

ESG Performance, New-Quality Productive Forces, and Corporate Carbon Emission Reduction

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Abstract

Drawing on data from Chinese A-share private listed enterprises covering the period 2011–2022, this research investigates the interrelationships between ESG performance, new-quality productive forces (NQF), and carbon emission reduction through the integrated application of dynamic threshold modeling, instrumental variable two-stage least squares (IV-2SLS), and the Generalized Method of Moments (GMM) approach. Benchmark regression results demonstrate that NQF exerts a suppressive effect on carbon emission growth. Notably, this inhibitory impact is more pronounced when a firm's ESG performance lies within the high-threshold interval compared to the low-threshold range. In other words, once a company's ESG performance surpasses the identified threshold value, it reinforces the carbon emission reduction effect of NQF. The findings of this study not only deepen the understanding of how the "technology-powered nation" strategy-epitomized by the development of NQF-influences carbon emissions but also offer theoretical underpinnings for enterprises aiming to enhance their ESG performance. Additionally, they provide actionable insights for local governments to improve environmental outcomes, capitalize on the development opportunities presented by NQF, and unlock new avenues for low-carbon development.

Keywords

Corporate ESG; New-Quality Productive Forces; Carbon Emission Reduction.

1. Introduction

The Report to the 19th National Congress of the Communist Party of China clearly endorsed the development concept that "lucid waters and lush mountains are invaluable assets," while further advancing environmental protection and the construction of ecological civilization. Currently, curbing carbon emissions and safeguarding the ecological environment stand as crucial pillars for China to promote the development of ecological civilization and ensure the successful achievement of the "dual carbon goals." In practical terms, remarkable advancements have been achieved in relevant fields: For one, the efficiency of energy and resource utilization has maintained a steady upward trajectory[11]. By 2021, the comprehensive energy consumption per unit product for key industries in China-such as iron and steel, electrolytic aluminum, cement clinker, and flat glass-had decreased by more than 9% compared with 2012. Meanwhile, the coal consumption per kilowatt-hour of thermal power units across the country dropped to 302.5 grams of standard coal, with both indicators reaching world-leading levels[13]. Second, green supply capacity has been significantly strengthened. Gigawatt-class hydraulic turbine generator units have been successfully commissioned and connected to the grid for power generation; the global market share of polysilicon, silicon wafers, batteries, and modules each exceeds 70%; and new energy vehicles have maintained the world's top position in production and sales for eight consecutive years. Third, the

integration of digitalization and green development has been progressively advanced, characterized by the accelerated convergence of digital technologies with the manufacturing sector. Specifically, the numerical control rate of key processes in critical industrial domains increased from 24.6% in 2012 to 55.3% in 2021. Concurrently, the energy consumption per 5G base station has been reduced by over 20% relative to the initial commercialization period[2]. Nevertheless, it is noteworthy that China's total energy consumption remains the highest globally, and its energy mix is still dominated by fossil fuels such as coal, rendering the carbon emission situation relatively severe. General Secretary published an important article titled "Developing New Quality Productive Forces Is an Inherent Requirement and Key Focus for Promoting High-Quality Development" in the 11th issue of Qiushi Magazine on June 1, 2024. This article further underscores that high-quality development must be guided by the theory of new quality productive forces. From the theoretical research perspective on new quality productive forces (NQF), the academic community has reached a broad consensus that NQF represents a qualitative leap beyond traditional productive forces, embodying the transformative evolution of productive forces from quantitative expansion to qualitative enhancement[27]. In essence, NQF is a scientific, technological, and green-oriented form of productive forces, whose core connotation hinges on the leapfrog development of key productive elements-including laborers, means of labor, and objects of labor-and the optimal integration of these elements[22]. In terms of its formative drivers, NQF originates from revolutionary technological breakthroughs, the innovative allocation of production factors, and the in-depth transformation and upgrading of industries, distinguished by inherent attributes of high technology, high efficiency, and high quality[23]. Regarding its realization pathways, scholars generally concur that fostering NQF necessitates reinforcing the guiding role of scientific and technological innovation, promoting industrial innovation and upgrading, cultivating interdisciplinary talents, and empowering the transition toward a green economy[25, 26].

From the empirical research perspective on new quality productive forces (NQF), three primary measurement approaches prevail in existing literature. These include word frequency statistical analysis leveraging the Word2Vec neural network model combined with Python web crawling technology; comprehensive index evaluation methods based on the entropy weight method[5, 8, 17]; and measurement frameworks that utilize total factor productivity as a proxy for the development level of NQF. Additionally, scholars have constructed diverse empirical models to explore two core research directions: on one hand, the impacts of contemporary hot topics such as artificial intelligence, digital inclusive finance, and corporate ESG performance on NQF; on the other hand, the effects of NQF on urban-rural integrated development, industrial structure upgrading, and green finance[5].

The ESG (Environmental, Social, and Governance) concept centers on enterprises' comprehensive performance in three dimensions: environmental protection, social responsibility fulfillment, and corporate governance. It advocates that enterprises should not only prioritize their own development and economic benefits but also emphasize green environmental protection, energy conservation, and carbon reduction, value human-centric development, and continuously optimize their governance mechanisms to achieve the sustainable development of both enterprises and society. Specifically, ESG encourages enterprises to engage in positive environmental initiatives, pursue green production, implement energy conservation and emission reduction measures, and adopt low-carbon development models to minimize negative impacts on the natural environment, thereby promoting ecological balance and long-term sustainability[13,14].

Given the high alignment between the ESG concept and the theoretical connotation of NQF, this study integrates corporate ESG performance, NQF, and carbon emission reduction into a unified analytical framework to examine how NQF influences carbon emissions under varying levels of

corporate ESG performance. The marginal contributions of this paper are potentially twofold: First, from a methodological standpoint, it employs a dynamic threshold effect model to investigate the relationship between NQF and carbon emissions, identifying a threshold nonlinearity characteristic and avoiding potential biases associated with simplistic linear assumptions. Second, in terms of research content, it analyzes the internal mechanisms through which NQF inhibits carbon emissions via two pathways (digital transformation and green innovation) and multiple indicators, effectively deepening the theoretical understanding of the nexus between NQF and carbon emissions.

2. Theoretical Analysis and Research Hypotheses

2.1. The Impact of New Quality Productive Forces on Carbon Emissions

New quality productive forces (NQF) denote an advanced form of productive forces centered on innovation, which breaks away from traditional economic growth models and the conventional development path of productive forces. Characterized by high technology, high efficiency, and high quality, NQF is inherently aligned with the new development philosophy[23]. Specifically, the "newness" of NQF is predominantly manifested in the emergence of new production factors and innovative modes of factor combination, while its "quality" is mainly reflected in a high-quality industrial foundation and sustainable development momentum.[20]. Faced with the severe challenge of global warming, Friedrich Engels stated in *Anti-Dühring*: "Men develop themselves in their environment and along with their environment[4]". This view on the relationship between humans and nature affirms their unity and inseparability. Therefore, China has put forward the "dual carbon" goals after assessing the situation, and reducing carbon emissions and promoting the green and low-carbon transformation of the economy have become important development directions. As an advanced form of productive forces congruent with the new-era development philosophy, new quality productive forces (NQF) demonstrate prominent "green-oriented" attributes. Leveraging the robust driving momentum of scientific and technological innovation, NQF can exert a substantial effect on enhancing production efficiency and energy utilization efficiency, thereby laying a solid foundational support for the attainment of the carbon neutrality target. This paper argues that new quality productive forces curb carbon emissions mainly through two pathways: enhancing enterprises' green innovation capabilities and promoting their digital transformation. On the other hand, they encourage enterprises to establish more scientific environmental assessment and management systems and implement low-carbon production models. Such management innovations can also improve enterprises' environmental management capabilities and resource utilization efficiency, thereby reducing carbon emission intensity[18].

Additionally, new quality productive forces (NQF) represent a technology-driven form of productive forces, with scientific and technological innovation as their core constituent element[23]. The societal advancement of NQF is inherently conducive to elevating the digital transformation level of enterprises, and this mechanism manifests through three specific channels: First, digital transformation can mitigate internal information asymmetry within enterprises, enhance information processing capabilities, and strengthen operational stability[11]. This, in turn, helps avoid frequent adjustments to business strategies, ensures the continuity of corporate R&D activities, and thereby facilitates the low-carbon transformation of enterprises. Second, digital transformation contributes to improving the transparency of corporate information, alleviating the information asymmetry between financial institutions (e.g., banks) and enterprises. This reduction in information frictions helps lower financing costs and ease financing constraints, ultimately providing crucial financial support for enterprises' low-carbon transformation and green development initiatives[19]. Third, the process of

corporate digital transformation involves technology absorption and technology spillover effects. The diffusion of digital technologies can promote the establishment of inter-enterprise information-sharing platforms and facilitate technological cooperation, which in turn enhances enterprises' green R&D capabilities. In light of the aforementioned theoretical and logical analysis, this study puts forward the following research hypotheses:

H1: The advancement of new quality productive forces (NQF) exerts a positive facilitation effect on enterprises' carbon emission reduction performance.

H2: New quality productive forces contribute to the reduction of carbon emissions by enhancing the level of corporate green innovation.

H3: New quality productive forces promote carbon emission reduction through advancing the digital transformation degree of enterprises.

2.2. The Role of Corporate ESG in the Process of New-Quality Productive Forces Curbing Carbon Emissions

The ESG concept originates from the Corporate Social Responsibility (CSR) theory, sustainable development theory, and economic externality theory. Its evolution and expansion reflect enterprises' comprehensive response strategies when facing social, environmental, and governance challenges[24]. Initially, CSR emphasized enterprises' responsibilities to society, covering aspects such as charitable donations, business ethics, and employee welfare. However, with the increasing prominence of global environmental issues and the emerging challenges in corporate governance, CSR has gradually evolved into the ESG concept, which integrates three dimensions-Environmental, Social, and Governance. It has now become a crucial consideration in corporate management and investment decision-making.

The ESG concept inherently embodies new-quality productive forces and represents the key elements essential for enterprises to achieve sustainable development.

First, from the Environmental dimension, ESG requires enterprises to proactively assume the responsibility of environmental protection, which is closely aligned with the green concept of new-quality productive forces. Enterprises need to take active measures to reduce their negative impact on the natural environment-through green R&D and innovation, optimized resource allocation, and the promotion of environmentally friendly production models-to contribute to carbon emission reduction. Such environmental awareness not only aligns with the pursuit of environmental sustainability in the ESG concept but also reflects the high emphasis on and integration of environmental friendliness in the production processes of new-quality productive forces[24].

Second, the Social dimension of ESG mandates enterprises to take the initiative in fulfilling social responsibilities, such as caring for employee welfare, supporting community development, and abiding by business ethics, with the goal of promoting social fairness and harmony. This requirement is highly consistent with the concept of harmonious coexistence with society advocated by new-quality productive forces.

Finally, the Governance dimension emphasizes that enterprises should establish a sound corporate governance structure to ensure transparency, legality, and compliance in their operations. This helps enterprises address various complex challenges and potential risks, thereby improving their operational efficiency and long-term market competitiveness. This concept closely echoes the integrity and comprehensiveness inherent in new-quality productive forces.

Building on existing literature, which has verified that new-quality productive forces (NQF) exert a linear inhibitory impact on carbon emissions [21,25], this study further considers the inherent alignment between the ESG concept and NQF. It is posited that when corporate ESG performance is incorporated as a threshold variable, the carbon emission reduction effect of

NQF may deviate from a simple linear pattern and exhibit nonlinear characteristics. Accordingly, the following research hypothesis is formulated:

H4: Corporate ESG performance plays a facilitative role in enhancing the carbon emission reduction effect of new-quality productive forces. Specifically, when ESG performance surpasses a certain threshold value, this promotional effect will be further amplified.

3. Model Construction and Variable Selection

3.1. Model Construction and Variable Design

3.1.1. Model Construction

Existing studies have confirmed the linear impact of New-Quality Productive Forces (NQPF) on carbon emission reduction. Further considering the potential non-linear nature of NQPF's inhibitory effect on carbon emissions, as well as the possible reverse causality between carbon neutrality performance, green finance development, and public environmental attention, this paper adopts the dynamic threshold effect model constructed by Kremer (2013)[18] et al. as the benchmark regression model for empirical testing. By integrating the traditional threshold effect model with the GMM model, this approach can effectively reveal the dynamic threshold relationship between variables and mitigate potential endogeneity issues in the model. The specific form is shown in Equation (1) below:

$$CE_{it} = \alpha + \beta_0 CE_{i,t-1} + \beta_1 NPF_{it} \times I(ESG_{it} \leq \gamma) + \beta_2 NPF_{it} \times I(ESG_{it} > \gamma) + \delta Z_{it} + \varepsilon_{it} \quad (1)$$

CE_{it} denotes the explained variable (carbon emissions); $CE_{i,t-1}$ is the first-order lag term of the explained variable; NPF_{it} represents the core explanatory variable (New-Quality Productive Forces); ESG_{it} is the threshold variable (public environmental attention); Z_{it} denotes the control variables, including firm size, firm age, asset-liability ratio (Lev), return on assets (Roa), free cash flow (Cashflow), fixed asset ratio (Fx), board size (Board), and operating growth rate (Growth); β_1 and β_2 respectively indicate the impact coefficients of ESG on carbon emissions when the firm-level threshold variable is below and above the threshold value γ . ε_{it} is the random error term; $I(\cdot)$ is an indicator function; γ is the threshold value of ESG.

3.2. Variable Design

3.2.1. Explained Variable

Carbon emissions (CE): Internationally recognized greenhouse gas (GHG) accounting methods mainly fall into three categories: The GHG Protocol stipulates that organizations shall cover three scopes when assessing and reporting GHG emissions: direct emissions (e.g., coal combustion, natural gas use), indirect energy-related emissions (e.g., purchased electricity, heat), and other indirect emissions (e.g., employee commuting, supply chains); The IPCC Guidelines for National Greenhouse Gas Inventories (2006) categorizes greenhouse gas (GHG) emissions into three distinct scopes: direct emissions (e.g., from coal combustion and natural gas utilization), indirect emissions (e.g., from purchased electricity and heat consumption), and life-cycle emissions. Furthermore, the ISO 14064 standard specifies that carbon dioxide emissions should be adjusted using the Global Warming Potential (GWP). Specifically, the quantified carbon dioxide emissions are calculated as the product of actual emission volumes and the GWP of carbon dioxide.

Building on this foundation, the National Development and Reform Commission (NDRC) has formulated a suite of guidelines governing the accounting and reporting of corporate greenhouse gas (GHG) emissions, which categorizes corporate carbon emissions into three distinct scopes:

Scope 1: Direct GHG emissions originating from sources owned or controlled by the enterprise, including combustion emissions from enterprise-owned or controlled boilers, furnaces, vehicles, and other equipment, as well as process emissions generated from chemical production activities involving owned or controlled process facilities; Scope 2: Indirect GHG emissions associated with the purchased electricity and heat consumed by the enterprise; Scope 3: Total indirect GHG emissions arising from all operational activities of the enterprise [2].

Considering the overlap between Scope 3 and Scopes 1 & 2 in accounting, this paper refers to the methods of Cui Yeguang (2014) [3] and Wang Hao (2022) [4] to calculate total corporate carbon emissions:

For enterprises that directly disclose annual direct carbon emissions, indirect carbon emissions, or total carbon emissions in their official reports, the disclosed data are adopted directly for this study.

For enterprises that do not explicitly disclose annual carbon emission figures, Scope 1 and Scope 2 emissions are calculated separately in accordance with the industry-specific Guidelines for Corporate Greenhouse Gas Emission Accounting and Reporting formulated by the National Development and Reform Commission (NDRC). Where both Scope 1 and Scope 2 emission data of an enterprise are obtainable through such calculations, the total carbon emissions are derived by summing these two categories of emissions.

3.2.2. Core Explanatory Variable

New-Quality Productive Forces (NQPF): Based on existing research, scholars mainly adopt two methods to measure NQPF: The first is constructing a comprehensive multi-dimensional evaluation index system and measuring it using the entropy weight method. In terms of index system construction: Song Jia (2024) [1] considers laborers and means of production as the most fundamental components of productive forces, thus measuring NQPF from two dimensions: labor force and means of production; Wang Yu [6] argues that NQPF is an advanced new form of productive forces formed by technological innovation and high-end industrial integration under the context of informatization and intellectualization, and therefore measures it from four aspects: innovation leadership, enterprise upgrading, production optimization, and sustainable development; Xiao Bo [8] argues that new-quality productive forces (NQPF) are essentially an innovative form of productive forces driven by technological innovation, which realizes pivotal and disruptive technological breakthroughs through the integration of digital technologies and emerging production factors. Based on this understanding, he constructs NQPF measurement indicators encompassing three dimensions: technological productive forces, green productive forces, and digital productive forces. The second measurement approach is word frequency statistical analysis. Chen Yulei [9] selects seed terms such as "advanced productive forces", "high technology", "high efficiency", and "high quality", and employs the Word2Vec neural network model to quantify the frequency of these seed words and their synonymous expressions in corporate annual reports. In addition, other scholars adopt Python web scraping technology to conduct word frequency statistics on the disclosure reports of listed companies and government work reports, thereby measuring the development level of NQPF (Wei Feng, 2024; Sun Ming, 2024 [10], [11]).

Given that the core connotation of new-quality productive forces (NQPF) resides in the qualitative evolution of laborers, means of production, objects of labor, and their optimal integration [12], and production tools constitute the most critical component of means of production, this study refers to the two-factor theory of productive forces and the methodological framework proposed by Song Jia (2024) [5] to construct a comprehensive evaluation system for NQPF. The specific indicator composition is presented in Table 1. Position of indicators is shown in Table 1.

Table 1. Composition of New-Quality Productive Forces (NQPF) Indicators

Dimension	Sub-Dimension	Indicator	Indicator Selection
Labor Force	Living Labor	Ratio of R&D personnel salaries	R&D Expenses - Salaries and Remunerations) / Operating Income
		Ratio of R&D personnel	Number of R&D Personnel / Total Number of Employees
		Ratio of highly educated personnel	Number of Personnel with Bachelor's Degree or Above / Total Number of Employees
	Dead Labor (Objects of Labor)	Ratio of fixed assets	Total Fixed Assets / Total Assets
		Ratio of manufacturing expenses	Manufacturing Expenses / Operating Income
Production Tools	Hard Technology	Ratio of R&D depreciation and amortization	R&D Expenses - Depreciation and Amortization) / Operating Income
		Ratio of Total R&D Expenses	R&D Expenses - Rental Expenses) / Operating Income
		Ratio of Total R&D Expenses	R&D Expenses - Direct R&D Investment) / Operating Income
		Ratio of intangible assets	Total Intangible Assets / Total Assets
	Soft Technology	Total asset turnover rate	Operating Income / Average Total Assets
		Reciprocal of equity multiplier	Total Assets / Total Equity

3.2.3. Threshold Variable

Corporate ESG Performance, This paper measures corporate performance using the China Securities Index (CSI) ESG Rating Database. The CSI ESG rating system covers three core dimensions: Environmental (E), Social (S), and Governance (G), with each dimension further divided into multiple secondary and tertiary indicators[10].

Environmental indicators mainly assess a company's performance in environmental protection, resource utilization, and climate change response; Social indicators focus on evaluating a company's efforts in employee welfare, social responsibility, and public relations; Governance indicators primarily measure a company's performance in corporate governance, internal control, and risk management [13]. Given that the CSI ESG ratings are quarterly data, this paper calculates the annual average to obtain an annual rating scored from 1 to 9. These scores correspond to nine rating grades ranging from "C" to "AAA", where a higher score indicates better corporate ESG performance.

3.2.4. Control Variables

Firm Size (Size): According to the economies of scale effect, as a firm's scale expands, its average cost decreases and economic efficiency improves. On one hand, lower average costs enable the firm to allocate more surplus funds to R&D and innovation of green technologies, thereby reducing carbon emissions. On the other hand, improved economic efficiency itself enhances energy utilization efficiency, which also contributes to lower carbon emissions. However, based on the diseconomies of scale effect, the expansion of firm scale may lead to higher energy consumption, thereby increasing carbon emissions. Therefore, this paper argues that firm size is a key variable affecting carbon emissions and thus introduces it as a control variable for empirical testing. Here, firm size is measured by the logarithm of total assets.

In addition, with reference to the research findings of Wei Hao (2022) [14] and other scholars, this study selects the following variables as control variables: firm age (Age), asset-liability ratio (Lev), return on assets (ROA), free cash flow (FCF), fixed asset ratio (FA), board size (BS), and operating growth rate (OGR). The specific composition of these indicators is displayed in Table 2.

Table 2. Variable Meanings and Composition Table

Variable Type	Variable Name	Symbol	Variable Composition
Explained Variable	Carbon Emissions	CE	Combustion and fugitive emissions + production process emissions + waste emissions + emissions from land use conversion (forest to industrial land)
Threshold Variable	Threshold Variable	Enterprise ESG Performance	Annual average of Huazheng ESG score
Key Explanatory Variable	New Quality Productivity	NPF	Comprehensive indicator of labor and production tools based on the entropy weight method
Control Variables	Enterprise Size	Size	Logarithm of total assets of the enterprise
	Enterprise Age	Age	Logarithm of (enterprise age + 1)
	Asset-Liability Ratio	Lev	Total liabilities / Total assets
	Return on Assets	Roa	Net profit / Total assets
	Free Cash Flow	Cashflow	Net cash flow from operating activities
	Fixed Asset Ratio	Fixed	Fixed assets / Total assets
	Board Size	Board	Logarithm of (number of board members + 1)
	Operating Growth Rate	Growth	Operating revenue growth amount / Current year's operating revenue

3.3. Data Selection and Descriptive Statistics

Table 3. Characteristic Values of Each Variable

Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
CE	35545	13.343	1.577	0.693	20.613
ESG	35545	4.128	1.076	1	8
NPF	35545	1.492	0.580	-3.229	6.690
Size	36798	22.166	1.563	14.942	31.310
Age	35769	7.702	8.669	-11	32
Lev	34623	0.442	0.912	-0.195	178.346
Roa	35851	0.040	0.192	-14.586	20.788
Cashflow	34277	18.630	1.931	7.909	26.410
Fixed	37521	0.199	0.159	0	0.971
Board	33589	8.190	1.530	0	18
Growth	35628	-1.774	1.291	-10.102	11.810

Considering data availability, this study selects data of Chinese listed companies spanning the period 2011–2022 as the research sample. After excluding enterprise observations with severe data deficiencies, a final sample of 4,117 private enterprise data points is obtained. Regarding data sources: The explained variable (carbon emissions,CE) is extracted from listed companies'

annual reports, social responsibility reports, and environmental, social, and governance (ESG) reports. Data for core explanatory variables, control variables, threshold variables, and mechanism variables are collected from the CSMAR database, China Statistical Yearbook, and Wind database. Descriptive statistical characteristics of all variables are presented in Table 4. As shown in the table: The mean value of new-quality productive forces (NQPF) development level among private enterprises is 1.492 with a standard deviation of 0.580; the mean value of carbon emissions (CE) is 13.343 with a standard deviation of 1.577; and the mean value of corporate ESG performance is 4.128 with a standard deviation of 1.076. These results indicate that significant disparities exist in ESG performance and carbon emissions across enterprises, whereas the variation in NQPF development levels among sample enterprises is relatively moderate.

4. Empirical Tests and Result Analysis

4.1. Benchmark Model Regression

This study employs the dynamic panel threshold effect model (Equation 1) to empirically examine the relational mechanism among ESG performance, new-quality productive forces (NQPF), and carbon emission reduction, with regression results presented in Table 5. As indicated in the table, the threshold value of the threshold variable (ESG performance) is 4.000, and the model passes the single-threshold test-this confirms that the inhibitory effect of NQPF on carbon emissions exhibits a threshold-based nonlinear characteristic. Both in the low-threshold interval ($ESG \leq 4.000$) and high-threshold interval ($ESG > 4.000$), the regression coefficient of NQPF on carbon emissions is significantly negative. This finding verifies that NQPF can indeed exert a suppressive effect on total carbon emissions, thus providing empirical support for Hypothesis 1. Detailed results are shown in Table 5.

Table 4. Regression Results of the Benchmark Model

Variable	Parameter Estimate	Standard Deviation	z-value	P-value	95% Confidence Interval
L1.CE	-0.1037	0.1096	-0.9500	0.3440	[-0.3185, 0.1111]
NPF($ESG \leq 1.1100$)	-2.4923**	1.2705	-1.96 00	0.0500	[-4.9825, -0.0020]
NPF($ESG > 1.1100$)	-7.9615***	1.6704	-4.7700	0.0000	[-11.2354, -4.6877]
cons	-106.9752				
N	35545				
Wald	510.1400				
Threshold Value	4.0000				

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

In terms of the magnitude and significance level of the regression coefficients, the coefficient of new-quality productive forces (NQPF) on carbon emissions in the low-threshold interval (-2.4923) is smaller than that in the high-threshold interval (-7.9615), and its significance level (5%) is also lower than the 1% significance level observed in the high-threshold interval. This result indicates that the inhibitory effect of NQPF on carbon emissions follows the law of increasing marginal effects. Specifically, when corporate ESG performance exceeds the threshold value (4.000), the suppressive effect of NQPF development on carbon emissions is significantly enhanced, thereby providing empirical validation for Hypothesis 4. The underlying mechanism lies in the inherent consistency between the ESG concept and the core attributes of NQPF: the ESG framework emphasizes enterprises' performance in environmental protection,

social responsibility fulfillment, and corporate governance optimization, which aligns with NQPF's pursuit of high quality, high efficiency, and high technology. Additionally, the improvement of corporate ESG performance helps accelerate the transformation and upgrading of advanced productive forces. This synergistic effect between ESG and NQPF enables the carbon emission reduction effect of NQPF to be substantially amplified when corporate ESG performance crosses the specified threshold.

4.2. Robustness Tests

To ensure the robustness of the benchmark regression results, the following robustness tests are conducted:

4.2.1. Endogeneity Test

To mitigate endogeneity issues arising from sample selection bias, omitted variables, and reverse causality, this study employs the two-stage least squares instrumental variable method (IV-2SLS) for endogeneity testing. Drawing on the instrumental variable selection logic proposed by Pan Hongyu (2024) [15], the ratio of R&D investment to operating income is adopted as the instrumental variable, and the rationality of this selection is justified by two core conditions: First, new-quality productive forces (NQPF) essentially originate from the cross-integration and breakthrough innovation of technological progress, and R&D investment intensity directly affects the development level of the core explanatory variable (NQPF), which satisfies the relevance requirement for instrumental variable selection. Second, the ratio of R&D investment to operating income exerts no direct impact on the explained variable (carbon emissions), thus meeting the exogeneity requirement for instrumental variable selection. Test results are presented in Column (1) of Table 6. The regression coefficient of NQPF on carbon emissions is significantly negative at the 1% significance level, indicating that after addressing endogeneity issues, NQPF still exerts a significant inhibitory effect on carbon emissions. Furthermore, the F-statistic is significant at the 1% level, which confirms that the selected instrumental variable avoids the problems of underidentification and weak instruments.

4.2.2. Changing Empirical Methods

Table 5. Endogeneity Test and GMM Regression Results

Variable	(1) IV-2SLS	(2) System GMM	(3) Difference GMM
L1.CE		0.3176***	0.1129**
NPF	-0.1386***	-0.0817***	-0.1175**
AR(1)		0.0000	0.0000
AR(2)		0.6090	0.1280
Sargen			0.1130
Hansen		0.4270	
N	35545	35545	35545
Wald	37452.4700***		
F test	187.6000***		
cons	-7.8443***		
Control Variables	YES	YES	YES
Individual Effects	YES	YES	YES
Time Effects	YES	YES	YES

From the linear analytical perspective of the conventional dynamic panel data model, this study employs the system generalized method of moments (System GMM) and difference generalized method of moments (Difference GMM) for robustness testing. Specifically, the first-order and second-order lags of the core explanatory variable-new-quality productive forces (NQPF)-are

selected as instrumental variables, respectively. The test results are presented in Columns (2) and (3) of Table 5. The regression results indicate that the impact coefficients of NQPF on carbon emissions are -0.0817 and -0.1175, which are statistically significant at the 1% and 5% levels, respectively. This finding demonstrates that even after altering the empirical methodology, NQPF still exerts a significant inhibitory effect on carbon emissions, which is consistent with the conclusions derived from the benchmark regression model. Furthermore, diagnostic test results for the two GMM models show that the p-values of the AR(1) tests are both less than 0.1, while the p-values of the AR(2) tests are greater than 0.1-indicating that there is no first-order or second-order serial correlation in the random disturbance terms. Additionally, the p-value of the Hansen test for the System GMM model and the p-value of the Sargan test for the Difference GMM model are both greater than 0.1, which confirms that the selected instrumental variables do not suffer from the problem of overidentification, thereby validating the reliability of the regression results.

4.3. Changing the Measurement Method of the Key Explanatory Variable

Given that new productive forces are fueled by revolutionary technological breakthroughs, innovative allocation of production factors, and in-depth industrial transformation and upgrading-with the enhancement of total factor productivity as their core hallmark-this study adopts the measurement approach proposed by Xu Hao (2024) [7], using corporate total factor productivity as a proxy for new productive forces. Currently, the primary methodologies employed in academic circles to measure corporate total factor productivity include ordinary least squares (OLS), fixed effects (FE), the LP method (Levinsohn and Petrin, 2003) [16], and the OP method (Olley and Pakes, 1996) [17]. In this research, total factor productivity calculated via these four methods is utilized as a substitute for new productive forces to conduct robustness tests. Due to space constraints, only the results derived from the ordinary least squares method are presented, specifically detailed in Column (1) of Table 6.

4.4. Adjusting Control Variables

4.4.1. Replacement of Control Variable Measurement Methods

Considering the similarity or equivalence of indicator attributes among alternative variables, this study modifies the measurement methodologies of three control variables: return on assets (ROA) is replaced by return on equity (ROE), which is calculated as net profit divided by total shareholders' equity; free cash flow (FCF) is substituted with the operating cash flow ratio, defined as net cash flow from operating activities relative to total assets; and the operating growth rate (OGR) is replaced by the absolute value of operating income growth.

4.4.2. Addition of Supplementary Control Variables

To mitigate potential estimation biases arising from omitted variables, this study sequentially incorporates three additional control variables into the original regression framework: Tobin's Q (measured as the ratio of enterprise market value to asset replacement cost), R&D investment intensity (quantified as the capitalized amount of R&D expenditures), and the largest shareholder's ownership ratio (calculated as the proportion of shares held by the largest shareholder relative to the total share capital of the enterprise). Due to space constraints, Table 6 only reports the robustness test results for two representative scenarios in Columns (2) and (3): one involving the replacement of ROA with ROE, and the other involving the simultaneous inclusion of the three aforementioned supplementary control variables.

4.5. Changing the Data Sample

First, changing the sample time length: robustness tests are conducted using data samples from 2012-2022, 2013-2022, and 2011-2021, respectively. Second, changing the number of sample individuals: tests are conducted by randomly selecting 99%, 97%, and 95% of the samples

without replacement, respectively. Third, excluding listed companies with abnormal financial conditions or other conditions, that is, excluding ST or PT enterprises for testing. Due to space limitations, only the robustness test results of the 2013-2022 sample, randomly selecting 97% of the samples without replacement, and excluding ST or PT enterprises are shown.

The robustness test results displayed in Columns (1) to (6) of Table 7 demonstrate that across both the high-threshold and low-threshold intervals of the threshold variable (corporate ESG performance), the parameter estimates of the core explanatory variable (new productive forces) on the dependent variable (carbon emissions) are consistently negative and statistically significant at no less than the 10% level. This confirms that the advancement of new productive forces can effectively curb the escalation of carbon emissions. Moreover, a cross-comparison of the new productive forces coefficients between the two threshold regions reveals that the coefficients in the low-threshold segment are uniformly smaller than those in the high-threshold segment. This implies that as public environmental attention intensifies and surpasses the threshold value, the facilitative effect of green finance on carbon neutrality performance will experience a decline. As a result, excessively high levels of public attention are not conducive to fully unleashing the promotional role of green finance in driving carbon neutrality. In conclusion, there exists an optimal scope of public attention that enables the promotional effect of green finance on carbon neutrality performance to reach its maximum. These robustness test findings are consistent with the outcomes of the benchmark model regression, thereby verifying the reliability and stability of the benchmark regression results.

Table 6. Other Robustness Test Results

CE	(1)	(2)	(3)	(4)	(5)	(6)
L1. CE	0.2312***	-0.1053	1.0028***	-0.0750	0.3649***	0.0970
NPF (ESG ≤ 4.000)	-8.7354**	-2.4338*		-2.3374***	-6.2651**	-1.5436**
NPF (ESG > 4.000)	-8.7399***	-7.9019***		-4.1837***	-14.9179***	-3.67945***
NPF (ESG ≤ 4.250)			-2.0702***			
NPF (ESG > 4.250)			-3.4958***			
cons	1.8539	-111.4311	-210.9950*	-370.8098***	-473.9289***	-217.5038***
N	35545	35545	35545	34478	29860	34693
Wald test	76.9400***	512.8300***	1065.5200***	1013.3900***	81.8500***	1204.4500***
Threshold Value	4.0000	4.0000	4.2500	4.0000	4.000	4.000
Control Variables	YES	YES	YES	YES	YES	YES

5. Conclusion and Policy Recommendations

5.1. Research Conclusion

This study takes 2011–2022 data of Chinese A-share private listed companies as the research sample, and adopts a combined empirical approach integrating dynamic threshold model, instrumental variable two-stage least squares (IV-2SLS) and generalized method of moments (GMM) models to explore the interactive mechanism among ESG performance, new-quality productive forces (NQPF) and carbon emission reduction. The core research findings are summarized as follows:

Benchmark regression results show that the development of NQPF exerts a significant inhibitory effect on carbon emissions, and this negative regulatory effect presents a nonlinear characteristic. Specifically, corporate ESG performance acts as a key moderating factor: the higher the level of corporate ESG performance, the more prominent the inhibitory effect of NQPF on carbon emissions. When corporate ESG performance exceeds a specific threshold value, the carbon emission reduction effect of NQPF is significantly enhanced; compared with

the low ESG threshold interval, the inhibitory effect of NQPF on carbon emissions is more remarkable in the high ESG threshold interval.

5.2. Policy Recommendations

5.2.1. Accelerate Technological Innovation to Bolster the Inherent Momentum of New Productive Forces Development

To promote the high-quality development of new-quality productive forces (NQPF), it is imperative to prioritize technological innovation as the core driving force. Essentially, NQPF is predominantly underpinned by disruptive technological breakthroughs, where innovation acts as the fundamental cornerstone for spawning emerging industries, innovative business models, and new growth engines. As such, efforts should be intensified to advance technological innovation, with a particular focus on original and disruptive innovations, to expedite the attainment of high-level technological self-reliance and independence. Beyond fostering innovation, translating technological achievements into tangible productive capacity is equally critical. This process manifests in nurturing emerging industries and driving profound transformation and upgrading across existing sectors. It is crucial to promptly embed cutting-edge technological achievements into specific industries and industrial chains. Specifically, efforts should be directed toward advancing the modernization of traditional industries, expanding the scale of emerging industries, deploying and fostering future-oriented industries, and comprehensively optimizing the modern industrial system.

Notably, new productive forces are inherently aligned with green development, a fundamental attribute of high-quality growth. To support the goals of carbon peaking and carbon neutrality, accelerating the green transition of development models is non-negotiable. Additionally, in line with the demands of cultivating new productive forces, it is necessary to unblock the positive cycle connecting education, science and technology, and talent. This involves optimizing mechanisms for talent cultivation, recruitment, utilization, and rational mobility to ensure a steady supply of skilled personnel that underpins sustained innovation and development.

5.2.2. Inject ESG Concept into Ecological Environment Greenization to Release the Potential for the Development of New Productive Forces

The connotation of the ESG concept is highly consistent with the modernization goals of green development, sustainable development, and high-quality development. First, enterprises should increase investment in natural resources and natural assets, strengthen investment in ecological construction such as afforestation, ecological restoration, and biodiversity protection, consolidate the country's natural capital strength, and provide a sustainable natural material foundation for the development of new productive forces. Second, enterprises should augment investment in green science and technology, accelerate technological innovation in the ecological environment field, and promote technological breakthroughs in green energy-related sectors, thereby providing sustainable technological impetus for the development of new-quality productive forces (NQPF). Third, enterprises ought to increase capital input in green industries, with targeted investments in green manufacturing, green service industries, green energy industries, and other related fields. This approach aims to cultivate new growth pillars and lay a solid and sustainable industrial foundation for the advancement of NQPF. Fourth, the government should expand investment in public infrastructure such as ecological environment infrastructure, drive the growth of green employment, and consolidate the achievements of ecological poverty alleviation. These measures will collectively provide a stable and sustainable socio-economic underpinning for the development of NQPF.

5.2.3. Introduce Enterprise Compliance Self-inspection and New Productive Forces Development Planning Policies in Light of Local Conditions[25]

The results of the heterogeneity test show that the effect of new productive forces on inhibiting carbon emissions varies in regions with different geographical locations and comprehensive endowments. Therefore, when the government explores the experience of new productive forces and carbon emissions, it should fully combine regional endowments and factor characteristics, and introduce enterprise compliance self-inspection and new productive forces development planning policies suitable for local development in light of local conditions, so as to give full play to the promoting effect of corporate ESG performance on the carbon emission inhibition effect of new productive forces. Specifically, while promoting the development of new productive forces, it is necessary to consider the differences in factor bases, systems, and policies among various regions and industries, and continue to explore scientific regional environmental governance models; strengthen international cooperation, actively promote the green transformation of high-pollution and high-energy-consuming industries, narrow the technological innovation gap among regions and industries, and improve China's environmental performance level.

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