Research on the Relationship Among Corporate ESG Performance, Digital Transformation and Green Innovation

Jiahui Chen *

School of Finance, Shanghai University of Finance and Economics, Shanghai 200433, China

* Corresponding Author Email: 2023110739@stu.sufe.edu.cn

Abstract. Driven by China's carbon peak and carbon neutrality targets as well as sustainable development strategies, green innovation has attracted widespread attention. As a comprehensive indicator, ESG can establish correlations with green innovation through resource allocation and other channels. Using data from Chinese A-share listed companies over 2010–2024, this paper empirically examines the impact and mechanism of ESG ratings on corporate green innovation. The results indicate that the improvement of ESG rating significantly promotes corporate green innovation. The impact intensifies among large firms, light-polluting industries, and technologically mature sectors. Mechanism tests indicate that ESG can enhance green innovation output by boosting corporate digital transformation and alleviating financing constraints. The findings provide empirical evidence and practical enlightenment for regulators to improve the ESG disclosure system and for enterprises to implement green development strategies.

Keywords: ESG ratings; green patents; financial frictions; digitalization.

1. Introduction

In recent years, extreme climate events occur frequently worldwide, and resource and environmental constraints continue to tighten. Balancing economic growth and environmental protection has become a core issue for all countries. In September 2020, Chinese President Xi Jinping proposed and publicly promised at the 75th Session of the United Nations General Assembly that China would strive to peak carbon dioxide emissions before 2030 and achieve carbon neutrality by 2060. Under the background of the dual-carbon goal and sustainable development, ESG has gained increasing attention. To build a complete and compliant framework for corporate ESG information disclosure, the China Securities Regulatory Commission and other institutions have continuously strengthened supervision. In January 2025, under the guidance of the China Securities Regulatory Commission, the Shanghai, Shenzhen and Beijing Stock Exchanges issued the Guidelines for the Preparation of Sustainability Reports by Listed Companies. The guidelines provide detailed operational guidance and disclosure specifications for listed companies and further improve the comparability of ESG disclosure.

Current academic research on ESG mainly focuses on corporate value (Wang et al., 2022) [13], financing constraints (Zhang et al., 2022) [28], and green innovation (Li et al., 2023) [23]. Some scholars confirm that ESG positively affects green innovation and identify its underlying mechanism. Tan and Zhu (2022) find that ESG relieves financing constraints and raises managers' environmental awareness, which significantly improves both the quantity and quality of green innovation [25]. Other scholars argue that green innovation may form a bubble when ESG ratings are uncertain. Specifically, the number of innovative projects rises symbolically, while the innovation quality declines substantially (Li & Chen, 2024) [9]. What is the exact relationship between ESG and corporate innovation? Will such relationship change with firm and industry characteristics? Furthermore, can financing constraints and digital transformation act as bridge variables between ESG and green innovation? Clarifying these issues is of great practical significance for the long-term development of enterprises and the realization of the dual-carbon goal.

This study contributes to the literature in three main aspects. First, based on the institutional background of China's capital market and the dual-carbon strategy, this study examines the driving effect of ESG performance on green innovation at the micro firm level. It offers new empirical

evidence for the governance effectiveness of localized ESG practices. Second, this paper explores the differences between high-tech and non-high-tech industries. Previous studies pay limited attention to industrial differences in technological sophistication. This research offers differentiated references for enterprises in different industries to carry out green innovation. Third, this paper introduces corporate digital transformation as a mediating variable. Existing studies have verified that digital innovation can significantly elevate corporate green innovation (Jin et al., 2022)[5], scant attention has been paid to digital transformation as a pathway through which ESG fosters green innovation. By adopting digital transformation as a mediating variable, this study identifies the technological transmission mechanism between ESG performance and green innovation

2. Theoretical Analysis and Research Hypotheses

2.1. Corporate ESG Performance and Green Innovation

According to stakeholder theory (Freeman, 2010), the economic and social achievements of enterprises affect not only themselves but also all types of stakeholders [21]. Therefore, the survival and development of enterprises need to meet the demands of stakeholders. In terms of ESG practices, enterprises can increase environmental investment to enhance public satisfaction. They can also optimize human resource management to improve social reputation. The improvement of ESG ratings further satisfies the demands of stakeholders and provides motivation for enterprises to conduct green innovation.

According to the market signaling theory (McCall, 1976), enterprises transmit internal quality and values by releasing signals [24]. A favorable ESG rating delivers the corporate philosophy of sustainable development to the whole society. Zhou et al. (2020) prove that institutional investors in China's A-share market show obvious preference for ESG responsibility. Firms with better ESG performance obtain higher excess returns and stronger risk resistance [19]. Therefore, the signaling effect of ESG helps enterprises absorb resources for green innovation and lays a foundation for subsequent R&D investment. On this basis, this paper proposes the following hypothesis:

H1: ESG upgrades substantially fuel green innovation.

2.2. ESG Performance, Digital Transformation, Financing Constraints and Green Innovation

With the continuous development of information technology, digitalization has become a key feature of the new era. In recent years, digital technologies have deeply integrated with the real economy. Digital transformation has become an approach for enterprises to improve governance efficiency and optimize resource allocation. Digitalization internalizes the externalities of ESG and strengthens corporate ESG practice capabilities, so as to enhance ESG performance (Hu, 2023) [3]. Meanwhile, digital transformation significantly promotes corporate green innovation and drives high-quality green innovation of technology enterprises (Feng et al., 2022) [20]. Digital transformation can boost green innovation by increasing corporate R&D input and obtaining government green subsidies (Xu et al., 2024) [27]. Liu et al. (2023) also point out that digital transformation amplifies citation impact and drives a quality-centric green innovation agenda [22]. Hence, digital transformation acts as a mediating channel between ESG performance and green innovation.

Different from conventional technological innovation, green innovation has the characteristics of long cycle, high investment and high risk. It relies more heavily on long-term and stable capital supply. Chen et al. (2024) find that government financial support is the main capital source for corporate green innovation in China, which still has a large gap with the actual capital demand of green projects [2]. As a comprehensive indicator covering environment, society and governance, ESG reduces corporate operational risks and alleviates financing constraints by improving information transparency (Li et al., 2023) [7]. In terms of financing channels, enterprises with good ESG performance can obtain financial support through equity financing, commercial credit and bank credit to ease financing constraints (Yi & Sun, 2023) [16]. After enterprises acquire funds through favorable ESG ratings, such resources can be steadily allocated to green innovation activities. In summary, ESG

provides impetus for green innovation by alleviating financing constraints. Accordingly, this paper proposes the second hypothesis:

H2: Corporate digital transformation and financing constraints play mediating roles in the promotion effect of ESG performance on green innovation.

3. Research Design

3.1. Sample Selection and Data Sources

This paper selects Chinese A-share listed companies from 2010 to 2024 as the research samples. The sample processing rules are set as follows: exclude financial industry samples; exclude ST and *ST enterprise samples; exclude enterprises newly listed in the current year. To eliminate the influence of extreme values, all continuous variables are processed with 1% two-tailed winsorization. The corporate ESG performance data are collected from the Huazheng ESG Database. The green innovation data are obtained from the CNRDS database. Other micro enterprise data are derived from the CSMAR database.

3.2. Variable Definition

3.2.1. Dependent Variable

Corporate Green Innovation (GreenPat). Referring to Yuan & Li (2023) [17] and Li et al. (2026) [8], Patent-granting lags render applications a more convincing indicator of green innovation. Green innovation is captured by firms' yearly filings of green invention and utility model patents. The natural logarithm of the sum plus one is used for measurement.

3.2.2. Independent Variable

Corporate ESG Performance (ESG). There is no unified standard for measuring corporate ESG at home and abroad. Given the local adaptability and wide coverage of Huazheng ESG ratings, this paper follows Yang & Liu (2025)[14] . It assigns scores from 9 to 1 to Huazheng ESG comprehensive ratings ranging from AAA to C. A higher score represents better corporate ESG performance.

3.2.3. Control Variables

Referring to Wang et al. (2023), this paper selects control variables including firm size (Size), listing age (Age), asset-liability ratio (Lev), return on assets (ROA), enterprise growth (Growth), Tobin's Q (TobinQ), ownership concentration (Top1) and cash flow ratio (CR)[26]. Table 1 presents the symbol and detailed definition of each variable.

Table 1. Variable Definitions.

Variable Type	Variable Name	Symbol	Measurement Method
Dependent variable	Corporate green innovation	GreenPat	Logged independent green invention patent counts, zero-adjusted.
Independent variable	Corporate ESG performance	ESG	Assign scores of 9 to 1 to Huazheng ESG comprehensive ratings from AAA to C
Control variable	Firm size	Size	Firm size, proxied by the log of total assets.
	Listing age	Age	Natural logarithm of one plus corporate listing years
	Asset-liability ratio	Lev	Total liabilities / Total assets
	Return on assets	ROA	Net profit / Total assets

3.3. Model Construction

To test the impact of corporate ESG performance on green innovation, the regression model is constructed as follows:

$$GreenPat_{i,t} = \beta_0 + \beta_1 \times ESG_{i,t} + \beta_2 \times Control_{i,t} + \gamma_t + v_i + \varepsilon_{i,t} \quad (1)$$

In Formula (1), subscript *i* refers to individual enterprise and *t* refers to year. $GreenPat_{i,t}$ denotes corporate green innovation; $ESG_{i,t}$ denotes corporate ESG performance; $Control_{i,t}$ represents the set of control variables; v_i denotes firm fixed effect; γ_t denotes year fixed effect; $\varepsilon_{i,t}$ is the random error term.

4. Empirical Analysis

4.1. Descriptive Statistics

Summary statistics for key variables appear in Table 2. For green innovation, the minimum and median values are both 0, the maximum value is 4.595, the mean value is 0.825, and the standard deviation is 1.134. It indicates significant differences in green innovation levels among enterprises, and only a few enterprises own strong green innovation capabilities. For ESG performance, the minimum value is 1, the median is 4, the maximum is 7, the mean is 4.163, and the standard deviation is 1.079. Corporate ESG outcomes generally exceed the median level. Although differences exist, no extreme imbalance appears, and there is still much room for improvement.

Table 2. Descriptive Statistical Results.

Variable	Obs	Mean	Std. Dev.	Min	Median	Max
GreenPat	44886	0.825	1.134	0.000	0.000	4.595
ESG	44886	4.163	1.079	1.000	4.000	7.000
Size	44886	22.249	1.288	20.001	22.037	26.332
Age	44886	2.065	0.930	0.000	2.197	3.401
Lev	44886	0.412	0.206	0.051	0.403	0.894
ROA	44886	0.036	0.061	-0.224	0.037	0.195
Growth	44824	0.324	0.851	-0.670	0.115	5.832
TobinQ	44388	1.976	1.212	0.833	1.585	7.946
Top1	44886	0.340	0.149	0.084	0.318	0.744
CR	44886	0.168	0.130	0.011	0.131	0.634

4.2. Benchmark Regression Results

Table 3 presents the benchmark regression results of ESG performance on corporate green innovation. Column (1) only controls year and firm fixed effects without adding control variables. ESG yields a positive and statistically significant coefficient of 0.039 at the 1% threshold.which means ESG positively affects corporate green innovation. Column (2) incorporates both control variables and fixed effects. The ESG coefficient is 0.016 and remains significant at the 1% level. It confirms that ESG performance has a significant positive promotion effect on green innovation. Sustained ESG practices spur the impetus for green innovation.

Table 3. Benchmark Model.

Variable	(1) GreenPat	(2) GreenPat
ESG	0.039***	0.016***
	(0.005)	(0.005)
Constant	0.665***	-7.471***
	(0.021)	(0.443)
Controls	NO	YES
Firm FE	YES	YES
Year FE	YES	YES
N	44,784	44,227
R^2	0.709	0.725

Note: Robust standard errors clustered at the firm level are reported in parentheses. \, \\, \\\ represent significance levels of 10%, 5% and 1% respectively. The same applies to the following tables.

4.3. Heterogeneity Test

4.3.1. Enterprise Size

Referring to Liang et al. (2026), this paper compares the average size of each enterprise with the annual-industrial average size [10]. Enterprises largersize [[the average are classified as large-scale enterprises, and the rest are small and medium-sized enterprises. As shown in Table 4, the ESG coefficient of large-scale enterprises in Column (1) is significantly positive at the 1% level, while the coefficient of small and medium-sized enterprises in Column (2) is insignificant. Size conditions the ESG effect on green innovation. Large enterprises have sufficient resource reserves to bear the trial-and-error costs of green innovation. In contrast, small and medium-sized enterprises face tight capital chains and imperfect R&D systems. They tend to adopt short-term operation strategies and delay green innovation activities. In addition, large enterprises face stricter environmental regulations and external pressure, so they actively promote green innovation. Small and medium-sized enterprises bear less external pressure and lack sufficient motivation for green innovation.

Table 4. Heterogeneity Analysis: Enterprise Size Difference.

Variable	(1) Large Enterprises GreenPat	(2) SMEs GreenPat
ESG	0.026***	0.000
	(0.008)	(0.006)
Constant	-5.679***	-6.699***
	(0.683)	(0.545)
Controls	YES	YES
Firm FE	YES	YES
Year FE	YES	YES
N	19,835	24,150
R^2	0.765	0.663

4.3.2. Industrial Pollution Degree

To explore the impact of industrial pollution intensity closely related to ESG on regression results, this paper divides samples into heavily polluting industries and non-heavily polluting industries following Li et al. (2021) [6]. Table 5 shows that the ESG coefficient of heavily polluting industries in Column (1) is insignificant, while the coefficient of non-heavily polluting industries in Column (2) is significantly positive at the 5% level. Heavily polluting enterprises face strict environmental regulation and have difficulties in rectifying pollution in the short term. They only meet the minimum environmental requirements to avoid risks, so ESG shows no obvious promotion effect on green innovation. For non-heavily polluting enterprises, ESG acts as an advantage to enhance corporate soft power. Such enterprises have more resources and willingness to transform ESG concepts into green innovation, so as to improve corporate value and long-term competitiveness. Cleaner industries reap greater green innovation gains from high ESG scores.

Table 5. Heterogeneity Analysis: Industrial Pollution Degree Difference.

Variable	(1) Heavily Polluting GreenPat	(2) Non-heavily Polluting GreenPat
ESG	0.012	0.014**
	(0.009)	(0.006)
Constant	-6.447***	-8.049***
	(0.778)	(0.548)
Controls	YES	YES
Firm FE	YES	YES
Year FE	YES	YES
N	11,596	32,489
R^2	0.689	0.744

4.3.3. Industrial Technology Level

This paper divides sample industries into high-tech and non-high-tech industries following Yang & Zhou (2020), to examine whether industrial technological sophistication moderates the ESG-green innovation relationship [15]. Table 6 shows that the ESG coefficient of high-tech industries in Column (1) is insignificant, while the coefficient of non-high-tech industries in Column (2) is significantly positive at the 1% level. High-tech industries stay at the forefront of technological iteration. They concentrate resources on core technological breakthroughs to maintain market competitiveness, and green innovation only accounts for a small part of daily business. Thus, the driving effect of ESG on green innovation is diluted in high-tech industries. For non-high-tech industries, outstanding ESG ratings and green innovation become core competitive tools. High ESG ratings enhance corporate reputation and ease financing constraints, and the development of green technology further optimizes ESG performance, forming a virtuous cycle. Hence, the incentive effect of ESG on green innovation is more significant in non-high-tech industries.

Table 6. Heterogeneity Analysis: Industrial Technology Level Difference.

Variable	(1) High-tech GreenPat	(2) Non-high-tech GreenPat
ESG	0.007	0.029***
	(0.006)	(0.008)
Constant	-8.243***	-6.350***
	(0.544)	(0.686)
Controls	YES	YES
Firm FE	YES	YES
Year FE	YES	YES
N	25,121	18,825
R^2	0.753	0.713

4.4. Mechanism Analysis

To open the black box, we estimate a mediation model that captures the ESG-to-green-innovation transmission. Based on the above theoretical analysis, this paper selects digital transformation and financing constraints as mediating variables to verify the mediating mechanism.

$$M_{i,t} = \alpha_0 + \alpha_1 \times ESG_{i,t} + \alpha_2 \times Control_{i,t} + \gamma_t + v_i + \varepsilon_{i,t} \quad (2)$$

$$GreenPat_{i,t} = \mu_0 + \mu_1 \times ESG_{i,t} + \mu_2 \times M_{i,t} + \mu_3 \times Control_{i,t} + \gamma_t + v_i + \varepsilon_{i,t} \quad (3)$$

In the formulas, $M_{i,t}$ represents mediating variables, including digital transformation (Dig) and financing constraints (SA). Other variables remain unchanged.

4.4.1. Digital Transformation

Following Zhang et al. (2025), this paper adopts the word frequency of digital transformation keywords in listed companies' annual reports to measure the degree of digital transformation [18]. According to Table 7, the ESG coefficient in Column (1) is 0.018 and significantly positive at the 1% level. It means the improvement of ESG rating promotes the process of corporate digital transformation. Column (2) takes both ESG and digital transformation as explanatory variables. The ESG coefficient is 0.016 and the digital transformation coefficient is 0.039, both significant at the 1% level. It proves that digital transformation plays a partial mediating role in the empowerment of green innovation by ESG. High-ESG firms attract more digital project support. Meanwhile, digital transformation solves technical difficulties in green innovation, improves innovation efficiency, optimizes resource allocation, integrates ESG-oriented environmental goals with production activities, and accelerates the realization of green innovation.

4.4.2. Financing Constraints

Given the strong exogeneity and robustness of the SA index, this paper follows Sun et al. (2025) and Financing constraints are quantified via the absolute SA index [12]. Table 7 shows that the ESG coefficient in Column (3) is significantly negative at the 1% level, which indicates that higher ESG ratings effectively alleviate financing constraints. In Column (4), the ESG coefficient is significantly positive at the 5% level, and the financing constraint coefficient is significantly negative at the 1% level. ESG reduces information asymmetry between enterprises and investors. Good ESG ratings reflect standardized governance structure and strong sustainable development capacity, which help enterprises obtain financing through multiple channels and reduce financing costs. Green innovation relies on stable capital supply. Many enterprises cut R&D investment to maintain daily cash flow when facing capital shortages. When financing conditions improve, enterprises have more disposable funds to promote long-term innovative projects. In conclusion, ESG breaks the capital barrier of green innovation by alleviating financing constraints.

Table 7. Mechanism Test Results.

Variable	(1) Dig	(2) GreenPat	(3) SA	(4) GreenPat
ESG	0.018***	0.016***	-0.005***	0.010**
	(0.005)	(0.005)	(0.001)	(0.005)
Dig		0.039***		
		(0.007)		
SA				-1.431***
				(0.132)
Constant	-4.363***	-7.301***	4.159***	-1.522**
	(0.432)	(0.441)	(0.082)	(0.619)
Controls	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
N	44,227	44,227	44,227	44,227
R^2	0.787	0.725	0.966	0.729

4.5. Instrumental Variable Method

Although the benchmark regression verifies the promoting effect of ESG on green innovation, endogenous problems such as reverse causality may exist. To alleviate such concerns, this paper follows Yang & Liu (2025) and adopts the one-period lagged ESG performance (LESG) as the instrumental variable of current ESG[14]. The two-stage least squares (2SLS) method is adopted for re-estimation. The first-stage results in Column (1) of Table 8 show that the coefficient of lagged ESG is 0.383 and significantly positive at the 1% level. It indicates that lagged ESG has a strong positive predictive power for current ESG. The F statistic is 3433.586, which excludes the possibility of weak instrumental variables. The second-stage results in Column (2) show that the ESG coefficient

remains significantly positive after controlling endogeneity. It confirms that the improvement of ESG performance still significantly promotes green innovation, and the core research conclusion is robust.

Table 8. Regression Results of Instrumental Variable Method.

Variable	(1) First-stage Regression ESG	(2) Second-stage Regression GreenPat
LESG	0.383***	
	(0.007)	
ESG		0.037*
		(0.015)
Controls	YES	YES
Firm FE	YES	YES
Year FE	YES	YES
N	38807	38807
F	3433.586	41350

4.6. Robustness Test

First, replace the independent variable. Referring to Jiang (2025), this paper uses the comprehensive score of Huazheng ESG as the alternative indicator [4]. Column (1) of Table 9 shows that the coefficient of ESG_Score remains significant at the 1% level. To eliminate the rating differences among different institutions, this paper adopts the ESG score from CNRDS for re-regression. The coefficient of ESG_CNRDS in Column (2) is significantly positive at the 1% level. The results prove that the improvement of ESG performance promotes green innovation.

Second, replace the dependent variable. Green invention patents better reflect the quality of green innovation. Following Ba et al. (2025), this paper uses the number of independently applied green invention patents to measure green innovation [1]. The ESG coefficient in Column (3) is significantly positive at the 1% level, which verifies that active ESG practices drive corporate green innovation.

Third, eliminate special samples. Municipalities have unique advantages in policy and resource allocation, which may interfere with regression results. Following Yao & Wang (2025), this paper excludes enterprises registered in municipalities[11]. Column (4) of Table 9 shows that the ESG coefficient is significantly positive at the 5% level, which further verifies the robustness of the core conclusion.

Table 9. Robustness Test Results.

Variable	(1) Replace Independent Variable GreenPat	(2) Replace Independent Variable GreenPat	(3) Replace Dependent Variable GreenInv	(4) Exclude Municipal Samples GreenPat
ESG_2	0.368***			
	(0.109)			
ESG_3		0.018***		
		(0.006)		
ESG			0.023***	0.012**
			(0.004)	(0.005)
Constant	-7.663***	-7.532***	-6.024***	-8.087***
	(0.440)	(0.442)	(0.411)	(0.487)
Controls	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
N	44,227	44,227	44,227	35,358
R^2	0.725	0.725	0.701	0.706

5. Conclusions and Recommendations

Taking Chinese A-share listed companies from 2010 to 2024 as research samples, this paper empirically tests the influence and internal mechanism of corporate ESG performance on green innovation. Three core conclusions are drawn. First, the effective implementation of corporate ESG concepts significantly stimulates green innovation. The result is robust to endogeneity and sensitivity analyses. Second, the relationship shows obvious heterogeneity. Large incumbents, cleaner industries, and non-high-tech fields reap greater gains. Third, digital transformation and financing constraints play partial mediating roles. Superior ESG performance promotes corporate green innovation by accelerating digital transformation and alleviating financing constraints.

Based on the above conclusions, this paper puts forward targeted recommendations. First, enterprises should promote green innovation in a long-term and targeted manner. Enterprises should integrate ESG concepts into long-term strategies and daily management and acquire green innovation resources by building a sustainable development image. They need to formulate differentiated strategies according to their own characteristics. Second, the government should improve the ESG policy system and implement differentiated supervision and incentive policies. It is necessary to accelerate the establishment of localized ESG rating standards, crack down on ESG reporting loopholes, and implement differentiated industrial and financial policies. Third, the market should optimize the resource allocation of green innovation. The capital market needs to improve the pricing mechanism of ESG performance and guide capital to favor enterprises with good ESG performance. Financial institutions are encouraged to develop ESG-related financial products and link corporate ESG performance with financing cost and quota, so as to relieve the financing constraints of corporate green innovation through financial means.

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