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ESG Rating and Green Innovation of Manufacturing Enterprises

-- Based on the Regulatory Role of Environmental Regulation and Market Competition

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Abstract

Under the guidance of the "dual carbon" goals leading the comprehensive green transformation of the economy and society, exploring the driving mechanisms of green innovation in manufacturing enterprises holds significant theoretical and practical implications. This paper aims to systematically examine the impact of corporate ESG ratings on their green innovation and test the moderating roles of environmental regulation and market competition. Using Chinese A-share listed manufacturing companies from 2014 to 2023 as research samples, this study constructs a two-way fixed effects model for empirical analysis. The findings reveal: (1) The improvement of corporate ESG ratings can significantly enhance their green innovation levels, a conclusion that remains valid after rigorous tests including lagged variables and exclusion of samples from special periods. (2) Both environmental regulation and market competition play positive moderating roles between ESG ratings and corporate green innovation. Specifically, in environments with higher environmental regulation intensity or fiercer market competition, ESG ratings demonstrate more significant promoting effects on green innovation. (3) Heterogeneity analysis reveals that the promoting effect of ESG on green innovation shows a gradual strengthening trend from eastern to central and western regions. This indicates that in areas with relatively lower marketization levels and more prominent information asymmetry, ESG, as a high-quality reputation signal, exhibits stronger marginal driving effects on corporate green innovation. The study uncovers the "ESG ratings-external context-green innovation" linkage mechanism, providing new empirical evidence for understanding the driving forces of corporate green transformation, and offers important implications for governments to formulate coordinated environmental and industrial policies and guide enterprises toward sustainable development.

Keywords

ESG Rating; Green Innovation; Environmental Regulation; Market Competition; Manufacturing Enterprises; Moderating Effect.

1. Introduction

Amid global efforts to combat climate change and advance sustainable development, "carbon peaking and carbon neutrality" has become China's core national strategy, driving comprehensive green transformation across its economy and society. President Xi Jinping emphasized that green development is both an essential requirement for building a modern economic system and the fundamental solution to pollution issues. As the backbone of the national economy, manufacturing serves as both the primary engine of economic growth and the main source of resource consumption and environmental impact. Its green transition and

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high-quality development are crucial for achieving the "dual carbon" goals [1]. Against this backdrop, effectively incentivizing manufacturing enterprises to shift from traditional factor-driven models to green innovation-driven approaches has emerged as a critical challenge requiring urgent resolution.

Traditional corporate evaluation paradigms, overly reliant on financial metrics, inherently lack the capacity to comprehensively assess long-term value creation and sustainability risks. To address this limitation, the Environmental, Social, and Governance (ESG) framework-rooted in responsible investment principles-has emerged as a groundbreaking approach, offering a fresh perspective for evaluating corporate value and sustainable development capabilities [2]. Not only does outstanding ESG performance demonstrate corporate social responsibility, but it also signals strong governance, effective risk management, and long-term growth potential to investors [3]. Theoretically, robust ESG ratings can help companies expand financing channels, reduce agency costs, and enhance brand reputation[4], thereby providing essential resource support and error-tolerant space for high-risk, long-term green innovation initiatives [5][6].

However, the transformation of ESG performance into high-quality green innovation is not a simple linear process. Some studies indicate that corporate responses to ESG pressures may remain at the level of "greenwashing" or strategic innovation, failing to effectively enhance the quality of substantive green innovation [7][8]. This suggests that the driving effect of ESG performance on green innovation may be profoundly influenced by external contextual factors. As key players in market economy activities, manufacturing enterprises face dual constraints from government environmental regulations and market competition pressures. On one hand, environmental regulations may strengthen or weaken corporate incentives for green innovation through mechanisms like the "innovation compensation effect" and "cost-effectiveness compliance" [9][10]; on the other hand, the intensity of market competition determines whether companies need to pursue green innovation to build differentiated advantages for survival and development [11].

While existing literature has examined the impacts of ESG, environmental regulations, and market competition on corporate innovation, few studies have systematically investigated whether the green innovation effects of ESG performance in manufacturing enterprises exhibit heterogeneity under varying regulatory intensities and competitive landscapes. This research gap hinders our comprehensive understanding of the complex driving mechanisms behind green transformation in manufacturing enterprises.

Given this context, this study focuses on A-share listed manufacturing companies in China to construct a moderating effect model, aiming to address three core questions: (1) Can ESG ratings significantly boost green innovation development in manufacturing enterprises? (2) How do environmental regulations moderate the relationship between ESG ratings and green innovation? (3) What role does market competition play as a moderating factor in this process?

This study makes three key contributions: First, it provides empirical evidence for macro-level ESG application research by focusing on manufacturing-the core sector of the national economy. Second, it establishes an integrated analytical framework of "ESG ratings, external contexts, and green innovation," revealing the moderating effects of two critical external factors: environmental regulations and market competition, thereby deepening our understanding of corporate mechanisms for green innovation-driven development. Third, it differentiates various types of environmental regulations, offering micro-level policy recommendations for governments to design more effective and differentiated environmental policy combinations.

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2. Theoretical Analysis and Hypothesis Formulation

2.1. Enterprise ESG Rating and Green Innovation

Green innovation poses a severe challenge to enterprises due to its inherent high risk, high investment and uncertain return. The performance of enterprises in environmental, social and governance (ESG) is widely recognized as an important driving force to overcome these obstacles and promote green transformation.

Stakeholder theory posits that enterprises serve as the nexus of multi-stakeholder contracts, with their sustainable development contingent upon effectively managing relationships with key groups including governments, investors, customers, and employees. Exceptional ESG performance indicates a company's capability to better coordinate stakeholder relations [12], respond to stakeholder demands, and thereby secure crucial legitimacy and strategic resources [13]. For instance, strong environmental (E) performance enables companies to obtain government policy support and regulatory exemptions; exemplary social (S) practices enhance customer loyalty and employee engagement; while robust governance (G) structures bolster investor confidence [14]. These resources provide a solid foundation for enterprises to sustain long-term green innovation initiatives.

Furthermore, according to signaling theory, high ESG ratings serve as positive signals in markets with information asymmetry. They convey to capital markets a company's commitment to long-term value sustainability and superior risk management capabilities [3]. This signal transmission helps reduce information asymmetry between enterprises and investors/creditors, thereby effectively alleviating financing constraints [15] and lowering financing costs. Adequate funding serves as a prerequisite for capital-intensive manufacturing enterprises engaged in green technology R&D and equipment upgrades. Based on the comprehensive analysis above, we hereby propose the following hypotheses.

Hypothesis 1 (H1): Under the condition of other conditions unchanged, ESG rating of manufacturing enterprises has a significant promoting effect on green innovation.

2.2. The Regulatory Role of Environmental Regulation

Environmental regulations serve as the most direct external institutional force shaping corporate environmental behaviors and innovation decisions. The "Porter Hypothesis" posits that well-designed environmental regulations can stimulate a "compensatory innovation effect" [9], encouraging companies to enhance efficiency through technological innovation, thereby offsetting or even surpassing compliance costs. Based on their mechanisms, environmental regulations are typically categorized into two types: command-and-control (CER) and market-motivated (MER) [16]. This study examines how these two regulatory types act as moderating variables in the relationship between ESG ratings and green innovation.

Specifically, command-and-control environmental regulations impose direct compliance pressure on enterprises by establishing unified environmental standards and technical specifications, with non-compliance leading to severe penalties. Market-driven regulatory mechanisms internalize environmental costs through economic instruments such as environmental taxes and emission trading systems, providing direct financial incentives for corporate emission reduction [17]. The former approach emphasizes bottom-line constraints, potentially inducing strategic or adaptive innovations by enterprises to avoid penalties; the latter focuses on efficiency incentives, effectively motivating substantive or performance-oriented innovation [8]. However, whether through bottom-line constraints or efficiency guidance, stringent environmental regulations amplify the "compliance dividends" and potential competitive advantages for green innovation by increasing compliance costs and operational risks in traditional production models.

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Under such stringent environmental regulations, manufacturing enterprises face substantial compliance costs and strict legal liabilities. In this context, the strategic value of ESG ratings becomes significantly amplified. Companies with outstanding ESG performance have already internalized green development concepts in their operational models and strategic plans, enabling them to navigate regulatory requirements more effectively. For these enterprises, the rigorous regulatory environment amplifies the competitive advantages derived from exceptional ESG performance. For instance, under command-and-control regulations, they can achieve compliance targets more swiftly, capturing market opportunities vacated by eliminated competitors. Under market-driven regulations, they can more efficiently leverage policy incentives to reduce costs. Meanwhile, governments increasingly support these "model enterprises" through R&D subsidies and tax breaks, reinforcing the positive incentives for green innovation driven by ESG performance [18].

In contrast, under low-intensity environmental regulations, companies face lower costs for environmental violations and insufficient external pressure to pursue green innovation. Even when enterprises have high ESG ratings, the "compliance dividends" or "market advantages" gained through green innovation remain difficult to materialize. The market lacks effective screening mechanisms to reward genuine green practitioners, weakening the value signaling role of ESG ratings and consequently diminishing their driving force for green innovation. Based on this comprehensive analysis, the following hypotheses are proposed.

Hypothesis 2 (H2): Environmental regulation plays a positive moderating role between ESG rating and green innovation in manufacturing enterprises. That is, the higher the intensity of environmental regulation, the stronger the promoting effect of ESG rating on green innovation.

2.3. The Regulating Role of Market Competition

Market competition is the core external mechanism to drive enterprise efficiency improvement and strategic transformation. The pressure of competition forces enterprises to constantly seek new ways to reduce costs, improve efficiency and create differentiated advantages.

In the fiercely competitive manufacturing sector, product homogenization has severely compressed profit margins. Under the dual pressures of intense market competition and tightening environmental policies, companies increasingly need to pursue differentiation through green innovation. Initiatives such as developing eco-friendly products, adopting energy-saving technologies to reduce costs, and building responsible brand images collectively form crucial competitive advantages for enterprises in this cutthroat environment [19]. At this juncture, outstanding ESG performance becomes a powerful tool for companies to convey their differentiated value propositions of "green," "reliable," and "responsible" to the market. Consumers and downstream enterprises are more willing to pay premium prices for products with strong ESG credentials. Consequently, intense market competition compels companies to translate ESG principles into tangible green technologies and products to gain market share, thereby reinforcing the driving force of ESG ratings on green innovation.

Conversely, in industries with weaker market competition (such as monopolies or oligopolies), companies can more easily obtain excess profits through their market power, naturally reducing their motivation for high-risk innovation [20]. In such scenarios, even enterprises with strong ESG ratings might treat them merely as "window projects" to maintain public relations or meet basic regulatory requirements, lacking the urgency and necessity to convert ESG reputation into substantial green innovation outcomes. Therefore, based on the above analysis, we propose the following hypotheses.

Hypothesis 3 (H3): Market competition plays a positive moderating role between ESG rating and green innovation development in manufacturing enterprises. That is, the higher the degree of market competition, the stronger the promoting effect of ESG rating on green innovation.

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3. Research Design and Variable Description

3.1. Sample Selection and Data Sources

This paper selects Chinese manufacturing listed companies on the Shanghai and Shenzhen A-shares from 2014 to 2023 as research samples, with industry classification based on China's "National Economic Industry Classification" (GB/T 4754-2017), including all manufacturing companies starting with industry code C. The data primarily originate from the following databases: corporate ESG rating data mainly comes from the Huazheng ESG Rating Database; corporate green patent data is sourced from the Green Patent Research Database of China National Research Data Service for Scientific and Technological Information (CNRDS); corporate financial data, corporate governance data, and industry classification data are derived from the Guotai An (CSMAR) Database and Wind (WIND) Database; in environmental regulation-related data, industrial added value is sourced from the National Bureau of Statistics, while environmental protection taxes, pollution discharge fees, and industrial pollution control investment completion amounts are derived from the China Environmental Statistical Yearbook and China Statistical Yearbook.

To ensure the reliability and validity of research data, this paper conducted the following screening procedures on the initial sample: (1) Removing companies with ST, *ST, or delisted status during the study period; (2) Eliminating samples with missing values in key variables such as ESG ratings, green patents, and financial data; (3) Considering the characteristics of the sample data, this study compared the effects of different tailing ratios (e.g., 1% and 2.5%) to minimize the interference of outliers on regression results. It was found that even a moderate 1% tailing ratio still failed to fully mitigate the impact of extreme values. Therefore, we selected the 2.5th and 97.5th percentile tails to process the data, which effectively controlled outliers while preserving as much information as possible from the original dataset. After these screenings, we obtained 3,651 companies with a total of 23,104 annual observation units in non-balanced panel data.

3.2. Variable Definition and Measurement

3.2.1. Dependent Variable

Green Innovation (GTI). Based on existing literature, green innovation capability is primarily measured through indicators such as patent acquisition, R&D investment, and the number of green patent applications. Following the methodologies adopted by Shen Minghao [21] (2022) and Wang Xin & Wang Ying [22] (2021), this study employs the natural logarithm of the total number of a firm's green patent applications in the current year plus one.

3.2.2. Explanatory Variable

Corporate ESG Rating (ESG). This study employs the Huazheng ESG Rating as the core explanatory variable. This rating system combines international standards with China's national conditions, demonstrating high authority and applicability. The nine-tiered scale (AAA, AA, A, BBB, BB, B, CCC, CC, C) is assigned numerical values from 9 to 1, where higher numbers indicate better corporate ESG performance.

3.2.3. Moderating Variables

Environmental regulation (ER): distinguish between command control and market incentive.

Command-control environmental regulation (CER): Following the approach of Cai Wuhan and Zhou Xiaoliang [9] (2017), this indicator measures the proportion of "industrial pollution control investment" to the province's "industrial added value". This metric directly reflects the government's mandatory investments and requirements in environmental protection.

Market Incentive Environmental Regulation (MER): Following the approach of Zhang Jiangxue et al. [23] (2015), this indicator measures the proportion of "total revenue from pollution

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discharge fees and environmental protection taxes" to the "industrial added value" of each province. This index reflects the degree to which environmental costs are internalized through market-oriented means.

Market Competition (HHI): Drawing on the research of Xie Weimin and Wei Huaqian [11] (2016), the Herfindahl-Hirschman $HHI = \sum_{i=1}^{N}(X_i/X)^2$, $X = \sum X_i$ Index (HHI) is adopted to measure industry competition. Here, Xi represents the main business revenue of enterprise i, while X denotes the total main business revenue of all enterprises in the industry.

3.2.4. Control Variables

To control for other factors that may influence corporate green innovation, this study draws on the research of Qin Weinan [3] (2023) and Xie Weimin & Wei Huaqing [11] (2016), selecting a series of corporate-level control variables: firm size (SIZE, logarithm of total assets), debt-to-asset ratio (DAR), return on total assets (ROA), firm age (AGE, natural logarithm of listing years plus one), ownership nature (SOE, 1 for state-owned enterprises, 0 otherwise), R&D investment intensity (RD, proportion of R&D expenditure to operating revenue), equity concentration (OC, shareholding ratio of the largest shareholder), and board independence (BOARD, ratio of independent directors to total board members). These variables are controlled in this study. Definitions and calculation methods are shown in Table 1.

Table 1. Variable indicators

type of variable		variable symbol	Data and notes
explained variable	Green innovation capacity	GTI	The total number of green patent applications of enterprises in that year is added by 1 and then the natural logarithm is taken
explanatory variable	ESG grade	ESG	Huade ESG rating
regulated variable	Command-controlled environmental regulation	CER	The proportion of the "investment in industrial pollution control" in each province to the "industrial added value" of the province
	Market incentive environmental regulation	MER	The proportion of the total "pollution discharge fee and environmental tax revenue" of each province to the "industrial added value" of the province
	market competition	HHI	Hendel-Hirschman index
controlled variable	size	SIZE	Logarithm of total assets
	asset-liability ratio	DAR	The ratio of total liabilities to total assets
	all capital earnings rate	ROA	The ratio of net profit to total assets after tax
	enterprise age	AGE	Take the natural logarithm of the listing age plus 1
	Nature of property rights	SOE	A value of 1 is assigned to a state-owned enterprise, otherwise it is assigned a value of 0
	R& D investment intensity	RD	The proportion of R&D expenses to operating revenue
	Equity concentration	OC	Shareholding ratio of the largest shareholder
	Board independence	BOARD	The ratio of independent directors to the total number of directors on the board

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3.3. Model Setting

In order to test the hypothesis H1, that is, the direct impact of enterprise ESG rating on green innovation, this paper builds the following benchmark model (1) by drawing lessons from Zhou Yunbo et al. [8] (2025):

$$GTI_{i,t} = \alpha_0 + \beta_1 ESG_{i,t} + \sum Controls_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \quad (1)$$

Here, i represents the firm and t denotes the year$Controls_{i,t}\mu_i\delta_t\varepsilon_{i,t}\beta_1$. The control variables set indicates the control variables for firm i in period t, including individual fixed effects for firms, year fixed effects, and random disturbance terms. The coefficients under primary focus are expected to be significantly positive.

In order to test hypothesis H2 and H3, that is, the moderating effect of environmental regulation and market competition, this paper further introduces the interaction term of ESG rating and moderating variables (environmental regulation and market competition) on the basis of benchmark model (1), and constructs the following moderating effect model (2):

$$\begin{aligned} GTI_{i,t} = {} & \alpha_0 + \beta_1 ESG_{i,t} + \beta_2 Controls_{i,t} + \beta_3 ModV_{i,t} \\ & + \beta_4 (ESG_{i,t} \times ModV_{i,t}) + \mu_i + \delta_t + \varepsilon_{i,t} \end{aligned} \quad (2)$$

Among $ModV_{i,t}ESG_{i,t} \times ModV_{i,t}\beta_4$them, they represent environmental regulation and market competition respectively. The coefficient of the interaction term is mainly concerned, which is expected to be significantly positive, indicating that both environmental regulation and market competition have positive moderating effects.

4. Empirical Results and Analysis

4.1. Descriptive Statistics and Correlation Analysis

Table 2 presents the descriptive statistics of the sample data after tail trimming to mitigate extreme values. The mean of the Green Innovation Index (GTI), the dependent variable, was 0.930 with a median of 0.693 and standard deviation of 1.152, indicating significant variations in green innovation levels among sample enterprises. The distribution shows a pronounced right-skewed pattern, with a few standout performers. The core explanatory variable, Corporate ESG Rating (ESG), had a mean of 4.158 and standard deviation of 0.947, ranging from 2 to 6. This suggests that most enterprises 'ESG performance falls within the lower-middle range, though notable gaps exist between companies. Market Concentration Index (HHI) averaged 0.0623 with a median of 0.0399, both significantly below the mean and remaining at relatively low levels. This reflects China's manufacturing sector generally having low industry concentration and intense competition. The large standard deviation (0.0503) and wide range between maximum and minimum values indicate significant competitive disparities, with some industries experiencing intense or even excessive competition while others maintain higher concentration. Command-and-Control (CER) and Market Incentive (MER) indices averaged 0.00162 and 0.000564 respectively, showing substantial deviations from their respective means. These figures suggest noteworthy regional differences in environmental regulation intensity across provinces. Among the key control variables, the mean value of enterprise size (SIZE) was 22.07, while the mean R&D investment intensity (RD) stood at 0.0512. However, its lower median (0.0412) indicates a right-skewed distribution with a few enterprises exhibiting high-intensity R&D investments. Overall, all variables fell within reasonable ranges, and the

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heterogeneity in data distribution provided an excellent sample foundation for this empirical study.

Table 2. Descriptive analysis of the main variables

Stats	name of index	sample number	average value	crest value	least value	median	standard error	skewness	kurtosis
GTI	Green innovation capacity	23104	0.930	4.043	0	0.693	1.152	1.094	3.188
ESG	ESG grade	23104	4.158	6	2	4	0.947	-0.196	2.877
HHI	market competition	23104	0.0623	0.217	0.0150	0.0399	0.0503	1.465	4.532
CER	Command-controlled environmental regulation	23104	0.00162	0.00618	0.000150	0.00111	0.00142	1.560	5.027
MER	Market incentive environmental regulation	23104	0.000564	0.00209	0.000118	0.000440	0.000475	1.576	5.283
SIZE	scale	23104	22.07	24.90	20.19	21.91	1.129	0.604	2.888
DAR	asset-liability ratio	23104	0.381	0.771	0.0747	0.370	0.186	0.244	2.144
ROA	all capital earnings rate	23104	0.0454	0.183	-0.127	0.0440	0.0609	-0.357	4.042
AGE	enterprise age	23104	2.057	3.313	0.373	2.125	0.830	-0.323	2.095
SOE	Nature of property rights	23104	0.225	1	0	0	0.418	1.317	2.734
RD	R& D investment intensity	23104	0.0512	0.198	0.000700	0.0412	0.0411	1.776	6.502
OC	Equity concentration	23104	0.326	0.643	0.107	0.306	0.136	0.487	2.518
BOARD	Board independence	23104	0.376	0.500	0.333	0.364	0.0496	0.751	2.447

Table 3. Correlation analysis

	GTI	ESG	HHI	CER	MER	SIZE	DAR
GTI	1						
ESG	0.142***	1					
HHI	-0.022***	-0.043***	1				
CER	-0.051***	-0.072***	0.127***	1			
MER	0.016**	-0.044***	0.029***	0.306***	1		
SIZE	0.512***	0.169***	0.077***	0.020***	0.089***	1	
DAR	0.308***	-0.143***	0.100***	0.051***	0.026***	0.462***	1
ROA	-0.015**	0.239***	-0.041***	-0.00700	-0.043***	0.018***	-0.384***
AGE	0.213***	-0.139***	0.077***	0.100***	0.122***	0.457***	0.368***
SOE	0.184***	0.017**	0.088***	0.126***	0.175***	0.322***	0.240***
RD	0.063***	0.095***	-0.245***	-0.177***	-0.00300	-0.142***	-0.223***
OC	-0.00700	0.089***	0.098***	0.050***	0.019***	0.073***	-0.042***
BOARD	-0.00400	0.061***	-0.022***	-0.060***	-0.033***	-0.031***	-0.012*
	ROA	AGE	SOE	RD	OC	BOARD	
ROA	1						
AGE	-0.243***	1					
SOE	-0.110***	0.434***	1				
RD	-0.090***	-0.220***	-0.135***	1			
OC	0.169***	-0.139***	0.129***	-0.111***	1		
BOARD	-0.018***	-0.031***	-0.062***	0.044***	0.054***	1	

Note: * p <0.1, ** p <0.05, *** p <0.01; same below

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Table 4. VIF variance expansion factor

Variable	VIF	1/VIF
SIZE	1.77	0.563476
AGE	1.73	0.578967
DAR	1.72	0.581548
ROA	1.41	0.707154
SOE	1.33	0.753204
ESG	1.18	0.847633
RD	1.17	0.857768
OC	1.13	0.887523
BOARD	1.02	0.984021
MeanVIF	1.36	

As shown in Table 3, the correlation test reveals a significant positive correlation (0.142) between Green Technology Innovation (GTI) and the explanatory variable ESG rating (ESG), indicating an upward trend in both metrics. Correlation analysis further demonstrates that, except for the previously mentioned interchangeable variables, the absolute values of correlation coefficients between most variables remain below 0.5, confirming the absence of significant multicollinearity in the model. Prior to conducting benchmark regression analysis, this study performed variance inflation factor (VIF) tests on all explanatory variables, as shown in Table 4. Typically, VIF values exceeding 5 indicate high multicollinearity. The results show maximum VIF values of 1.77 and minimum values of 1.02, with an average of 1.36. This average value suggests moderate-to-low levels of collinearity among variables within the overall model, further validating the absence of significant multicollinearity issues.

4.2. Benchmark Regression Analysis

To examine the direct impact of corporate ESG ratings on green innovation (Hypothesis H1), this study constructed Model (1) for benchmark regression. Considering that firm characteristics and time-varying macroeconomic factors might influence regression results, we employed a two-way fixed effects model that simultaneously includes ESG and all control variables while controlling for year and firm identification. The Hausman test (Prob>chi^2=0.0000) rejected the null hypothesis of random effects modeling, confirming the suitability of fixed effects analysis. As shown in Table 5's basic regression analysis: Column (1) contains only the dependent variable and control variables without including the core explanatory variable ESG, serving as a baseline for subsequent models. Column (2) incorporates ESG but excludes control variables to assess its explanatory power. Column (3) combines all control variables with the explanatory variable. During fixed effects regression, observations with single occurrences were automatically excluded, resulting in a final sample size of 22,821. The coefficients for ESG ratings remain significantly positive at the 1% level, with the benchmark regression providing clear and robust evidence that enhancing ESG ratings serves as an effective pathway to promote green innovation in Chinese manufacturing enterprises, thereby validating Hypothesis H1.

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Table 5. Benchmark regression analysis

	model1	model2	model3
SIZE	0.367***		0.363***
	(15.30)		(15.04)
DAR	0.017		0.031
	(0.23)		(0.41)
ROA	0.195		0.188
	(1.48)		(1.43)
AGE	-0.038		-0.031
	(-1.32)		(-1.08)
SOE	-0.043		-0.045
	(-0.89)		(-0.92)
RD	1.813***		1.800***
	(5.15)		(5.11)
OC	-0.004		-0.001
	(-0.02)		(-0.01)
BOARD	-0.027		-0.048
	(-0.14)		(-0.25)
ESG		0.030***	0.019***
		(4.12)	(2.73)
Constant	-7.183***	0.812***	-7.170***
	(-13.51)	(26.96)	(-13.50)
"Observational values" "Intra-group R-square"	22821	22821	22821
r2_within	0.039	0.001	0.040

4.3. Analysis of Regulatory Effect

As shown in Table 6, Models 1-3 establish regression models using three moderating variables: market competition (HHI), command-control regulation (CER), and market incentive regulation (MER). In Model 1, the interaction term between market competition (HHI) and the explanatory variable ESG rating is significantly positive at the 5% significance level. In Model 2, the interaction term ESGGTI×CER shows a significant positive effect on green innovation capability at the 5% level. In Model 3, the interaction term ESGGTI×quality demonstrates a significant positive impact on green innovation capability at the 1% significance level. These findings indicate that the three moderating variables exert positive moderating effects on the relationship between green innovation capability and ESG rating, thereby validating Hypotheses H2 and H3.

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Table 6. Analysis of regulatory effects

	(1)	(2)	(3)
	GTI	GTI	GTI
ESG	0.0899***	0.0890***	0.0907***
	(12.37)	(12.31)	(12.43)
ESG×HHI	0.350**		
	(2.12)		
HHI	-0.750***		
	(-5.67)		
SIZE	0.441***	0.442***	0.442***
	(58.65)	(58.83)	(58.76)
DAR	1.036***	1.025***	1.023***
	(23.23)	(23.01)	(22.89)
ROA	0.568***	0.589***	0.582***
	(4.58)	(4.77)	(4.70)
AGE	-0.00980	-0.00596	-0.00752
	(-0.98)	(-0.60)	(-0.75)
SOE	0.117***	0.126***	0.130***
	(6.74)	(7.23)	(7.40)
RD	5.181***	5.279***	5.428***
	(30.15)	(31.44)	(32.40)
OC	-0.225***	-0.239***	-0.239***
	(-4.56)	(-4.88)	(-4.87)
BOARD	0.0905	0.0667	0.0881
	(0.71)	(0.52)	(0.69)
ESG×CER		12.63**	
		(2.07)	
CER		-56.50***	
		(-9.87)	
ESGI×MER			77.00***
			(4.12)
MER			-88.83***
			(-6.44)
_cons	-9.785***	-9.751***	-9.820***
	(-63.28)	(-63.04)	(-63.54)
N	23104	23104	23104
R2	0.314	0.316	0.315
adj. R2	0.314	0.316	0.314

4.4. Robustness Test and Endogeneity Test

4.4.1. Robustness Test of Sample Removal in Special Period

Given that the COVID-19 pandemic outbreak in early 2020 constituted a significant external shock, which may have exerted systemic impacts on corporate operations, investment decisions, and innovation activities-thereby disrupting relationships among key variables-this study conducted robustness tests by excluding pandemic-period samples to mitigate the potential effects of this exceptional event and ensure conclusion robustness. Specifically, all observations from 2020 onward were removed, retaining only the data subset from 2014-2019. The baseline

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model (1) was then regressed using this refined dataset. The regression results are presented in Table 7.

As shown in Table 7, after excluding the pandemic period samples, the regression coefficient of the core explanatory variable ESG was 0.0304, which is significantly positive at the 1% level (t=3.13). This result shows high consistency with the benchmark regression results of the full sample (coefficient 0.019, t=2.73) in both direction and significance, with even higher absolute values and t-values for the coefficients. This strongly indicates that the promoting effect of corporate ESG performance on green innovation is not a product of the pandemic period alone. After removing the interference from major macroeconomic shocks, the core conclusions of this study remain valid, demonstrating strong robustness.

Table 7. Regression analysis after excluding samples after 2020

	(1)
	GTI
ESG	0.0304***
	(3.13)
SIZE	0.370***
	(10.33)
DAR	-0.0468
	(-0.44)
ROA	0.205
	(1.04)
AGE	-0.0853*
	(-1.82)
SOE	-0.0716
	(-0.92)
RD	2.408***
	(4.32)
OC	-0.0563
	(-0.26)
BOARD	-0.178
	(-0.67)
_cons	-7.179***
	(-9.23)
N	11055
R2	0.797
adj. R2	0.745

4.4.2. Robustness Test for Substitution of Core Explanatory Variables

To further validate the reliability of the conclusions, this study conducts robustness tests by substituting core explanatory variables. In the benchmark regression, we utilize HuaZheng ESG ratings (AAA-C) as a sequential graded variable (ESG) with values ranging from 9 to 1. Considering that graded variables may partially obscure nuanced differences in corporate ESG performance, this section adopts HuaZheng's original composite ESG score (ESG Score) as an alternative indicator for core explanatory variables. This refined continuous variable provides a more comprehensive reflection of enterprises' ESG performance levels.

The regression results are presented in Table 8. Column (1) shows the benchmark regression, while column (2) presents the results after substituting explanatory variables. The coefficient of ESG Score is 0.003, which is significantly positive at the 5% level. This indicates that even

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when using more refined ESG metrics as evaluation indicators, corporate ESG performance continues to demonstrate a robust promoting effect on green innovation. The findings maintain high consistency with the benchmark regression in both directionality and significance, thereby strongly demonstrating that the core conclusions of this study remain unaffected by specific variable measurement methods, exhibiting excellent robustness.

Table 8. Robustness test -- Replace core explanatory variables

	(1)	(2)
	Benchmark model (ESG rating)	Stability (ESG score)
ESG	0.017**	
	(2.50)	
SIZE	0.363***	0.364***
	(15.05)	(15.05)
DAR	0.030	0.030
	(0.39)	(0.40)
ROA	0.188	0.190
	(1.43)	(1.44)
AGE	-0.032	-0.032
	(-1.10)	(-1.12)
SOE	-0.044	-0.045
	(-0.92)	(-0.92)
RD	1.804***	1.802***
	(5.12)	(5.11)
OC	-0.001	-0.002
	(-0.01)	(-0.01)
BOARD	-0.046	-0.043
	(-0.25)	(-0.23)
ESG_score		0.003**
		(2.11)
_cons	-7.169***	-7.332***
	(-13.49)	(-13.81)
sample capacity	22821	22821
Within-group R-squared	0.039	0.039

4.4.3. Consider the Lag Effect Test of Reverse Causation

To address the potential reverse causality between corporate ESG ratings and green innovation (where companies with superior green innovation tend to achieve higher ESG ratings) and to examine the time lag effect of ESG impacts, this study applies one to three-period lags to the core explanatory variable ESG rating and conducts regression analyses. As shown in Table 9: Columns (1) to (3) present regression results for ESG ratings with one, two, and three periods of lag respectively. The analysis reveals that the coefficient for L1_ESG is 0.010 (t=1.32), L2_ESG's coefficient is 0.007 (t=0.88), and L3_ESG's coefficient is-0.007 (t=-0.79), none of which passed the traditional significance level tests. Column (4) incorporates all lagged terms into the model, yet the results remain statistically insignificant.

The findings indicate that the lag effect of ESG ratings is not statistically significant.

This suggests that ESG ratings primarily enhance corporate green innovation in the current period. Two key factors contribute to this phenomenon: First, as a market signal, ESG ratings demonstrate strong time-sensitive information value and investor appeal. To align with evolving market expectations, companies tend to adjust their green innovation strategies

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during the rating disclosure year. Second, green innovation initiatives-particularly patent application-driven projects-often complete the entire cycle faster than anticipated, allowing improved ESG performance to manifest in innovation outcomes more promptly. The absence of a lag term indicates that ESG signals can rapidly guide corporate resource allocation and innovation decisions, demonstrating strong timeliness. Taken together, the regression results remain robust.

Table 9. Lag effect test of explanatory variables

	(1)	(2)	(3)	(4)
	Lag 1 period	2nd lag	3rd lag	dynamic effect
L1_ESG	0.010			-0.002
	(1.32)			(-0.20)
SIZE	0.386***	0.372***	0.367***	0.362***
	(13.67)	(11.30)	(9.62)	(9.14)
DAR	0.034	0.059	0.105	0.088
	(0.40)	(0.60)	(0.92)	(0.76)
ROA	0.143	-0.000	-0.106	-0.047
	(1.00)	(-0.00)	(-0.62)	(-0.28)
AGE	-0.125***	-0.168**	-0.149	-0.119
	(-2.76)	(-2.46)	(-1.53)	(-1.21)
SOE	-0.040	-0.012	-0.032	-0.056
	(-0.79)	(-0.22)	(-0.51)	(-0.88)
RD	1.431***	1.227***	1.178**	1.248***
	(3.76)	(2.94)	(2.41)	(2.62)
OC	-0.082	-0.184	0.024	-0.054
	(-0.46)	(-0.95)	(0.11)	(-0.24)
BOARD	-0.141	-0.305	-0.380	-0.504*
	(-0.66)	(-1.30)	(-1.49)	(-1.93)
L2_ESG		0.007		0.009
		(0.88)		(1.08)
L3_ESG			-0.007	-0.006
			(-0.79)	(-0.63)
_cons	-7.543***	-6.934***	-6.767***	-6.655***
	(-12.22)	(-9.60)	(-7.96)	(-7.58)
sample capacity	19,258	15,889	12,917	12,672
Group R within the group	0.109	0.089	0.079	0.078

4.5. Heterogeneity Analysis

Considering the significant differences in economic development levels, marketization processes, institutional environments, and environmental regulation enforcement across eastern, central, and western regions of China, these disparities may influence the pathways and effectiveness of ESG ratings. To test whether the core conclusions of this study are universally applicable across different regional contexts, we categorized sample companies into three major regions-eastern, central, and western-based on their provincial registration locations according to the classification criteria in the China Statistical Yearbook, and conducted grouped regression tests for each subsample. As shown in Table 10, the regression coefficients of ESG

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ratings in eastern, central, and western regions were 0.084,0.089, and 0.094 respectively, all significantly positive at the 1% level. This finding demonstrates that the promoting effect of ESG on corporate green innovation exhibits remarkable universality, strongly supporting the robustness of the main conclusions of this study.

Table 10. Heterogeneity analysis

	(1)	(2)	(3)
	GTI	GTI	GTI
ESG	0.0839***	0.0888***	0.0938***
	(9.58)	(5.18)	(4.82)
SIZE	0.432***	0.480***	0.435***
	(46.64)	(26.87)	(23.95)
DAR	1.186***	0.662***	0.692***
	(22.23)	(5.85)	(5.92)
ROA	0.899***	-0.0735	-0.187
	(6.04)	(-0.24)	(-0.57)
AGE	0.0164	-0.0363	-0.0803***
	(1.34)	(-1.54)	(-3.05)
SOE	0.135***	0.136***	0.139***
	(5.93)	(3.65)	(3.44)
RD	5.305***	7.080***	3.129***
	(26.75)	(16.90)	(6.53)
OC	-0.250***	-0.336***	-0.125
	(-4.26)	(-2.74)	(-0.95)
BOARD	0.260*	-0.504*	-0.0803
	(1.69)	(-1.66)	(-0.22)
_cons	-9.774***	-10.30***	-9.387***
	(-51.33)	(-28.36)	(-24.66)
N	16661	3715	2728
R2	0.310	0.340	0.342
adj. R2	0.309	0.337	0.337

A closer examination reveals that the promotional effect of ESG ratings shows a gradual strengthening trend from eastern (0.084) to central (0.089) and western (0.094) regions. This seemingly counterintuitive phenomenon may conceal profound economic logic: Against the backdrop of advancing the construction of a unified national market, compared to the eastern regions with more sophisticated institutional environments and mature market mechanisms, ESG ratings in central and western regions-where information asymmetry is more pronounced and market efficiency relatively weaker-may demonstrate greater marginal effects as a scarce high-quality "reputation signal." For enterprises in these regions, an outstanding ESG rating can help them stand out among numerous competitors, enabling more effective access to critical limited resources like government subsidies and green credit. This ultimately facilitates stronger conversion of ESG performance into green innovation outcomes.

5. Conclusion

This study employs stakeholder theory and signaling theory to empirically examine the impact of corporate ESG ratings on green innovation among A-share listed manufacturing companies in China (2014-2023). It further explores the moderating effects of two external contextual

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factors: environmental regulations and market competition. Through constructing a two-way fixed-effects model and conducting a series of robustness tests, the paper derives the following key conclusions:

First, ESG ratings serve as a powerful internal driver for green innovation in manufacturing enterprises. Empirical evidence demonstrates a significant positive correlation between corporate ESG ratings and their level of green innovation, validating Hypothesis H1. As a comprehensive indicator of sustainable development capabilities, outstanding ESG performance enables companies to secure critical resources and establish legitimacy for undertaking high-investment, long-term green innovation initiatives through multiple channels: alleviating financing constraints, enhancing stakeholder trust, and sending positive market signals.

Second, environmental regulations and market competition serve as crucial external conditions for enhancing the ESG-driven green innovation effect. This study demonstrates that both environmental regulations (including mandatory compliance and market incentives) and market competition exert significant positive moderating effects on the relationship between ESG ratings and green innovation, thereby validating Hypotheses H2 and H3. This indicates that when enterprises face intensified external compliance pressures (high-intensity environmental regulations) and survival pressures (fierce market competition), their motivation to transform ESG reputation into core competitiveness becomes more pronounced.

Third, ESG's role in promoting green innovation demonstrates broad applicability across regions, though showing significant marginal effect variations. Robustness tests reveal that core conclusions remain valid after accounting for potential endogeneity issues (lagged effects) and external shocks (excluding pandemic samples). Subregional heterogeneity analysis confirms that the positive impact of ESG ratings on corporate green innovation is evident in eastern, central, and western regions, validating the generalizability of the basic hypothesis. Notably, this positive effect shows a gradual strengthening trend from eastern to central and western regions. This suggests that in areas with relatively lower marketization levels and more pronounced information asymmetry, ESG serves as a high-quality reputation signal, exerting stronger marginal driving effects on corporate green innovation.

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