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ESG PERFORMANCE, NEW QUALITY PRODUCTIVITY, AND CORPORATE GREEN INNOVATION EFFICIENCY

ESG performance, new quality productivity, and corporate green innovation efficiency

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ABSTRACT

This study integrates ESG performance, new quality productivity, and enterprise green innovation efficiency into a cohesive framework, with the objective of examining the impact and mechanisms through which ESG performance influences enterprise green innovation efficiency. This study empirically investigates the relationship between ESG performance, new quality productivity, and the green innovation efficiency of A-share listed enterprises on the Shanghai and Shenzhen stock exchanges from 2013 to 2023. The analysis employs the system GMM model alongside the mechanism effect model. The research findings indicate that ESG performance can significantly improve the efficiency of green innovation within enterprises, a conclusion that remains valid following extensive robustness tests. Mechanism analysis demonstrates that ESG performance enhances the green innovation efficiency of enterprises by fostering the development of new quality productivity. Furthermore, heterogeneity analysis reveals that ESG performance exerts a more pronounced effect on the green innovation efficiency of enterprises located in the eastern region, as well as among non-state-owned enterprises, small enterprises, high-tech enterprises, and those operating in competitive industries. In light of this, it is proposed that innovative measures be adopted, including the enhancement of enterprises' ESG performance capabilities, the improvement of their mechanisms for developing new quality productivity, and the implementation of a "differentiated" green development strategy. These initiatives aim to comprehensively enhance the green innovation efficiency of enterprises.

Keywords: ESG performance, Corporate green innovation efficiency, New quality productivity, System GMM Model
JEL: Q55, O31, M14, L25

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ABSTRACT

Este estudo integra desempenho ESG, nova produtividade de qualidade e eficiência em inovação verde empresarial em um arcabouço coeso, com o objetivo de examinar o impacto e os mecanismos pelos quais o desempenho ESG influencia a eficiência da inovação verde empresarial. Este estudo investiga empiricamente a relação entre desempenho ESG, nova produtividade de qualidade e a eficiência de inovação verde das empresas listadas em A-share nas bolsas de valores de Xangai e Shenzhen entre 2013 e 2023. A análise utiliza o modelo GMM do sistema junto com o modelo de efeito do mecanismo. Os resultados da pesquisa indicam que o desempenho ESG pode melhorar significativamente a eficiência da inovação verde nas empresas, uma conclusão que permanece válida após extensos testes de robustez. A análise de mecanismos demonstra que o desempenho ESG aumenta a eficiência da inovação verde das empresas ao promover o desenvolvimento de nova produtividade de qualidade. Além disso, a análise de heterogeneidade revela que o desempenho ESG exerce um efeito mais pronunciado sobre a eficiência da inovação verde das empresas localizadas na região leste, bem como entre empresas não estatais, pequenas empresas, empresas de alta tecnologia e aquelas que atuam em setores competitivos. Diante disso, propõe-se que sejam adotadas medidas inovadoras, incluindo o aprimoramento das capacidades de desempenho ESG das empresas, a melhoria de seus mecanismos para desenvolver nova produtividade de qualidade e a implementação de uma estratégia de desenvolvimento verde "diferenciada". Essas iniciativas visam aprimorar de forma abrangente a eficiência da inovação verde das empresas.
Palavras-chave: Desempenho ESG, Eficiência corporativa de inovação verde, Nova produtividade de qualidade, Modelo de Sistema GMM

INTRODUCTION AND LITERATURE REVIEW

Compared to general innovation efficiency, improving green innovation efficiency not only reduces corporate environmental pollution but also maximizes enterprises' core market competitiveness, achieving a win-win outcome for both the ecological environment and economic growth. According to survey data from the Ministry of Industry and Information Technology, by the end of 2024, China had established 6,430 national-level green factories. The export delivery value of the environmental protection equipment manufacturing industry increased by 1.8% year-on-year, reaching 39.2 billion yuan, providing a solid foundation for enhancing corporate green innovation efficiency. However, at this stage, environmental pollution caused by the traditional high-energy-consuming and extensive development model [1, 2] has somewhat hindered the improvement of corporate green innovation efficiency. Therefore, in the face of the new wave of technological revolution, effectively improving corporate green innovation efficiency under the guidance of green, high-end, and intelligent-driven development has gradually become key to the steady advancement of China's green and low-carbon economy. In February 2024, seven ministries and commissions, including the Ministry of Industry and Information Technology, jointly issued the Guiding Opinions on Accelerating the Green Development of the Manufacturing Industry. These guidelines emphasize the need to "give full play to the leading role of chain master enterprises, assist small and medium-sized enterprises in the industrial chain in identifying shortcomings in green and low-carbon transformation, and organize technological transformation in a planned and phased manner," providing important institutional guidance for improving corporate green innovation efficiency in China. In summary, comprehensively enhancing corporate green innovation efficiency is of great significance for sustainable economic development.

As a crucial indicator of an enterprise's sustainable development, strong ESG performance can create new opportunities to enhance corporate green innovation efficiency. Firstly, ESG performance, characterized by high transparency, can effectively reduce information transmission barriers, expand channels for interaction and cooperation between enterprises and investors, lower transaction costs for external investors, and improve the transparency of internal corporate information [3]. This, in turn, enables investors to provide enterprises with abundant green resources, thereby boosting green innovation efficiency. Secondly, robust ESG performance can drive innovation in internal corporate governance, curb speculative behaviors by management, promote the gradual disclosure of information regarding environmental, social, and governance capabilities, and strengthen enterprises' environmental awareness. These factors collectively improve green innovation decision-making and enhance green innovation efficiency. Furthermore, strong ESG performance helps optimize an enterprise's market reputation and brand value, increasing recognition among consumers and investors [4]. This recognition encourages greater investment in green innovation, accelerates the development of new-quality productivity, attracts top talent, stimulates enthusiasm for green R&D, and significantly improves green innovation efficiency. Therefore, it is essential to objectively analyze the impact of ESG performance on corporate green innovation outcomes and to explore effective ways to leverage ESG performance to drive innovation in the context of new-quality productivity.

Currently, the academic community places great importance on the enabling effect of ESG performance on corporate green innovation and has conducted extensive research on the relationship between the two. Zhang et al. (2025) [5] found that ESG performance significantly promotes corporate green technological innovation. Liu et al. (2023) [6] demonstrated that ESG performance can enhance enterprises' green innovation capabilities, with corporate capital costs and financing constraints serving as important mediating factors. Qin (2024) [7] indicated that ESG performance significantly fosters both the quantity and quality of corporate green innovation, primarily by alleviating corporate financing constraints. Yao and Chen (2024) [8] found that divergence in ESG ratings can significantly improve the level of substantive green innovation in enterprises; however, this promoting effect is less pronounced in firms with high information transparency. Yu and Tang (2024) [9] showed that ESG performance significantly enhances corporate green technological innovation, with debt and equity financing costs playing key mechanistic roles in this relationship. Peng et al. (2024) [10] found that strong ESG performance significantly improves corporate green innovation efficiency, mainly through two channels: increasing enterprises' risk-taking capacity and strengthening their influence within the supply chain.

Essentially, the development of new-quality productivity can effectively promote the close integration of corporate production processes with digital technologies, continuously innovate corporate development models, and significantly enhance corporate green innovation efficiency. Based on this, some scholars have conducted in-depth research on the relationship between new-quality productivity and enterprises. Song and Lü (2024) [11] argued that new-quality productivity is a crucial driving force for state-owned enterprises to achieve high-quality development, and that the high-quality development of these enterprises is also fundamental to the rapid formation and sustainable growth of new-quality productivity. Huang and Wu (2025) [12] posited that new-quality productivity is an inherent requirement for high-quality development and a vital measure to realize Chinese-style modernization in the new era, offering broad development prospects for the green growth of private enterprises. These studies collectively indicate that new-quality productivity is a key support for corporate innovation, reflecting the correlation between new-quality productivity and corporate green innovation efficiency.

ESG performance, characterized by innovation and a long-term perspective, can effectively promote the transformation and upgrading of traditional industries, continuously expand emerging sectors, support the development of a modern industrial system driven by advanced manufacturing, and accelerate the formation of new-quality productivity. Currently, academic research on the relationship between ESG and new-quality productivity remains in its early exploratory stages. Song et al. (2024) [13] demonstrated that ESG development can significantly enhance enterprises' new-quality productivity, with a more pronounced effect observed in non-state-owned enterprises, real economy firms, and small, medium, and micro enterprises. Xiang and Zhang (2025) [14] argued that gradually integrating ESG concepts through five channels—green, innovation, openness, coordination, and sharing—can accelerate the creation of a new management environment that is highly conducive to the development of new-quality productivity, thereby maximizing the efficiency gains in enterprises' new-quality productivity.

A review of the existing literature reveals that the academic community has examined the relationships between ESG performance and corporate green innovation, new-quality productivity and enterprises, as well as ESG and new-quality productivity individually. However, few studies have integrated ESG performance, new-quality productivity, and corporate green innovation efficiency within a single framework for in-depth analysis. Compared to prior research, this paper offers two potential innovative contributions. First, by focusing on A-share listed companies in Shanghai and Shenzhen from 2010 to 2023, it incorporates ESG performance, new-quality productivity, and corporate green innovation efficiency into a unified framework to explore the impact and mechanisms of ESG performance on corporate green innovation efficiency, thereby addressing a research gap and expanding empirical research approaches. Second, from the perspectives of geographical location, ownership type, enterprise scale, and enterprise category, this study examines the heterogeneous effects of ESG performance on corporate green innovation efficiency, aiming to provide valuable insights for comprehensively enhancing enterprises' ESG capabilities and formulating differentiated corporate green innovation strategies tailored to local conditions.

1 THEORETICAL ANALYSIS AND RESEARCH HYPOTHESES

1.1 Direct effect of ESG performance on corporate green innovation efficiency

Green innovation efficiency is a crucial metric for assessing the level of corporate green innovation and serves as a key indicator for evaluating the quality of corporate economic development [15]. In the contemporary business environment, the significance of enterprises' Environmental, Social, and Governance (ESG) performance has become increasingly prominent, as it effectively influences corporate green innovation efficiency. First, from the perspective of information transmission theory, strong ESG performance enables enterprises to communicate their commitment to social responsibilities and environmental stewardship to external stakeholders. This enhances their reputation as socially responsible and low-carbon organizations, strengthens long-term and stable strategic relationships with external partners, reduces external risks associated with green innovation activities, and ultimately improves green innovation efficiency. Additionally, robust ESG performance facilitates the integration of external environmental factors with corporate information, increases transparency, addresses information

asymmetry among stakeholders [16], lowers the capital costs of green innovation initiatives, enhances research and development (R&D) capabilities in green innovation, and thereby boosts green innovation efficiency. Second, from the standpoint of employee commitment theory, effective ESG performance safeguards employees' legitimate rights and interests, strengthens internal cohesion and workforce competitiveness, and stimulates employees' enthusiasm for green technology R&D [17]. This fosters employees' low-carbon learning and green innovation capabilities, driving significant improvements in corporate green innovation efficiency. Furthermore, strong ESG performance helps create a positive working environment, cultivates a green and low-carbon organizational culture, enhances employees' sense of belonging and identity, and improves the enterprise's sustainable development capacity and market competitiveness in low-carbon sectors, thereby promoting overall green innovation efficiency. Third, from the perspective of cost-benefit theory, exemplary ESG performance fosters a strong corporate awareness of environmental protection and sustainable development. It continuously optimizes the R&D and commercialization processes of environmentally friendly technologies and products, elevates the level of green technological innovation [18], reduces production costs, and significantly enhances green innovation efficiency. Moreover, good ESG performance motivates corporate management teams to exercise diligent oversight, avoid short-sighted decisions [19], maintain a high level of attention to green innovation development, adopt more scientific and rational approaches to green innovation, reduce the costs associated with green production, and thereby promote improvements in green innovation efficiency. Based on the above analysis, the following Research Hypothesis 1 is proposed:

Hypothesis 1: ESG performance can significantly enhance the efficiency of corporate green innovation.

1.2 Mechanism of the effect of new-quality productivity

Good ESG performance can standardize enterprises' green operational activities, promote the advancement of enterprises' new-quality productivity, and indirectly enhance corporate green innovation efficiency. On one hand, strong ESG performance significantly improves the development level of new-quality productivity. It effectively motivates enterprises to reduce resource consumption and emissions [20], utilize green energy and environmentally friendly materials efficiently to achieve waste recycling, improve production efficiency and market competitiveness, and accelerate the formation of new-quality productivity. Additionally, good ESG performance helps optimize supply chain management systems, mitigate risks identified and managed from a responsibility perspective [21], foster an innovation-driven connotative growth model, continuously innovate production processes, align with the development requirement of "ensuring independent control, safety, and reliability of the industrial system," and thereby enhance new-quality productivity. On the other hand, the rapid development of new-quality productivity significantly improves corporate green innovation efficiency. First, it helps optimize the visual monitoring systems of production processes, enabling enterprises to promptly identify and address pollution issues, improve resource utilization efficiency [22], and achieve integrated green and environmental protection goals during production, thus enhancing green innovation efficiency. Second, it allows enterprises to better utilize virtual production prototypes for timely green simulation experiments, reduce product R&D and innovation costs [23], improve the accuracy and environmental sustainability of product design, realize green objectives throughout the product life cycle, and significantly boost corporate green innovation efficiency. Based on this analysis, the following Research Hypothesis 2 is proposed:

Hypothesis 2: ESG performance can enhance corporate green innovation efficiency by fostering the development of new quality productivity.

2 MODEL CONSTRUCTION AND VARIABLE SELECTION

2.1 Sample Selection and Data Sources

Following the principles of accessibility and comprehensiveness, A-share listed companies in Shanghai and Shenzhen from 2013 to 2023 were selected as research samples, resulting in a total of 21,894 observations. To enhance the accuracy of the research findings, the data were processed as follows: first, ST* and ST-listed

enterprises during the research period were excluded; second, financial and insurance companies were excluded; third, enterprises with missing variables or abnormal data were removed. Additionally, the basic information and financial data of the listed companies involved in the empirical research—including enterprise size, enterprise age, corporate capital expenditure, and corporate cash holdings—were obtained from the WIND and CSMAR databases. Relevant data on ESG performance were sourced from the Bloomberg database.

2.2 Variable Selection

Dependent Variable: Corporate Green Innovation Efficiency (GIE). As a crucial indicator for assessing the level and quality of corporate green innovation development, green innovation efficiency must consider not only resource and environmental constraints but also the efficiency of innovation inputs and outputs. Therefore, drawing on the methodologies of numerous scholars [24, 25], the two-stage SBM-DEA model is employed to measure corporate green innovation efficiency. This model divides efficiency into two stages: corporate green technology R&D efficiency and corporate green achievement transformation efficiency. The specific indicators for these two stages are as follows: In the corporate green technology R&D stage, input indicators primarily encompass two dimensions: human resources and capital. Human input is measured by the full-time equivalent of R&D personnel, while capital input is represented by the proportion of R&D expenditure within the low-carbon development expenditure for new products. Output indicators include the number of corporate green invention patents, the number of patent applications, and the number of new green product development projects. In the corporate green innovation achievement transformation stage, input indicators mainly consist of expenditures on low-carbon technology introduction and low-carbon technology transformation. Output indicators are categorized into expected and unexpected outputs. Expected outputs are represented by the proportion of sales revenue from new green products relative to the total corporate output value. Unexpected outputs include energy consumption per unit of GDP and pollutant emissions per unit of GDP. Notably, research indicators such as corporate solid waste, wastewater, waste gas, and industrial smoke and dust are all calculated using the entropy weight method to derive the final pollutant emission index. Reason: The revision improves clarity, coherence, and technical precision by restructuring sentences, enhancing vocabulary, and ensuring consistent terminology. It also corrects minor grammatical issues and improves readability by breaking up long sentences and clarifying the relationships between concepts.

Core Independent Variable: ESG Performance (ESG). ESG performance refers to an enterprise's social performance in environmental protection, social responsibility, and internal governance [26]. Following the research approach of Yan et al. (2025) [27], the authoritative comprehensive ESG evaluation score from the Bloomberg Database is used to quantify an enterprise's ESG performance. These scores range from 0 to 100, with higher scores indicating better ESG performance.

Mediating Variable: New-Quality Productivity (NQP). From a corporate perspective, new-quality productivity represents an advanced state of productive forces in which enterprises are driven by innovation and focus on upgrading labor objects, laborers, and means of labor. This approach gradually moves away from traditional economic growth models and development paths [28]. Based on the research frameworks of previous scholars [29, 30], an evaluation index system for new-quality productivity is constructed across three dimensions: new-quality labor objects, new-quality laborers, and new-quality means of labor (see Table 1). Additionally, the entropy weight method is employed to measure the development level of new-quality productivity.

Table 1 - Evaluation Index System for the Development Level of New-Quality Productivity (NQP)

First-level Indicators	Second-level Indicators	Third-level Indicators	Measurement Methods	Unit	Attribute
New-Quality Productivity (NQP)	New-Quality Laborers	Corporate Laborers' Capability	Number of Engineering and Technical Personnel in Enterprises	Persons	+
			Number of Students in Higher Education Institutions	10,000 persons	+
		Corporate Laborers' Productivity	Number of Technology Development Institutions in Enterprises	units	+
			Number of Annual Average Wage of Employees in Enterprises above Designated Size Nationwide	10,000 yuan	+
	New-Quality Means of Production	Corporate Material Means of Production	Area of Land Acquired by Enterprises	square meters	+
			Number of Enterprise Mobile Phone Users	10,000 persons	+
			Number of Websites per 100 Enterprises	units	+
		Corporate Intangible Means of Production	Number of patent applications by enterprises	pieces	+
			Enterprise technology activity expenditure amount	10,000 yuan	+
			Enterprise Technology Contract Transaction Amount	10,000 yuan	+
	New-Quality Objects of Labor	Emerging Enterprises	Number of corporate robots	sets	+
			Total Revenue of Software and Information Technology Service Enterprises	10,000 yuan	+
		Technology Enterprises	Growth rate of investment in high-tech enterprises	%	+
			Number of high-tech enterprises	10,000 units	+

Control Variables: To account for the influence of other factors on the efficiency of green innovation in enterprises, this study draws on the research of numerous scholars [31, 32] and focuses on variable control from both macro and micro perspectives. From a macro perspective, the level of regional economic development is measured by the natural logarithm of per capita regional GDP. Research and education investment is calculated as the proportion of regional education expenditure to the fiscal budget expenditure. The industrial structure is represented by the proportion of the output value of the secondary industry to the total regional output value. Government subsidies are measured by the ratio of local fiscal subsidies to GDP. From a micro perspective, enterprise size is represented by the natural logarithm of the total assets of the enterprise. The age of the enterprise is calculated as the difference between the observation year and the establishment year of the enterprise. Enterprise

capital expenditures are measured by the proportion of fixed, intangible, and other long-term assets purchased or constructed by the enterprise relative to total assets at the end of the year. Cash holdings are expressed as the proportion of total trading financial assets and monetary funds to total assets at the end of the year.

2.3 Model Specification

Considering the potential dynamic relationship between ESG performance and enterprises' green innovation efficiency, the one-period lag of the dependent variable (enterprises' green innovation efficiency) should be incorporated into the model. To address the endogeneity issue between the two variables, the system GMM method within a dynamic panel model is employed for estimation. The specific model is constructed as follows:

$$EGIE_{i,t} = \alpha_0 + \alpha_1 EGIE_{i,t-1} + \alpha_2 ESG_{i,t} + \alpha_3 X_{i,t} + \gamma_i + \phi_t + \varepsilon_{i,t} \quad (1)$$

In the above formula, i、t denote individual and time respectively, $EGIE_{i,t}$ represents the green innovation efficiency of enterprise i in period t; $EGIE_{i,t-1}$ represents the green innovation efficiency of enterprise i in period $t-1$; $ESG_{i,t}$ represents the ESG performance of enterprise i in period i; α_0 is the intercept term; X denotes the set of control variables; γ_i、ϕ_t denote individual and time fixed effects respectively, ε_{it} is the random disturbance term。

To conduct an in-depth investigation into the mechanisms underlying the relationship between ESG performance and enterprises' green innovation efficiency, the following mechanism effect models have been constructed:

$$EGIE_{i,t} = \delta_0 + \delta_1 EGIE_{i,t-1} + \delta_2 ESG_{i,t} + \delta_3 NQP_{i,t} + \delta_4 X_{i,t} + \gamma_i + \phi_t + \varepsilon_{i,t} \quad (2)$$

$$NQP_{i,t} = \beta_0 + \beta_1 NQP_{i,t-1} + \beta_2 ESG_{i,t} + \beta_3 X_{i,t} + \gamma_i + \phi_t + \varepsilon_{i,t} \quad (3)$$

In which, $NQP_{i,t}$ is the mediating variable the development level of new-quality productive forces of enterprise i in period t.The definitions of the remaining variables are basically consistent with those in Formula (1).

(3.4) Descriptive Statistics

Table 2 presents the descriptive statistics for all research variables. The maximum, minimum, and average values of enterprises' green innovation efficiency are 0.794, 0.251, and 0.485, respectively, indicating notable disparities in green innovation efficiency among enterprises across different regions of China at the current stage. For ESG performance, the maximum, minimum, and average values are 67.598, 4.254, and 38.145, respectively, demonstrating that the overall ESG performance of the sample enterprises is relatively low, with significant variation across regions. Regarding the mediating variable−new-quality productive forces−the maximum, minimum, and average values are 0.684, 0.285, and 0.427, respectively, suggesting that the development level of new-quality productive forces among enterprises in various Chinese regions is generally low, leaving considerable room for future improvement.

Table 2 - Descriptive Statistics and Variable Definitions

Variables		Sample Size	Mean	Std. Dev.	Max	Min
Explained Variable	*EGIE*	21894	0.485	0.052	0.794	0.251
Core Explanatory Variable	*ESG*	21894	38.145	0.145	67.598	4.254
Mediating Variable	*NQP*	21894	0.427	0.022	0.684	0.285
Control Variables	*PGDP*	21894	13.475	0.092	18.584	7.458
	ISRE	21894	0.496	0.039	0.821	0.147
	IS	21894	0.625	0.043	0.838	0.342
	SUB	21894	0.541	0.029	0.767	0.284
	SIZE	21894	9.638	0.094	14.856	4.596
	EA	21894	7.826	0.041	14.256	0.586
	EXP	21894	0.512	0.012	0.726	0.345
	CASH	21894	0.562	0.031	0.629	0.415

3 Empirical Test Analysis

3.1 Benchmark Regression Analysis

To enhance the robustness of the research conclusions, a comparative analysis was conducted using the pooled OLS, panel fixed effects, and system GMM models, with specific estimation results presented in Table 3. Column (1) displays the estimation results of the pooled OLS model without incorporating time and individual fixed effects. The estimated coefficient for the impact of ESG performance on enterprises' green innovation efficiency is 0.240, which is statistically significant at the 10% level. Column (2) reports the results of the panel fixed effects model after including time and individual fixed effects. These results indicate that ESG performance positively influences enterprises' green innovation efficiency, with significance at the 5% level. To address potential endogeneity issues, a dynamic panel regression model was employed, with results shown in Column (3). The estimated coefficients for both the core explanatory variable (ESG performance) and the lagged dependent variable are significantly positive at the 1% level. Additionally, the AR(2) test result is insignificant, supporting the null hypothesis of no second-order autocorrelation in the residuals. The Sargan test is also insignificant, confirming the validity of the instrumental variables used. These findings demonstrate that the choice of the system GMM model and estimation method is appropriate and rigorous. In summary, the following conclusions can be drawn from the regression results: First, ESG performance significantly promotes enterprises' green innovation efficiency, thereby validating Research Hypothesis 1. Second, comparing the pooled OLS, panel fixed effects, and system GMM models reveals that the estimated coefficient of ESG performance increases progressively, with improving levels of statistical significance. This suggests that ESG performance not only positively affects green innovation efficiency but also that its impact and promotional effect are substantially strengthened. Regarding the control variables, the estimated coefficients for regional economic development, investment in scientific research

and education, industrial structure, government subsidies, firm size, corporate capital expenditure, and corporate cash holdings are all significantly positive at the 1% level. This indicates that these factors significantly enhance enterprises' green technological innovation efficiency. The coefficient for firm age is positive but not statistically significant, suggesting that firm age does not have a meaningful impact on improving green technological innovation efficiency. Reason: The revision improves clarity, readability, and technical accuracy by refining sentence structure, ensuring consistent tense usage, and enhancing vocabulary. It corrects minor grammatical errors and awkward phrasing while preserving the original meaning and technical content. Additionally, statistical terminology and test interpretations are clarified for precision.

Table 3 - Benchmark Regression Results

Variables	Pooled OLS （1）	Panel Fixed Effect Model （2）	System GMM Model （3）
L.EGIE	0.289***	0.312***	0.682***
	（4.845）	（3.241）	（5.436）
ESG	0.240*	0.352**	0.595***
	（1.524）	（2.259）	（8.664）
PGDP	0.235***	0.341***	0.574***
	（5.017）	（4.014）	（4.031）
ISRE	0.337***	0.484**	0.417***
	（5.137）	（2.252）	（5.145）
IS	0.387***	0.481***	0.503***
	（2.274）	（4.086）	（6.139）
SUB	0.343**	0.318*	0.543***
	（2.237）	（1.839）	（5.071）
SIZE	0.541**	0.458***	0.497***
	（2.218）	（6.019）	（4.047）
EA	0.297	0.282	0.358
	（0.098）	（0.102）	（0.098）
EXP	0.415***	0.524***	0.635***
	（5.234）	（6.234）	（5.236）
CASH	0.315***	0.419***	0.518***
	（5.412）	（5.236）	（5.745）
AR（1）			0.831
AR（2）			0.834
Sargan test			0.938
Fixed Effect	NO	YES	YES

N	21894	21894	21894

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Values in parentheses are t-statistics. AR(1) and AR(2) denote the p-values of the first- and second-order autocorrelation tests, respectively. The Sargan test represents the p-value of the overidentification test.

3.2 Robustness Tests

Replacing the Measurement Method for Key Variables

First, to mitigate differences in industry peer effects, and following the research approach of Xiao Renqiao et al. (2025) [33], we use the number of enterprise green patent applications as a specific measure of enterprises' green innovation efficiency and conduct regression analysis accordingly. The results are presented in Column (1) of Table 4. It can be seen that the estimated coefficient of ESG performance is significantly positive at the 1% level. This indicates that, after replacing the measurement indicator of the dependent variable, ESG performance still significantly enhances enterprises' green innovation efficiency, thereby confirming the robustness of the aforementioned estimation conclusions.

Winsorization (1% Level)

To mitigate the impact of extreme values in each research variable, we re-ran the analysis after applying 1% Winsorization to all variables. The specific results are presented in Column (2) of Table 4. It can be observed that the estimated coefficient for ESG performance is positive and statistically significant at the 1% level, thereby fully supporting the conclusion that ESG performance significantly enhances enterprises' green innovation efficiency.

Table 4 - Robustness Tests

Variables	Replacing the Measurement Method of Key Variables （1）	Winsorization （2）
L.NGP	0.676*** （6.382）	
L.EGIE		0.584*** （5.368）
ESG	0.572*** （7.581）	0.581*** （8.351）
Control Variables	YES	YES
LMstatistic		
Pvalue		
WaldFstatistic		
AR（1）	0.007	0.052
AR（2）	0.605	0.705
Sargan test	0.149	0.345
Fixed Effect	YES	YES

N	21894	21894

3.3 Mechanism Analysis of New-Quality Productive Forces

Based on the aforementioned theoretical mechanism analysis, this paper uses new-quality productive forces as the mediating variable to conduct an in-depth investigation into the impact mechanism of ESG performance on enterprises' green innovation efficiency, with specific results presented in Table 5. First, we systematically estimate the model using Formula (1), and the results show that ESG performance has a significantly positive effect on enterprises' green innovation efficiency. Second, we empirically test the indirect impact of ESG performance on enterprises' green innovation efficiency using Formulas (2) and (3). In other words, by incorporating new-quality productive forces, we explore the intrinsic impact mechanism of ESG performance on enterprises' green innovation efficiency in detail; the specific test results are shown in Table 4. Notably, the estimated impact coefficient in Column (1) is 0.357, which is significant at the 1% level, indicating that ESG performance has a significantly positive effect on new-quality productive forces. Column (2) incorporates the mediating variable of new-quality productive forces based on the benchmark regression results. The results show that new-quality productive forces significantly improve enterprises' green innovation efficiency, and the estimated impact coefficient of ESG performance remains significantly positive at the 1% level, though slightly smaller than in the benchmark regression results. This fully confirms that ESG performance can enhance enterprises' green innovation efficiency by fostering the development of new-quality productive forces. Further analysis leads to the following conclusions: first, ESG performance has a significantly positive impact on new-quality productive forces; second, as a mediating variable through which ESG performance influences the improvement of enterprises' green innovation efficiency, new-quality productive forces exert a mediating effect. Therefore, ESG performance can drive the continuous improvement of enterprises' green innovation efficiency by promoting the development of new-quality productive forces, thereby fully verifying the aforementioned Research Hypothesis 2.

Table 5 - Mechanism Analysis of New Quality Productive Forces

Variables	*NQP*	*EGIE*
	（1）	（2）
L.NQP	0.864***	
	（7.099）	
L.EGIE		0.283***
		（6.124）
ESG	0.357***	0.562***
	（5.368）	（6.541）
Control Variables	YES	YES
NQP		0.485***
		（6.582）
AR（1）	0.002	0.000
AR（2）	0.852	0.265
Sargan test	0.268	0.845
Fixed Effect	YES	YES

N	21894	21894

3.4 Heterogeneity Analysis

Impact of Regional Heterogeneity

Given the differences in geographical location, historical policies, and resource endowments, the impact of ESG performance on enterprises' green innovation efficiency may vary across different regions of China. Accordingly, in accordance with the regional division standards of the National Bureau of Statistics of China, the 21,894 enterprise research samples nationwide are divided into four major regions: Eastern, Central, Western, and Northeast China. We test the impact of ESG performance on enterprises' green innovation efficiency in each region separately and analyze the empirical results based on the constraints faced by different regions. The specific regression results are presented in Table 6.

Analysis of the test results reveals that ESG performance has a significantly positive impact on enterprises' green innovation efficiency across all four regions, with significance confirmed at least at the 10% level. Moreover, notable regional differences exist in the impact of ESG performance: the promotional effect is strongest in Eastern China, followed by Central and Northeast China, and weakest in Western China. This may be attributed to Eastern China's faster economic growth rate and relatively higher adoption of green technologies, which can maximize improvements in ESG performance. Consequently, this further stimulates enterprises' enthusiasm for engaging in green technological innovation activities, thereby enhancing their green innovation efficiency.

Table 6 - Heterogeneity Analysis

Variables	Eastern China （1）	Central China （2）	Western China （3）	Northeast China （4）
L.EGIE	0.978*** （5.236）	0.584** （2.245）	0.347* （1.785）	0.485** （2.314）
ESG	0.647*** （8.235）	0.428*** （3.568）	0.216* （1.756）	0.362*** （3.698）
Control Variables	YES	YES	YES	YES
Constant Term	0.612*** （6.251）	0.538*** （5.214）	0.589*** （7.120）	0.485*** （6.741）
AR（1）	0.856	0.951	0.668	0.685
AR（2）	0.828	0.231	0.805	0.887
Sargan test	0.918	0.857	0.269	0.261
Fixed Effect	YES	YES	YES	YES
N	9850	5124	3987	2933

Impact of the Nature of Property Rights

To conduct an in-depth analysis of the impact of ESG performance on the green innovation efficiency of enterprises with different ownership types, the sample is divided into two groups—state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs)—in accordance with national property rights classification standards for empirical analysis. The results are presented in Columns (1) and (2) of Table 7. It is evident that the estimated

coefficients of ESG performance are significantly positive in both the SOE and non-SOE subsamples, indicating that ESG performance can significantly enhance the green innovation efficiency of both types of enterprises. Comparative analysis reveals that ESG performance has a stronger promotional effect on the green innovation efficiency of non-SOEs than on that of SOEs. This is because, compared with SOEs, non-SOEs can obtain more policy and financial support through good ESG performance, which helps them to overcome financing constraints more easily, stimulates the vitality of low-carbon factor capital allocation, and provides a fundamental guarantee for improving green innovation efficiency. Therefore, the promotional effect of ESG performance on the green innovation efficiency of non-SOEs is more pronounced.

Impact of Firm Size

To further investigate the impact of ESG performance on the green innovation efficiency of enterprises of varying sizes, the research samples were broadly categorized into two groups—large enterprises and small enterprises—based on the median annual total operating income. The comparative analysis results are presented in Columns (3) and (4) of Table 7. The findings indicate that the estimated coefficients for ESG performance are significantly positive, demonstrating that ESG performance substantially promotes green innovation efficiency in both large and small enterprises. A further comparison of the coefficient magnitudes and significance levels reveals that ESG performance has a more pronounced effect on the green innovation efficiency of small enterprises than on that of large enterprises. This is because small enterprises possess greater autonomy than large enterprises, enabling them to adjust their green governance decisions quickly and flexibly in response to environmental and social changes, thereby striving to improve the modern environmental governance system and enhance green innovation efficiency. Consequently, the effect of ESG performance on the green innovation efficiency of small enterprises is relatively more significant.

Impact of Enterprise Type

Considering that the impact of ESG performance on the green innovation efficiency of different types of enterprises may vary, and referring to the research approach of Ye Tanglin et al. (2025) [34], the research samples are divided into two categories—high-tech enterprises and non-high-tech enterprises—for comparative analysis. The specific estimation results are presented in Columns (5) and (6) of Table 7. It can be observed that the estimated coefficients of ESG performance are significantly positive, indicating that ESG performance can substantially improve the green innovation efficiency of both high-tech and non-high-tech enterprises. A comparative analysis of the coefficient magnitudes and significance levels reveals that ESG performance has a more pronounced promotional effect on the green innovation efficiency of high-tech enterprises than on that of non-high-tech enterprises. The primary reason is that the technology-oriented R&D activities undertaken by high-tech enterprises have longer cycles, making them more dependent on ESG performance. Therefore, strong ESG performance helps high-tech enterprises to quickly grasp changes in the market environment, enhance their green operational benefits, and thereby drive a significant improvement in green innovation efficiency.

Impact of Industry Competition Intensity

The intensity of industry competition has a discernible impact on the green innovation efficiency of enterprises. To conduct a thorough analysis of the effect of ESG performance on the green innovation efficiency of enterprises operating in industries with varying levels of competition, and following the research methodology of Zou Xiang and Jia Yongfei (2025) [35], the sample is divided into two categories: enterprises in competitive industries and those in monopolistic industries. The specific results are presented in Columns (7) and (8) of Table 7. It is evident that the estimated coefficients for ESG performance are significantly positive, indicating that ESG performance substantially enhances the green innovation efficiency of enterprises in both competitive and monopolistic industries. Further comparative analysis reveals that ESG performance has a more pronounced effect on improving the innovation quality of enterprises in competitive industries than those in monopolistic ones. This is because, in their efforts to compete for limited external resources, enterprises in competitive industries tend to mitigate information asymmetry between internal and external stakeholders, continuously improve their level of information disclosure, strengthen their capacity to maintain strong ESG performance, and effectively 164 standardize green R&D and innovation practices, thereby enhancing green innovation efficiency.

Table 7 - Heterogeneity Analysis

Variables	State-Owned Enterprises	non-State-Owned Enterprises	Large Enterprises	Small Enterprises	High-Tech Enterprises	Non-High-Tech Enterprises	Enterprises in Competitive Industries	Enterprises in Monopolistic Industries
	（1）	（2）	（3）	（4）	（5）	（6）	（7）	（8）
L.EGIE	0.385**	0.712***	0.347**	0.728***	0.694***	0.405*	0.718***	0.328*
	（2.296）	（7.528）	（2.235）	（9.512）	（5.412）	（1.896）	（8.521）	（1.925）
ESG	0.309***	0.574***	0.335**	0.571***	0.582***	0.276*	0.591***	0.315**
	（5.234）	（4.568）	（2.324）	（5.214）	（7.125）	（1.845）	（8.254）	（2.251）
Control Variables	YES	YES	YES	YES	YES	YES	YES	YES
AR（1）	0.856	0.897	0.585	0.668	0.759	0.661	0.958	0.864
AR（2）	0.254	0.821	0.757	0.805	0.615	0.526	0.832	0.681
Sargan test	0.881	0.954	0.242	0.269	0.965	0.825	0.854	0.769
Fixed Effect	YES	YES	YES	YES	YES	YES	YES	YES
N	6620	15274	9041	12853	9255	12639	8998	12896

CONCLUSION

Based on research samples from Shanghai and Shenzhen A-share listed enterprises between 2013 and 2023, this paper integrates ESG performance, new-quality productive forces, and enterprises' green innovation efficiency within a unified framework, conducting an in-depth analysis of the relationships among these factors from both theoretical and empirical perspectives. The main research findings are as follows: First, ESG performance significantly enhances enterprises' green innovation efficiency, a conclusion that remains robust after a series of tests. Second, the mechanism analysis reveals that ESG performance improves green innovation efficiency by fostering the development of new-quality productive forces. Third, heterogeneity analysis indicates that the positive impact of ESG performance on green innovation efficiency is more pronounced in enterprises located in Eastern China, non-state-owned enterprises, small enterprises, high-tech enterprises, and those operating in competitive industries.

Recommendations

Improve Enterprises' ESG Performance Capabilities

Empirical results demonstrate that ESG performance has a significant positive impact on enterprises' green innovation efficiency. Accordingly, relevant departments should actively enhance enterprises' ESG performance capabilities to boost their green innovation efficiency. Firstly, the state should prioritize research and development, as well as the application, of cutting-edge low-carbon technologies such as cloud computing, 3D modelling, and the Internet of Things (IoT) for communication. It should establish an ESG standards system that aligns with international benchmarks while reflecting Chinese characteristics, formulate specialized and green cutting-edge development standards, strengthen enterprises' competitive advantages in green and low-carbon technologies, improve their ESG performance capabilities, and thereby promote the enhancement of green innovation efficiency. Secondly, relevant R&D institutions should utilize modern information technologies, including big data and

artificial intelligence, to develop high-end new material transformation bases and green hydrogen low-carbon production facilities. This assists enterprises in swiftly identifying potential risks associated with green innovation activities, accelerating the enhancement of their ESG performance capabilities, continuously innovating green innovation management methods, and improving green innovation efficiency. Thirdly, relevant regulatory authorities should continue to strengthen the application of digital technology, upgrade the comprehensive supervision system for pollution emission management, establish and refine the corporate carbon emission information disclosure system, and develop a low-carbon integrated service model that combines human, material, and financial resources. These measures will enhance enterprises' ESG performance capabilities and significantly improve their green innovation efficiency.

Improving the Development Mechanism of Enterprises' New-Quality Productive Forces

Mechanism results indicate that ESG performance can enhance enterprises' green innovation efficiency by fostering the development of new-quality productive forces. Accordingly, relevant departments need to actively adapt to the trends of economic digitalization and intellectualization, continuously improve the development mechanisms of enterprises' new-quality productive forces, and provide a robust foundation for enhancing enterprises' green innovation efficiency. Firstly, local governments should prioritize the ESG strategic framework, promote close collaboration among enterprises, universities, and research institutes, and facilitate the efficient allocation of resources such as information, capital, and talent. They should continuously build green innovation consortia comprising new-quality enterprises, improve the development mechanisms of enterprises' new-quality productive forces, elevate the level of new-quality productive force development, optimize the low-carbon business environment for enterprises, and thereby promote improvements in their green innovation efficiency. Secondly, relevant departments should utilize advanced technologies such as 5G and enhanced computing power to improve enterprise production methods through "online intelligent identification plus offline comprehensive data". They should actively optimize and upgrade traditional industries, cultivate and expand emerging sectors, improve the development mechanisms of enterprises' new-quality productive forces, continuously enhance the green and low-carbon economic impact of enterprises, and thereby improve their green innovation efficiency. Third, relevant enterprises should actively implement ESG strategies, comprehensively considering multiple influencing factors such as corporate governance, the environment, and society in their investment decision-making processes. They should take the initiative to improve the development mechanisms of new-quality productive forces, promote the rapid growth of these forces within enterprises, and simultaneously enhance their green innovation efficiency.

Implement a Differentiated Green Development Strategy

The above research findings indicate that the impact of the digital economy on enterprises' green technological innovation may vary due to differences in region, property rights, scale, type, and industry. Therefore, enterprises in different regions and of different types should effectively implement a differentiated regional green development strategy and enhance their green innovation efficiency according to local conditions. Enterprises in the central, western, and northeastern regions should utilize digital technologies such as the Internet of Things (IoT) and artificial intelligence to improve the availability of internal digital low-carbon services, strengthen the comprehensive integration of green and low-carbon technologies into enterprises' production, governance, and service processes, and thereby improve their green innovation efficiency. State-owned enterprises should align with the national "dual carbon" strategy and the broader green development agenda, actively incorporating the concept of "green" transformation into their development pathways, achieving "carbon reduction" in production processes and "sustainability" in raw material utilization, and enhancing green innovation efficiency. Large enterprises should attract high-quality talent and market resources conducive to their green innovation activities, establish and improve supporting innovation service systems and guarantee mechanisms, and effectively enhance green innovation efficiency. Non-high-tech enterprises and those in monopolistic industries can, based on their actual development characteristics, employ cutting-edge information technologies such as detection and sensing, machine recognition, and big data analysis to build intelligent management and control cloud platforms, strictly supervise internal green and low-carbon production practices, effectively standardize pollution discharge standards, and improve green innovation efficiency.

Declaration of Interest Statement
All authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data Availability Statement
The basic information and financial data of listed companies involved in the empirical research—including enterprise size, enterprise age, capital expenditure, and cash holdings—are all sourced from the WIND and CSMAR databases. The relevant data on ESG performance are obtained from the Bloomberg database.
The code used for data analysis in this study is available from the corresponding author upon reasonable request. Email:546120611@qq.com.

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Ethical Statement
This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. The study has been reviewed by the Ethics Review Committee of Zhujiang College, South China Agricultural University. All participants provided informed consent before participation. Participants' privacy and confidentiality were safeguarded throughout the research process, and all data were collected and analyzed in compliance with ethical standards.

Disclosure
We declare that we have no known competing financial interests or personal relationships, no relevant financial or no financial interests to disclose.

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