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The Impact of ESG Performance on Corporate Green Innovation Efficiency

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Abstract

With the continuous deepening of the new development philosophy and the proposal of the "dual carbon" strategic goals, firms face greater challenges in their capacity for green and sustainable development, and an increasing number of investors have begun to pay attention to corporate environmental, social, and governance (ESG) performance. Taking A-share listed companies on the Shanghai and Shenzhen stock exchanges over the period 2012-2022 as the sample, this paper empirically examines the relationship between ESG performance and corporate green innovation efficiency (GIE) by means of a fixed-effects model, and further introduces managerial ability to test the mediating role of managerial ability between the ESG performance of listed companies and their GIE. The findings are as follows. First, sound corporate ESG performance can improve corporate GIE, and managerial ability plays a partial mediating role between the two: sound ESG performance is negatively associated with managerial ability suggesting a substitution relationship between the two channels. Second, the results of the heterogeneity analysis show that the enhancing effect of sound ESG performance on GIE is more pronounced for firms in economically developed regions (the eastern region), for state-owned enterprises, and for firms in non-heavily polluting industries. Finally, on the basis of the above conclusions, reasonable reference suggestions for the sustainable development of firms are put forward from different perspectives.

Keywords

ESG Performance, Green Innovation Efficiency, Empirical Analysis

1. Introduction

In the face of the challenges brought by global climate change, sustainable development has gradually become the consensus and the pursued goal of the interna-

tional community. Against this background, China has actively responded to global climate action and has successively put forward the new development philosophy of "innovation, coordination, green, openness, and sharing" as well as the "dual carbon" strategic goals, committing itself to pushing carbon dioxide emissions to a peak before 2030 while making every effort to realise the vision of carbon neutrality before 2060. These goals not only reflect China's firm determination to address climate change, but also bring major opportunities and challenges to the green transformation of various industries.

The introduction of the concept of ESG (environmental, social, and governance) performance follows precisely this trend of the times. In addition to taking traditional financial indicators into account, it evaluates corporate achievements in environmental protection, the fulfilment of social responsibilities, and corporate governance from a more comprehensive perspective. In the process of corporate green transformation, ESG ratings have gradually become an important criterion for measuring a firm's capacity for sustainable development, and an increasing number of investors and stakeholders have begun to pay attention to firms' ESG performance, expecting to screen out firms with long-term value and a sense of social responsibility through ESG ratings. For a firm, a sound ESG rating not only helps to improve its image and reputation and to attract investment, but also drives internal green innovation and change. However, at present no unified and in-depth research conclusion has been reached on how ESG ratings actually affect corporate green innovation efficiency. Against this background, an in-depth investigation of the impact of ESG ratings on corporate green innovation efficiency and of the underlying mechanism is of great theoretical and practical significance for promoting corporate sustainable development and for facilitating the realisation of the national "dual carbon" goals.

2. Literature Review

2.1. ESG Ratings and Green Innovation

Research on ESG performance and green innovation has so far yielded relatively abundant results. With regard to the relationship between ESG ratings and green innovation, numerous studies show that ESG ratings have a significant positive effect on corporate green innovation, whereas rating divergence inhibits corporate green innovation; in addition, rating divergence acts on different aspects of corporate green innovation through different mechanisms. Ba et al. (2025), studying Chinese listed companies, revealed that a positive association exists between firms' ESG ratings and green innovation. Dong et al. (2024) pointed out that ESG rating divergence affects the green innovation of listed companies and analysed the mechanism involved in depth. Fan (2024) argued that ESG rating divergence inhibits corporate green innovation and explored the specific paths through which ESG rating divergence affects corporate green innovation. Li and Li (2024a) focused on the effect of rating divergence on corporate green innovation efficiency and found that the greater the ESG rating divergence, the lower the corporate green innova-

tion efficiency. Shi et al. (2024) analysed the ways in which ESG ratings promote improvements in both the quantity and the quality of corporate green innovation.

As for the relationship between ESG performance and green innovation, a large number of empirical studies based on different samples and methods have all concluded that sound corporate ESG performance can promote green innovation. For example, Li et al. (2023) took China Securities Index (CSI) ESG rating data for the period 2017-2019 as the sample; Wang and Guo (2024), focusing on manufacturing firms, took the Huazheng ESG rating data of A-share manufacturing listed companies for the period 2018-2022 as the sample; and Xu et al. (2024) took the Huazheng ESG rating data of A-share listed companies on the Shenzhen and Shanghai stock exchanges for the period 2012-2022 as the sample. All of these studies verified the effect of ESG performance on corporate green innovation through empirical analysis and found that ESG performance has a significant positive effect on corporate green innovation. This promoting effect is reflected in multiple dimensions such as innovation performance, innovation quality, and innovation efficiency, and the effect of ESG performance on green innovation differs to some extent across industries (for example, manufacturing firms and heavily polluting firms) and across different degrees of information disclosure. Huang and Qi (2024), from the perspective of information disclosure, explained the effect of corporate disclosure of ESG-related information on green innovation. Li et al. (2022) studied the relationship between ESG information disclosure and corporate green innovation performance and concluded that ESG ratings may indirectly affect green innovation capacity by influencing corporate financing constraints.

In summary, most of these studies measure the effect of ESG performance on the green innovation of listed firms on the basis of Huazheng index ratings or Bloomberg index ratings, and only a small number of studies conduct empirical analysis using ESG ratings from other indices. Therefore, drawing on the research of Hu et al. (2023), this paper adopts SynTao Green Finance ESG rating data and uses the data for 2012-2022 that are currently available to conduct an empirical analysis of the relationship between the two, so as to gain an in-depth understanding of the effect of ESG ratings on corporate green innovation efficiency.

2.2. Green Innovation Efficiency

As regards research on the effect of ESG ratings on corporate green innovation efficiency, Peng et al. (2024) used the Huazheng ESG rating data of A-share listed companies on the Shenzhen and Shanghai stock exchanges for the period 2009-2021 as the sample, examined the effect of ESG performance on green innovation efficiency, and held that sound corporate ESG performance can significantly improve corporate green innovation efficiency. Through mechanism analysis, they identified two mechanisms through which corporate ESG performance affects green innovation efficiency, namely the improvement of the level of corporate risk-taking and the enhancement of supply chain discourse power.

In research on the relationship between green innovation efficiency and other

factors, Huang et al. (2024) studied the effects of industrial structure upgrading and governmental ecological and environmental attention on green innovation efficiency in resource-based cities; Liu and Li (2024) explored the effect of the digital economy on green innovation efficiency from the perspective of high-quality population development; Li and Tang (2024) examined the mechanism through which digital transformation affects the green innovation efficiency of manufacturing firms; Lyu et al. (2023) analysed the effect of the digital economy on regional green innovation efficiency and its transmission mechanism; Yang and Yang (2024) discussed the effect of digital technology innovation on corporate ESG performance, which indirectly reflects a potential link with green innovation; and Wu et al. (2024) studied the effect of the green finance pilot policy on the green innovation efficiency of agriculture-related firms. These studies found that external factors such as industrial structure upgrading, governmental ecological and environmental attention, the digital economy, digital transformation, and the green finance pilot policy are all closely related to corporate green innovation efficiency or quality. These factors affect corporate green innovation efficiency through different paths; for example, sound managerial ability can provide technical support and new development models for corporate green innovation, which offers a certain reference for research on the path through which ESG performance affects corporate green innovation efficiency.

In summary, existing research that directly addresses the effect of ESG performance on corporate green innovation efficiency is relatively scarce. This study therefore adopts a unified research method to examine the relationship between the two and further explores the dynamic relationship between ESG and green innovation efficiency under different regions, firm characteristics, and industry attributes, focusing on revealing, through grouped research, the similarities and differences among different types of firms in terms of the effect of ESG ratings on corporate green innovation. In addition, it analyses the influencing mechanism between the two, so as to understand more comprehensively the path through which ESG ratings affect corporate green innovation, to provide useful references and suggestions for policymakers and firms, and to offer more comprehensive theoretical support for corporate sustainable development.

3. Theoretical Analysis and Research Hypotheses

3.1. Stakeholder Theory

Stakeholder theory holds that corporate operating decisions must take into account the demands of multiple interest subjects such as shareholders, employees, consumers, communities, and the environment. Sound corporate ESG performance is essentially a response to the needs of multiple stakeholders: at the environmental (E) level, energy saving and emission reduction as well as green production can meet society's expectations for ecological protection; at the social responsibility (S) level, the protection of employees' rights and interests and investment in community public welfare can enhance corporate social recognition; and

at the corporate governance (G) level, transparent decision-making and risk management mechanisms help to increase stakeholder trust. This comprehensive process of value creation can win broader resource support and cooperation opportunities for firms, such as government green subsidies and consumers' brand preferences, which are directly transformed into investment in green innovation and thus improve green innovation efficiency.

3.2. Resource-Based Theory

Resource-based theory emphasises that a firm's unique resources and capabilities are the core source of competitive advantage. Firms with excellent ESG performance often possess the following three major resource advantages: first, physical resources such as green technologies and environmental patents; second, intangible resources such as a sustainable development brand reputation and stakeholder trust; and third, high-quality human resources. These resources can directly improve green innovation efficiency by optimising the allocation of innovation resources, reducing trial-and-error costs, and accelerating technology transformation. For example, the green technology knowledge accumulated by a firm through ESG practices can reduce repetitive investment in the R&D process and improve the efficiency of innovation output.

3.3. Institutional Theory

Institutional theory holds that the structure and behaviour of organisations are shaped and constrained by the external institutional environment. When the external environment in which a firm operates has high ESG requirements and strict supervision, the firm will be compelled to comply with the corresponding ESG standards in order to obtain legitimacy and room for survival. In such a case, even if managerial ability is average, the firm will, to a certain extent, carry out green innovation because of external institutional pressure so as to meet ESG requirements. In other words, under strong institutional pressure green innovation is driven mainly by institutional factors rather than by managerial ability, which is consistent with the negative association between ESG performance and managerial ability. For example, when the government introduces strict environmental regulations and reward and punishment systems, firms will actively carry out green innovation activities in order to avoid penalties for violations and to obtain policy preferences, and in this process the improvement of corporate green innovation efficiency will be promoted accordingly.

3.4. Research Hypotheses

H1: Sound corporate ESG performance has a promoting effect on corporate green innovation efficiency.

Based on the two theoretical pillars of stakeholder theory and resource-based theory, it is argued that a firm is not merely a tool for shareholders to create profits, but a complex network system composed of multiple stakeholders. When a firm's ESG performance is sound, it attracts more stakeholders who are concerned about

the environment and social responsibility; in order to meet stakeholders' expectations for sustainable development, the firm needs, under invisible pressure, to invest more resources in green innovation, thereby promoting the improvement of its green innovation efficiency. In addition, a firm's unique resources and capabilities are the source of competitive advantage. ESG performance can be transformed into the strategic resources required for green innovation in many ways; sound ESG performance facilitates a firm's access to resources and helps it accumulate intangible resources such as reputation capital and organisational trust. These resources can reduce the transaction costs arising in the process of green innovation, thereby prompting firms to improve green innovation efficiency. In summary, this paper proposes the hypothesis that sound corporate ESG performance has a promoting effect on corporate green innovation efficiency.

H2: Managerial ability plays a mediating role between corporate ESG performance and corporate green innovation efficiency.

Institutional theory holds that, in market competition, consumers' requirements concerning firms' environmentally friendly products and social responsibility are becoming increasingly strict. When a firm's ESG performance is sound, it is relatively easier for it to gain market recognition and consumer favour, and thus to obtain a larger market share and more profits. In order to win consumers' favour, the firm will, under invisible pressure, be compelled to carry out green product innovation. At this point, sound ESG performance helps the firm to attract external investment and to promote green innovation with the help of external forces, so that firms with sound ESG performance are not necessarily those with high managerial ability. On this basis, this paper proposes the hypothesis that managerial ability mediates the relationship between corporate ESG performance and corporate green innovation efficiency.

4. Research Design

4.1. Variable Definitions

4.1.1. Dependent Variable

The dependent variable is corporate green innovation efficiency. Drawing on the research of Li and Tang (2024), this paper uses the ratio of green innovation output to green innovation input, GIE, to measure corporate green innovation efficiency; that is, the larger the value of GIE, the higher the firm's green innovation efficiency. Owing to the lack of data on R&D investment in green innovation, this paper uses the firm's annual R&D investment data as a substitute in order to measure the input of corporate green innovation.

At the same time, drawing on the ideas of Hu et al. (2023), this study uses the number of green inventions (the number of green patents granted) obtained by the listed company itself in the current year to measure the output of corporate green innovation.

Finally, the formula for measuring corporate green innovation efficiency (GIE) is GIE = ln(number of green inventions + 1)/ln(R&D expenditure + 1); that is, the number of green inventions obtained by the firm in the current year plus one is

taken as a natural logarithm, and this value is divided by the natural logarithm of R&D expenditure plus one, so as to achieve a quantitative evaluation of corporate green innovation efficiency. We acknowledge that total R&D expenditure includes non-green activities and that current patent grants may reflect investments made in earlier periods. These limitations may affect how the green innovation efficiency measure should be interpreted.

4.1.2. Core Explanatory Variable

The core explanatory variable is corporate ESG performance (ESG). In terms of measurement, drawing on the research of Hu et al. (2023), this paper uses SynTao Green Finance comprehensive ESG rating data to quantify corporate ESG performance. At the same time, following the specific measurement method of Li and Li (2024b), the SynTao Green Finance comprehensive ESG rating data are assigned values from 10 to 1 in descending order for A+, A, A−, B+, B, B−, C+, C, C−, and D; the better the corporate ESG performance, the higher the score obtained.

4.1.3. Control Variables

Firm size (Size)

This study uses the natural logarithm of a firm's total assets at year-end to measure firm size, that is, Size = ln(total assets at year-end). Larger firms may invest more funds in corporate green innovation because they possess more abundant resources; by controlling for this indicator, the interference in corporate green innovation efficiency caused by resource differences arising from firm size can be reduced.

Debt-to-asset ratio (Lev)

The debt-to-asset ratio is the ratio of a firm's total liabilities to its total assets in the current year, that is, Lev = total liabilities/total assets. This indicator is used to measure a firm's long-term solvency and financial risk. A higher debt-to-asset ratio means that the firm faces a greater debt burden and higher financial risk, which may lead the firm to use more resources to repay debts, thereby reducing its investment in green innovation activities.

Return on total assets (ROA)

The return on total assets is the ratio of net profit to average total assets, that is, ROA = net profit/average total assets. This indicator intuitively measures the efficiency with which a firm converts all its assets into profits and clearly shows a firm's asset-based earning capacity. Firms with stronger profitability usually have more free cash with which to support their green innovation activities. Taking the return on total assets as a control variable can avoid interference by differences in corporate profitability in corporate green innovation efficiency.

Operating revenue growth rate (Growth)

The operating revenue growth rate is calculated as operating revenue of the current period/operating revenue of the previous period − 1. This indicator presents the fluctuation trajectory of a firm's operating revenue in quantitative terms and plays an important role in evaluating a firm's operating conditions and judg-

ing its operating performance. Firms in a stage of rapid growth have sound operating conditions and may increase their investment in green innovation, thereby exerting a certain influence on green innovation efficiency.

4.1.4. Mediating Variable

According to the institutional theory mentioned above, Hypothesis 2 is proposed, namely that managerial ability mediates the relationship between corporate ESG performance and corporate green innovation efficiency. This paper uses the managerial ability data released by Jingguan Zhijia, which are measured by a two-stage model combining data envelopment analysis and the Tobit model, to measure this indicator. In summary, the specific definitions of all the variables are shown in Table 1.

Table 1. Variable definitions.

Variable type	Variable name	Variable description
Dependent variable	Corporate green innovation efficiency (GIE)	ln (number of green inventions + 1)/ ln (R&D expenses + 1)
Core explanatory variable	ESG score	Rating data released by SynTao Green Finance, assigned values from 10 to 1
Control variable	Firm size (Size)	ln (total assets at year-end)
Control variable	Debt-to-asset ratio (Lev)	Total liabilities/total assets
Control variable	Return on total assets (ROA)	Net profit/average total assets
Control variable	Operating revenue growth rate (Growth)	Operating revenue of the current period/operating revenue of the previous period − 1
Mediating variable	Managerial ability	A two-stage model combining data envelopment analysis and the Tobit model

4.2. Sample Selection and Data Sources

On the basis of data availability and the needs of actual research, this study selects A-share listed companies on the Shanghai and Shenzhen stock exchanges over the period 2012-2022 as the research sample and carries out the following screening and processing: 1) financial listed companies and companies marked as ST, *ST, and PT are excluded; 2) companies newly listed in the current year are excluded so as to avoid data bias caused by too short a listing period; and 3) samples with severely missing data and abnormal values are excluded. After the above processing, 35,325 sample observations are finally obtained.

The data sources used in this study are as follows: 1) the SynTao Green Finance ESG rating data of A-share listed companies on the Shanghai and Shenzhen stock exchanges over 2012-2022, obtained from the Wind database; 2) the number of green inventions of A-share listed companies on the Shanghai and Shenzhen stock exchanges, obtained from the Chinese Research Data Services (CNRDS) platform; 3) data related to corporate finance, firm characteristics, and industry attributes,

most of which are obtained from the Chinese Research Data Services (CNRDS) platform; and 4) managerial ability data, obtained by Jingguan Zhijia on the basis of public information such as listed companies' annual reports.

4.3. Model Specification

On the basis of the foregoing definitions of the dependent variable, the core explanatory variable, the control variables, and the mediating variable, the following model (1) is constructed in order to study the effect of ESG ratings on corporate green innovation efficiency:

$$GIE_{it} = \beta_0 + \beta_1 ESG_{it} + \sum_{j=2}^{n} \beta_j Control_{jit} + \varepsilon_{it} \quad (1)$$

where GIE_{it} is the dependent variable, representing the green innovation efficiency of firm i in period t, calculated according to the formula GIE = ln(number of green inventions + 1)/ln(R&D expenditure + 1); ESG_{it} is the core explanatory variable, representing the assigned score of the SynTao Green Finance ESG rating data of firm i in period t; $Control_{jit}$ denotes a series of control variables; and ε_{it} is the random disturbance term, representing the influence on GIE_{it} of random factors in the model that cannot be observed or have not been taken into account.

This model is based on economic theory and holds that corporate green innovation efficiency is affected by ESG ratings and other relevant financial characteristics. By controlling for these factors, the net effect of ESG ratings on green innovation efficiency can be estimated accurately.

5. Empirical Analysis

5.1. Descriptive Statistics

In order to provide a more intuitive understanding of the explanatory variables and data values used in this paper, the descriptive statistics of the main variables are listed, as shown in **Table 2.** The mean value of the dependent variable GIE is 0.006, its standard deviation is 0.022, its maximum is 0.321, and its minimum is 0, indicating that most firms have relatively low green innovation efficiency and considerable room for development; moreover, the difference between the maximum and the minimum is relatively large compared with the mean, indicating that there are large differences in green innovation efficiency among different firms. The mean value of the ESG score of the core explanatory variable is 0.655, indicating that the overall ESG performance of the sample firms is poor, and the difference between the maximum and the minimum is extremely large, indicating that there are great differences in the ESG performance of the sample firms. Judging from the means and standard deviations of the control variables such as firm size and return on total assets, it can be seen that the sample listed companies are relatively large in size and possess a certain debt-servicing capacity and profitability. Judging from the operating revenue growth rate, the vast majority of the sample listed companies are in a relatively good growth situation, and their operating revenue shows a relatively stable growth trend.

Table 2. Descriptive statistics.

	Observations	Mean	Std. dev.	Min	Max
Firm size	35,325	22.199	1.338	14.942	28.636
Debt-to-asset ratio	35,325	0.415	0.21	0.008	1.957
Return on total assets	35,325	0.04	0.079	−1.859	1.285
Operating revenue growth rate	35,325	4.159	716.285	−1.309	134,607.06
ESG score	35,325	5.35	0.379	3	9
Corporate green innovation efficiency	35,325	0.006	0.022	0	0.321

After a certain understanding of the data of each variable used in this paper has been obtained, and in order to study whether ESG performance has an effect on corporate green innovation efficiency, how it is affected, and what the mechanism of the effect is, a correlation test is preliminarily conducted below.

5.2. Correlation Test

Table 3 is the statistical table of the correlation test. It can be seen from the table that corporate ESG performance shows a significant positive correlation with corporate green innovation efficiency GIE at the 5% level, and the correlation coefficient between them is 0.151, which preliminarily verifies Hypothesis 1, namely that the better a firm's ESG performance, the higher its green innovation efficiency. To a certain extent, this supports the hypothesis that sound corporate ESG performance has a promoting effect on corporate green innovation efficiency.

Table 3. Correlation test.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
(1) Corporate green innovation efficiency	1.000					
(2) ESG score	0.151*	1.000				
	(0.000)					
(3) Firm size	0.186*	0.533*	1.000			
	(0.000)	(0.000)				
(4) Debt-to-asset ratio	0.068*	0.110*	0.493*	1.000		
	(0.000)	(0.000)	(0.000)			
(5) Return on total assets	0.012*	0.088*	−0.001	−0.366*	1.000	
	(0.020)	(0.000)	(0.797)	(0.000)		
(6) Operating revenue growth rate	−0.002	−0.002	−0.003	0.005	0.000	1.000
	(0.777)	(0.702)	(0.539)	(0.324)	(0.945)	

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

In addition, it can be seen from Table 3 that the maximum correlation coefficient among the variables is 0.53 and that the variance inflation factor (VIF) is greater than or equal to 1 and far less than 10 (as shown in Table 4), indicating that the correlation among the variables is weak and the degree to which they are affected by multicollinearity is low, so that the data are suitable for the subsequent regression analysis.

Table 4. Multicollinearity test.

	VIF	1/VIF
Firm size	1.97	0.509
Debt-to-asset ratio	1.66	0.602
ESG score	1.46	0.685
Return on total assets	1.22	0.823
Operating revenue growth rate	1	0.999
Mean VIF	1.46	.

5.3. Baseline Regression

After a series of variables had passed the correlation test, an F test and a Hausman test were further carried out on the data (the specific test results are shown in the appendix). The value of the F test result is F (4961, 30358) = 7.55, with a significance p value of 0.000, which is less than 0.05; the value of the Hausman test result is 163.22, with a significance p value of 0.000, which is also less than 0.05. Both passed the significance test, indicating that the sample data of this paper are more suitable for a fixed-effects model. A fixed-effects model is therefore used for the regression, and the results are analysed below.

Table 5 reports the regression results based on the fixed-effects model. Column (1) presents the regression results of the model controlling for individual and time fixed effects before the core explanatory variable is added, and Column (2) presents the final regression results of the individual-time fixed-effects model after the core explanatory variable is added. The regression coefficient of ESG performance on GIE is 0.000 and is significantly positive at the 1% level, indicating that sound ESG performance helps to promote the improvement of corporate green innovation efficiency GIE. After the core explanatory variable is added, the effect of firm size on GIE weakens, indicating that the inclusion of ESG performance disperses part of the explanatory power of firm size for GIE. On the basis of the above baseline test results, it can be seen that a firm's excellent performance in the environmental, social, and governance (ESG) dimensions can significantly improve its green innovation efficiency. The results show that there is a significant positive correlation between ESG performance and corporate green innovation efficiency; that is, the higher a firm's ESG rating, the more obvious its promoting effect on green innovation efficiency. This conclusion is consistent with research Hypothesis H1 and effectively verifies the rationality of the hypothesis.

Table 5. Regression results.

	(1)	(2)
	GIE	GIE
Firm size	0.001***	0.000**
	(4.789)	(2.292)
Debt-to-asset ratio	−0.001	−0.001
	(−1.188)	(−0.566)
Return on total assets	−0.002	−0.002
	(−1.455)	(−1.223)
Operating revenue growth rate	0.000	0.000
	(0.023)	(0.016)
ESG score		0.000***
		(5.459)
Constant	−0.013***	−0.004
	(−3.222)	(−0.914)
N	35,325	35,325
R^2	0.001	0.002
F	6.164	10.896

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

6. Robustness Test and Difference Analysis

6.1. Robustness Test

As an important step in ensuring the reliability of the research conclusions, the robustness test aims to re-verify the results obtained from the empirical analysis and to ensure that they remain consistent and stable under various conditions. This paper uses the following three methods to carry out the robustness test. First, the sample size is changed: drawing on the research method of Wang and Guo (2024), manufacturing firms are selected from the original sample so as to construct a new sample subset. Second, the measurement method of the dependent variable is replaced: the indicator measuring corporate green innovation input is changed from the firm's annual R&D investment to the firm's annual number of R&D personnel, and a new indicator for measuring corporate green innovation efficiency (GIE2) is constructed accordingly, that is, GIE2 = ln(number of green inventions + 1)/ln(number of R&D personnel + 1). Third, the model specification is adjusted, and a random-effects model is selected for the regression analysis. Through the above methods, it is observed whether the research conclusions remain consistent.

Table 6 presents a comparison between the results of the original sample and those of the three robustness test methods. In the first column, after the sample

size is reduced, the regression coefficient of ESG performance on corporate green innovation efficiency does not change, and a weak positive correlation still exists between the two. In the second column, after the measurement method of the dependent variable is replaced, the regression coefficient increases from 0.000 to 0.003. In the third column, the regression results obtained using the random-effects model show that the regression coefficient of ESG performance on corporate green innovation efficiency remains at 0.000. All the above results are positive and significant at the 1% significance level, which fully verifies Hypothesis 1 of this paper, namely that sound corporate ESG performance has a positive promoting effect on the improvement of corporate green innovation efficiency, and strongly proves the reliability of the research conclusions of this paper.

Table 6. Robustness test.

	Manufacturing firms	Variable substitution	Random-effects model	Original sample
	GIE	GIE2	GIE	GIE
Firm size	0.000	0.005***	0.002***	0.000**
	(1.507)	(7.538)	(11.608)	(2.292)
Debt-to-asset ratio	0.000	0.001	−0.000	−0.001
	(0.150)	(0.219)	(−0.465)	(−0.566)
Return on total assets	−0.004*	−0.008*	−0.001	−0.002
	(−1.692)	(−1.747)	(−0.613)	(−1.223)
Operating revenue growth rate	0.000	0.000	−0.000	0.000
	(0.425)	(0.035)	(−0.007)	(0.016)
ESG score	0.000***	0.003***	0.000***	0.000***
	(4.356)	(12.317)	(6.432)	(5.459)
Constant	−0.003	−0.089***	−0.033***	−0.004
	(−0.443)	(−6.733)	(−10.352)	(−0.914)
N	23,264	35,325	35,325	35,325
R^2	0.002	0.011		0.002
F	7.315	69.499		10.896

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

6.2. Heterogeneity Analysis

Heterogeneity refers to the differences or inconsistencies that exist among research subjects; by classifying such differences, the differences among different types of groups are explored. Through the grouping comparison method, this paper conducts corresponding heterogeneity analyses on the basis of differences in the regions where listed companies are located, differences in ownership, and differences in industry attributes.

6.2.1. Heterogeneity Analysis Based on Regional Characteristics

From the perspective of heterogeneity in regional characteristics, according to the level of economic development of the regions where listed companies are located, firms can be divided into three categories: firms in economically developed regions, firms in moderately developed regions, and firms in less developed regions. The classified data are then subjected to a regression with individual and time fixed effects, and the results are shown in Table 7.

Table 7. Regional heterogeneity.

	Eastern region	Central region	Western region
	GIE	GIE	GIE
Firm size	0.000*	0.001	0.000
	(1.728)	(1.614)	(0.800)
Debt-to-asset ratio	−0.001	0.002	−0.003
	(−0.596)	(0.869)	(−1.500)
Return on total assets	−0.001	−0.001	−0.008**
	(−0.387)	(−0.290)	(−2.369)
Operating revenue growth rate	0.000	−0.000	0.000
	(0.221)	(−0.112)	(0.032)
ESG score	0.001***	0.000*	−0.000
	(6.072)	(1.660)	(−1.249)
Constant	−0.003	−0.012	−0.001
	(−0.615)	(−1.166)	(−0.103)
N	24,507	5486	4455
R^2	0.003	0.002	0.002
F	11.570	2.284	1.464

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

From the perspective of ESG rating performance, the regression coefficients of ESG performance on corporate green innovation efficiency GIE for firms in economically developed regions and firms in moderately economically developed regions are 0.001 and 0.000, respectively, and are significantly positive at the 1% and 10% levels, respectively, whereas the estimated coefficient of ESG performance on GIE for firms in less developed regions is negative and insignificant. Compared with less economically developed regions, the improvement of ESG performance in more developed regions has a more obvious effect on improving corporate green innovation efficiency. The possible reasons are as follows.

First, the financial markets in economically developed regions are more active and the financial strength of the government is strong. Firms in these regions have diverse financing channels, and abundant funds enable them to invest a large amount of resources in ESG practices and green innovation R&D. Correspondingly, the government is also more capable of introducing various subsidy and

reward policies for corporate ESG and green innovation, which directly reduce the cost of corporate green innovation, encourage firms to increase investment, and improve green innovation efficiency.

Second, economically developed regions are rich in educational resources. The eastern coastal economically developed regions have numerous universities and scientific research institutions, which have cultivated a large number of talents in relevant fields. Through close cooperation with these institutions, firms can obtain cutting-edge scientific research results and technical support, thus accelerating the process of corporate green innovation. In less developed regions, however, talents are scarce, the cooperation mechanism between firms and universities and scientific research institutions is relatively imperfect, and it is more difficult for firms to obtain external innovation resources, which is not conducive to the improvement of green innovation efficiency.

Third, market competition in economically developed regions is more intense. In fierce market competition, in order to stand out, firms compete not only in product quality and price but also in ESG performance. Sound ESG performance can become an advantage in differentiated competition, prompting firms to actively carry out green innovation. In the technology industry in developed regions, firms compete to launch environmentally friendly electronic products and enhance their competitiveness through green innovation. In less developed regions, the degree of market competition is relatively low, and the urgency for firms to enhance their competitiveness by improving their green innovation capacity is not strong.

Fourth, residents of economically developed regions have higher income levels and more advanced consumption concepts. Residents of such regions have a stronger demand for green, environmentally friendly, and sustainable products and services. In order to meet market demand, firms actively improve their ESG performance, intensify green innovation, and develop green products. In economically less developed regions, however, residents may pay more attention to product prices and have a relatively low demand for green products, so firms lack sufficient motivation for green innovation.

6.2.2. Heterogeneity Analysis Based on Firm Characteristics

From the perspective of heterogeneity in firm characteristics, with regard to the ownership of listed companies, they can be divided into two categories: state-owned enterprises and non-state-owned enterprises. The classified data are then subjected to a regression with individual and time fixed effects, and the results are shown in **Table 8**.

From the perspective of ESG rating performance, the effect of ESG performance on corporate green innovation efficiency GIE is significantly positive at the 1% level for state-owned enterprises, and the effect of ESG performance on GIE for non-state-owned enterprises is also positive at the 10% level. Compared with non-state-owned enterprises, the improvement of ESG performance by state-owned enterprises has a more obvious effect on improving corporate green innovation efficiency. The possible reasons are as follows.

Table 8. Ownership heterogeneity.

	State-owned enterprises	Non-state-owned enterprises
	GIE	GIE
Firm size	0.001*	0.001**
	(1.909)	(2.256)
Debt-to-asset ratio	−0.003	0.000
	(−1.234)	(0.190)
Return on total assets	−0.011**	−0.000
	(−2.500)	(−0.260)
Operating revenue growth rate	0.000	0.000
	(0.036)	(0.255)
ESG score	0.001***	0.000*
	(5.033)	(1.864)
Constant	−0.010	−0.006
	(−1.022)	(−1.240)
N	10,979	24,346
R^2	0.005	0.001
F	9.522	3.227

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

First, state-owned enterprises respond to policies more proactively. As an important pillar of national economic development, state-owned enterprises often bear more responsibility for policy implementation and strategic guidance. Against the policy background of vigorous advocacy of sustainable development, green transformation, and the "dual carbon" strategic goals, state-owned enterprises are more sensitive to policy orientation and will respond more proactively and incorporate the ESG concept into their strategic planning. Driven by the green energy transition policy, state-owned enterprises will take the lead in increasing their investment in the R&D and application of new energy, thereby improving green innovation efficiency.

Second, state-owned enterprises have strong financial strength and attach importance to long-term development. State-owned enterprises usually have stronger financial strength and financing advantages. Improving ESG performance and carrying out green innovation activities often require large capital investment, and state-owned enterprises often have better financing advantages, which provides a sufficient financial guarantee for corporate green innovation. In addition, state-owned enterprises attach more importance to long-term development, and the ESG concept is consistent with their long-term development strategic goals. Improving ESG performance helps state-owned enterprises to occupy a favourable position in the national layout for long-term development and to ensure their sustainable development. By contrast, some non-state-owned enterprises may focus

more on short-term economic benefits and have relatively insufficient motivation for ESG investment, which affects the improvement of green innovation efficiency.

Third, state-owned enterprises have accumulated stronger talent and technological resources. State-owned enterprises have long attracted and cultivated a large number of professional talents and have accumulated rich experience, especially in technology R&D and management. In promoting ESG practices, these talent and technological advantages can quickly be transformed into corporate green innovation capacity. By virtue of the advantages of their own scientific research teams, state-owned enterprises can rapidly carry out technology R&D for energy saving and emission reduction and improve green innovation efficiency, whereas non-state-owned enterprises may face problems such as a shortage of talents and technological bottlenecks, which to a certain extent limits the progress of their green innovation.

6.2.3. Heterogeneity Analysis Based on Industry Attributes

From the perspective of heterogeneity in industry attributes, according to the degree of pollution of the industries to which listed companies belong, firms can be divided into two categories: heavily polluting firms and non-heavily polluting firms. The classified data are then subjected to a regression with individual and time fixed effects, and the results are shown in Table 9.

Table 9. Industry attribute heterogeneity.

	Heavily polluting industries	Non-heavily polluting industries
	GIE	GIE
Firm size	0.000	0.001**
	(1.070)	(2.129)
Debt-to-asset ratio	−0.001	−0.001
	(−0.463)	(−0.748)
Return on total assets	−0.003	−0.001
	(−1.047)	(−0.612)
Operating revenue growth rate	0.000	0.000
	(0.490)	(0.014)
ESG score	−0.000	0.001***
	(−0.610)	(6.339)
Constant	−0.003	−0.005
	(−0.463)	(−0.927)
N	10,161	25,164
R^2	0.000	0.003
F	0.460	12.908

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

From the perspective of ESG rating performance, the regression coefficient of ESG performance on corporate green innovation efficiency GIE for non-heavily polluting firms is 0.001 and is significantly positive at the 1% level, whereas the estimated coefficient of ESG performance on GIE for heavily polluting firms is negative and insignificant. This indicates that, compared with heavily polluting firms, the improvement of ESG performance by non-heavily polluting firms has a more obvious effect on improving corporate green innovation efficiency. The possible reasons are as follows.

The businesses of non-heavily polluting firms are usually more diversified or belong to emerging industries, and their daily operating activities have relatively little negative impact on the environment, which gives them an obvious advantage in green transformation. In strategic adjustment, firms in non-heavily polluting industries can rapidly integrate the ESG concept into their overall strategy and take green innovation as a new engine of business growth. By contrast, firms in heavily polluting industries find strategic transformation extremely difficult because of their complex production processes and strong asset specificity, and it is hard for them to quickly adjust their business direction and innovation strategy around ESG, so the improvement of green innovation efficiency is relatively limited. Relatively speaking, firms in non-heavily polluting industries are more likely to improve their green innovation efficiency after improving their ESG performance.

7. Mechanism Analysis

7.1. Mediating Effect Model

In order to verify the partial mediating effect of managerial ability in the process through which ESG performance affects corporate green innovation efficiency, this study introduces managerial ability as a key mediating variable, constructs the following models (2) and (3), and combines them with the baseline model (1) to form a testing system, so as to systematically analyse the transmission path and the mechanism of action among the variables through stepwise regression and coefficient comparison.

$$MA_{it} = \beta_0 + \beta_1 ESG_{it} + \sum_{j=2}^{n} \beta_j Control_{jit} + \varepsilon_{it} \quad (2)$$

$$GIE_{it} = \beta_0 + \beta_1 ESG_{it} + \beta_2 MA_{it} + \sum_{j=3}^{n} \beta_j Control_{jit} + \varepsilon_{it} \quad (3)$$

where β_0 is the constant term; β_1 is the estimated coefficient of the core explanatory variable ESG performance; β_2 is the estimated coefficient of the mediating variable; β_j is the estimated coefficient of a series of control variables; and ε_{it} is the random disturbance term.

7.2. Interpretation of Results

This paper uses the stepwise regression method to test the mediating effect. First, managerial ability is taken as the dependent variable and is regressed on the inde-

pendent variable, and the results are shown in Table 10. Table 10 reports fewer observations than Table 5 because managerial ability, the mediating variable, contains missing values; the mediation regressions drop these 6270 observations listwise, leaving an estimation sample of 29,055.

Table 10. Mediating effect (managerial ability).

	(2)	(3)
	Managerial ability	GIE
ESG score	−0.019***	0.000***
	(−10.871)	(5.540)
Firm size	0.683***	0.001***
	(140.906)	(3.508)
Debt-to-asset ratio	0.341***	−0.000
	(14.662)	(−0.071)
Return on total assets	0.244***	−0.002
	(6.885)	(−1.183)
Operating revenue growth rate	0.000***	0.000
	(2.883)	(0.074)
Managerial ability		−0.001***
		(−3.375)
Constant	−12.919***	−0.014**
	(−122.632)	(−2.413)
N	29,055	29,055
R^2	0.505	0.003
F	5123.440	10.877

From Column (2) of Table 10, the regression coefficient between managerial ability and ESG performance is −0.019 and is significant at the 1% level, indicating that sound ESG performance is significantly and negatively associated with the level of managerial ability. On this basis, the mediating variable is introduced, and the mediating variable together with the independent variable are used to regress the dependent variable GIE simultaneously. The results are shown in Column (3) of Table 10: managerial ability is also negatively correlated with the dependent variable GIE at the 1% significance level, with a regression coefficient of −0.001, which indicates that a lower level of managerial ability is associated with a higher level of corporate green innovation efficiency. At this point, the core explanatory variable ESG performance is still significantly positively correlated with corporate green innovation efficiency, which is consistent with the conclusion obtained from model (1). It is therefore held that managerial ability indeed has a partial mediating effect between the two, which verifies Hypothesis 2, namely that managerial ability plays a partial mediating role between ESG performance and cor-

porate green innovation efficiency.

8. Conclusions and Recommendations

8.1. Research Conclusions

On the basis of existing research results, this paper sorts out a research framework for the effect of ESG performance on corporate green innovation efficiency, explores the mechanism through which ESG performance affects corporate green innovation efficiency, and selects relevant data of A-share listed companies on the Shanghai and Shenzhen stock exchanges over the period 2012-2022 for empirical testing. The main research conclusions are the following three. 1) ESG performance has a significant positive effect on corporate green innovation efficiency, and the conclusion still holds after a series of robustness tests. 2) The promotion of corporate green innovation efficiency by ESG performance exhibits a certain degree of regional, ownership, and industry heterogeneity; the effect differs considerably between firms in different regions and across different industries, and is specifically more obvious for firms in economically developed regions and for firms in non-heavily polluting industries. 3) The mechanism analysis reveals an additional channel: ESG performance is negatively associated with measured managerial ability, which is in turn negatively associated with corporate green innovation efficiency—a pattern consistent with ESG performance substituting for managerial ability in shaping green innovation efficiency.

8.2. Policy Recommendations

On the basis of the mechanism through which ESG performance affects corporate green innovation efficiency and the empirical conclusions of this study, and in combination with the mediating effect of managerial ability and the characteristics of corporate heterogeneity, the following targeted suggestions for corporate green and sustainable development are put forward from three aspects: strategic planning, differentiated implementation, and capacity building.

1) Improving the internal ESG governance mechanism of firms

Firms should incorporate the ESG system into their overall corporate strategic planning and set clear and quantifiable short-term and long-term goals. They should establish cross-departmental ESG innovation working groups to break down information barriers among R&D, production, marketing, and other links. For example, in new energy vehicle firms, the synergy between the ESG team and the battery R&D department can be promoted, transforming the goal of reducing carbon emissions into technical parameters for improving battery energy, and driving firms to carry out R&D on green technology projects in multiple dimensions such as material innovation and system optimisation.

In addition, an assessment system linking ESG performance with innovation incentives can be built, granting special awards to teams or individuals who contribute to the improvement of green processes and the R&D of low-carbon technologies, thereby strengthening the positive cycle of "ESG performance-innova-

tion efficiency".

2) Focusing on heterogeneity advantages and implementing differentiated paths for enhancing innovation

With regard to regional differentiation, firms in economically developed regions (the eastern region) should fully rely on the agglomeration effect of the universities, scientific research institutions, and industrial parks in the region to jointly build an innovation platform integrating government, industry, universities, research, and application, so as to accelerate the application of ESG-related technologies. Firms in the central and western regions, in contrast, should focus on local needs for green innovation, such as the R&D and application of water-saving technologies in the Yellow River Basin, and reduce innovation costs by taking over the transfer of green industries from the east, introducing mature technologies, and adapting them to local conditions.

With regard to ownership differentiation, state-owned enterprises should give full play to their advantages in policy response and resource integration, make key breakthroughs in "bottleneck" green technologies, and transform policy support into technological output capacity through measures such as taking the lead in setting up green innovation funds and organising R&D projects on generic industry technologies. Non-state-owned enterprises, by contrast, should sharpen their market acumen and build a green brand image, so that they can obtain a higher product premium and then invest these additional returns in new green innovation projects, forming a virtuous circle and continuously enhancing their competitiveness.

With regard to industry differentiation, heavily polluting industries (such as steel and chemicals) should take basic innovation as the entry point and give priority to end-of-pipe treatment technologies, such as ultra-low pollutant emission retrofitting and the resource utilisation of industrial solid waste, so as to improve the environmental performance of such firms through basic innovation and transformation while buying time for the innovative R&D of disruptive technologies. For non-heavily polluting industries, in contrast, the focus should be on value-added innovation, transforming ESG performance into an advantage in differentiated competition and using consumers' preference for green products to improve innovation efficiency, thus forming a virtuous circle of "market demand-innovation input-efficiency improvement".

3) Dynamically aligning ESG levels with the development of managerial capability

Firms should rationally allocate managerial resources according to their own ESG performance. The empirical results show that sound ESG performance is associated with a lower level of managerial ability and that managerial ability is negatively associated with corporate green innovation efficiency; managerial ability thus constitutes a channel through which ESG performance affects green innovation efficiency, and its role differs with firms' ESG levels. Firms should therefore dynamically adjust their allocation of managerial resources. For firms with excel-

lent ESG performance, it is suggested that they ensure the steady progress of corporate green innovation by improving relevant systems and processes; for example, they may transform existing mature green innovation processes into standardised operation manuals to form a "system-driven" innovation model, ensuring that green innovation efficiency can still improve steadily even if the management changes. For firms whose ESG performance needs improvement, in contrast, it is necessary to give full play to managers' subjective initiative, grant them autonomy in resource allocation, and encourage them to make up for ESG shortcomings through cross-boundary cooperation and other means, so as to lead the firm to achieve breakthrough progress in green innovation in the short term.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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