polluting corporations with superior ESG performance enhance ESG practices, they will correspondingly prompt themselves to deeply integrate intelligent technologies with environmental protection needs, use digital monitoring and regulation of dynamic data to improve environmental performance, while accumulating pollution controlling experience and

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providing a practical basis for R&D of green technological progress. Moreover, the requirements of ESG information disclosure also require enterprises to rely on digital platforms to alleviate information asymmetry, strengthen the supervision and financing incentives of stakeholders, to enhance the motivation for green innovation in corporations. Finally, the digital transformation of heavily polluting sectors under ESG pressure further integrates internal and external innovation resources, builds a collaborative platform for producers and consumers, precisely matches market demands with research and development directions, reduces the uncertainty of innovation as a whole, and ultimately improves the degree of green innovation.

Table 5 Mechanism identification test of digital transformation

Variable	(1) GI	(2) Digit	(3) GI
ESG	0.079***	0.084***	0.075***
	(2.85)	(2.80)	(2.70)
Digit			0.052***
			(2.75)
Lev	0.202***	0.018	0.201***
	(9.36)	(0.74)	(9.37)
ROA	0.276***	-0.039	0.278***
	(4.59)	(-0.48)	(4.58)
BM	0.164***	0.071**	0.161***
	(5.55)	(2.18)	(5.47)
Dual	-0.017**	0.013	-0.017**
	(-2.18)	(1.11)	(-2.29)
Constant	-0.155***	-0.102*	-0.150***
	(-3.10)	(-1.71)	(-3.01)
Observations	2,332	2,332	2,332
R^2	0.121	0.154	0.124
Control Variables	YES	YES	YES
Time FE	YES	YES	YES
Province FE	YES	YES	YES

3.4 Heterogeneity analysis

On the one hand, company size operationalized as the natural logarithm of total assets is introduced in this research. After sorting, listed enterprises with the smallest 30% of the scale are defined as small-sized enterprises, and those with the largest 30% are defined as large-sized enterprises [16]. The regression results are as shown in Columns (1) and (2) of Table.6, indicating that the ESG coefficient of large-sized enterprises is significantly positive at the 1% level, while the ESG coefficient of small-sized enterprises is not significant. This reveals that the ESG strategies of heavily polluting sectors has a magnificent promoting effect on the green technological innovation capability of large-sized enterprises. The reason may be that large-sized enterprises possess stronger financial resources and technical accumulation and pay more attention to sustainable development. Therefore, they can transform ESG investment into substantial green innovation. However, small-sized enterprises have limited funds and technology. ESG investment may affect the development of core businesses, leading to increased short-term performance pressure, which instead inhibits motivation for green innovation. They lack the ability to transform ESG into innovative achievements.

On the other hand, industry codes of high-tech listed corporations are determined according to *the Classification of High-Tech Industries (Manufacturing) (2013)* and *the Classification of High-Tech Industries (Services) (2013)* issued by the Chinese Bureau of Statistics. A total of 20 related industries such as C26, I63, L72, M73, and R85 are selected [17]. Combining with the enterprise samples of heavily polluting industries in this paper, the industry code of heavily polluting enterprises belonging to high-tech industries is finally determined as C26, manufacture of chemical raw materials and chemical products, and the remaining samples are defined as heavily polluting sectors in non-high-tech industries. Grouped regression is carried out and the results are shown in Columns (3) and (4) of Table 6, indicating that the ESG coefficient of enterprises in non-high-tech industries is significantly positive at the 1% level, while the ESG coefficient of enterprises in high-tech industries is not significant. It reveals that ESG strategies exerts a significant influence on the green technological innovation capability of high-pollution firms in non-high-tech industries. This association may stem from the fact that non-high-tech industries can quickly

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achieve technological leapfrogging through ESG-driven green innovation, and innovation results are easy to quantify. The "marginal contribution" of ESG investment is significant. In contrast, high-tech enterprises may invest more of their R&D resources in core technologies such as AI and chemical synthesis rather than in the field of green environmental protection, resulting in ESG investment crowding out core innovation resources.

Table 6 Heterogeneity analysis

	Enterprise Size		Industry	
	(1)	(2)	(3)	(4)
	Large Enterprises	Small Enterprises	High-Tech Industry	Non-High-Tech Industry
Variable	GI	GI	GI	GI
ESG	0.197***	-0.049	-0.005	0.118***
	(3.05)	(-1.21)	(-0.11)	(3.37)
Lev	-0.210*	0.012	0.169***	0.189***
	(-1.72)	(0.28)	(5.04)	(5.81)
ROA	-0.145	0.020	0.248***	0.219***
	(-0.77)	(0.31)	(2.77)	(2.61)
BM	0.108	-0.089**	-0.002	0.247***
	(0.94)	(-2.44)	(-0.05)	(6.10)
Dual	-0.032	0.021*	-0.000	-0.028***
	(-1.48)	(1.80)	(-0.00)	(-3.07)
Constant	0.329*	0.112*	-0.050	-0.159**
	(1.68)	(1.96)	(-0.65)	(-2.36)
Observations	700	700	817	1,515
R^2	0.202	0.134	0.181	0.163
Control Variables	YES	YES	YES	YES
Time FE	YES	YES	YES	YES
Province FE	YES	YES	YES	YES

4. Research conclusions and implications

This study employs a sample of heavily polluting A-share listed enterprises in China from 2012 to 2022 to empirically investigate the impact and underlying mechanisms of ESG performance on green innovation within high-pollution companies. The findings reveal: First, ESG performance significantly promotes green innovation in heavily polluting enterprises, with this promotional effect exhibiting heterogeneous outcomes. Specifically, in large-scale or non-high-tech heavily polluting firms, ESG strategies demonstrates a substantive driving impact on green technology innovation. Second, the mechanism test reveals that ESG practices in heavily polluting enterprises stimulates their digital transformation, thereby promoting green technology innovation through three pathways: internal efficiency optimization, external pressure transmission, and innovation ecosystem synergy.

At the corporate level, first, executives of heavily polluting enterprises should acknowledge the strategic significance of ESG principles in driving green development and innovation. They should incorporate ESG considerations into all facets of corporate governance and improve decision-making efficiency concerning green transformation and sustainable development. Furthermore, these enterprises should leverage ESG-driven digital transformation to advance green innovation through smart environmental production, digital knowledge accumulation, and digital platform. Strategic deployment of digital technologies could be applied to empower green technology innovation. At the governmental level, authorities should guide heavily polluting enterprises to effectively embed ESG principles into production and R&D processes, utilizing ESG frameworks to drive green innovation capacity-building. Additionally, policy design should account for firm heterogeneity, avoiding single incentive mechanisms that may disproportionately disadvantage other enterprises. For large or non-high-tech enterprises, policy optimization should focus on refining subsidy mechanisms for green innovation. For small-sized heavily polluting enterprises, beyond tax incentives and concessional financing, dedicated green innovation incubation hubs could be established to provide ESG technical guidance, talent development programs, and shared experimental facilities, helping smaller entities overcome technological and human capital barriers. For heavily polluting enterprises in high-tech sectors, differentiated ESG metrics like computational energy efficiency ratios and renewable energy utilization rates could be implemented to reasonably channel resources toward core green technologies.

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