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The Impact of Market-Incentivized Environmental Regulation on Green Innovation in Energy Enterprises

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Abstract: Against the backdrop of the "dual carbon" goals and the green transformation of the energy industry, whether market-incentivized environmental regulation can effectively promote green innovation in energy enterprises has become a key issue. This paper takes listed energy companies on the Shanghai and Shenzhen A-share markets from 2012 to 2022 as the sample, and based on data such as pollutant discharge fee amounts, empirically examines the impact of market-incentivized environmental regulation on green innovation in energy enterprises and its regional heterogeneity. The findings reveal that market-incentivized environmental regulation significantly promotes green innovation in energy enterprises overall, verifying the applicability of the Porter Hypothesis in the energy industry. This promotional effect is significant in non-coastal regions but not significant in coastal regions, reflecting differences in regional economic development stages, market maturity, and policy coordination capabilities. Accordingly, this paper proposes policy recommendations including regionally differentiated policy design, strengthening foundational support in non-coastal areas, and deepening market mechanism coordination in coastal areas, providing empirical evidence and policy references for optimizing environmental regulation policies and promoting the green transformation of energy enterprises.

Keywords: Market-based Environmental Regulation; Green Innovation of Energy Enterprises

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Introduction

In the context of deepening global climate governance and the continuous advancement of ecological civilization construction, energy enterprises, as foundational industries characterized by high pollution and high energy consumption, are facing an urgent need to transition towards green, low-carbon, intensive, and high-quality development. Achieving the "dual carbon" goals requires the construction of a clean, low-carbon modern energy system, which has spurred increasingly stringent and diversified environmental regulation policies[1]. Among these, market-incentivized environmental regulations, represented by emissions trading, green technology subsidies, and environmental taxes, are becoming core components of the policy toolkit. The essence of such tools lies in internalizing external environmental costs through price transmission mechanisms, providing economic incentives or penalties for corporate production activities to achieve pollution reduction. Their core characteristic is that they attempt to convey clear green development guidance signals and economic incentives to high-emission, high-energy-consumption energy enterprises by altering market factor prices and competition rules, thereby influencing their resource allocation and innovation decisions.

However, amidst this deep transformation process in the energy industry, a core and insufficiently answered key question is: Can current market-incentivized environmental regulation effectively promote green innovation in energy enterprises? More importantly, are there significant differences in this promotional effect under different contexts? Observations from reality add complexity to this inquiry: as the intensity of such regulations increases, green innovation activities in some energy enterprises are effectively stimulated, while others respond slowly or even experience innovation stagnation. This divergence forces us to confront a core question: Is the net effect of market-incentivized environmental regulation on green innovation in energy enterprises a powerful driving force, or does it vary depending on conditions?

Clarifying this fundamental issue is not only crucial for the applicability of environmental regulation theory in the context of energy transition but also directly determines whether policy design can be precisely targeted to effectively guide this key industry in breaking through green innovation bottlenecks, ultimately serving the realization of the national "dual carbon" strategic goals.

1. Mechanism Analysis and Hypothesis Development

1.1 Market-Incentivized Environmental Regulation and Corporate Green Innovation

The core of market-incentivized environmental regulation lies in its incentive compatibility attribute. It internalizes environmental costs into corporate decision-making variables through economic levers, guiding enterprises to optimize their environmental behavior. More importantly, market-incentivized environmental regulation itself is a powerful policy signal, conveying to enterprises the government's determination for green transformation and the core value orientation of environmental performance, reshaping enterprises' long-term expectations and strategic priorities for green innovation, and stimulating endogenous motivation. According to the Porter Hypothesis, appropriately designed environmental regulations can stimulate corporate green technology innovation through innovation compensation effects, enhancing long-term competitiveness. Therefore, market-incentivized environmental regulation is expected to become an important driving force for green innovation in energy enterprises. Accordingly, the following hypothesis is proposed:

H1: Market-incentivized environmental regulation has a significant promotional effect on green innovation in energy enterprises.

2. Research Design

2.1 Sample Selection and Data Sources

This study takes listed companies in the energy industry on the Shanghai and Shenzhen A-share markets from 2012 to 2022 as the initial sample, constructing an empirical analysis framework incorporating multi-source data. The specific data collection and processing procedures are as follows: Green patent application data originates from the CNRDS patent database. The market-incentivized environmental regulation indicator is constructed by quantifying relevant policy provisions from the China Environmental Statistics Yearbook, China Industry Statistics Yearbook, China Environment Yearbook, and China Tax Yearbook. To ensure data quality, the following screening procedures were applied sequentially: (1) Excluding companies with ST and *ST special treatment status to eliminate interference from abnormal operations; (2) Removing observations with missing data or extreme outliers in control variables. After the above processing, 1,141 valid observations were obtained.

2.2 Variable Definitions

This study uses Green Innovation (GI) as the dependent variable. Following mainstream research paradigms[2,3], it is measured using the natural logarithm of one plus the number of green patent applications filed by the enterprise. This indicator is based on the CNRDS patent database, which comprehensively covers the application and authorization information of green patents for Chinese listed companies. Green patents require meeting high technological R&D thresholds and can objectively reflect the comprehensive innovation achievements of enterprises in product performance improvement and green technology breakthroughs, ensuring the stability and reliability of the data source.

The core explanatory variable focuses on Market-Incentivized Environmental Regulation (ERI). Its quantification method follows the design of Wu Lei et al.[4], using the amount of pollutant discharge fee levied as a proxy variable.

Drawing on existing research, the control variables selected in this paper are: Board Size (BDS), Proportion of Independent

Directors (IDP), Supervisory Board Size (SBS), Book-to-Market Ratio (BM), Price-to-Book Ratio (PB), and Firm Age (Age). The variable definitions are shown in Table 1

Table 1: Variable Definitions

Variable Name	Symbol	Variable Definition
Green Innovation	GL	Natural logarithm of one plus the number of enterprise green patent applications
Market-Incentivized Environmental Regulation	ERI	Natural logarithm of the pollutant discharge fee amount
Board Size	BDS	Natural logarithm of one plus the total number of board members
Proportion of Independent Directors	IDP	Proportion of external directors not involved in company operations on the board
Supervisory Board Size	SBS	Natural logarithm of one plus the number of supervisory board members overseeing management
Book-to-Market Ratio	BM	Ratio of company book value to market value
Price-to-Book Ratio	PB	Ratio of stock price per share to net assets per share
Firm Age	Age	Time span since the company's registration and establishment

3. Empirical Analysis

3.1 Descriptive Statistics

The descriptive statistics for the main variables show that the mean of GL is 0.709, which is significantly greater than the median of 0, with a minimum of 0 and a maximum of 6.922, indicating that the green innovation capability of most energy enterprises is below the average level and that there is a large internal disparity in green innovation capability among energy enterprises. The mean of market-incentivized environmental regulation is 2.06, with a median of 2.017, indicating that nearly half of the energy enterprises face relatively large pollutant discharge fees or environmental tax amounts. The maximum value of institutional shareholding ratio is 0.987 and the minimum is 0, indicating a large disparity in institutional shareholding ratios among energy enterprises.

Table 2: Descriptive Statistics

VarName	Obs	Mean	SD	Median	Min	Max
GL	1141	0.709	1.077	0.000	0.000	6.922
ERI	1141	2.060	0.676	2.017	0.251	3.608
BDS	1141	2.303	0.202	2.303	1.386	2.944
IDP	1141	37.008	4.779	35.290	25.000	66.670
SBS	1141	1.561	0.257	1.386	0.693	2.485
BM	1141	0.707	0.246	0.713	0.064	1.288
PB	1141	3.651	15.024	2.208	0.476	324.161
Age	1141	2.873	0.319	2.890	1.386	3.611

3.2 Regression Analysis

3.2.1 Model Specification

To analyze the impact of market-incentivized environmental regulation on green innovation in energy enterprises, this paper constructs the following two-way fixed effects model:

$$GL=\beta_0+\varphi ERI_{it}+\gamma X_{it}+\alpha_i+\delta_t+\varepsilon_{it} \quad (1)$$

Where ERI represents market-incentivized environmental regulation, GL represents green innovation in energy enterprises, X represents the control variables;andrepresent individual and time fixed effects, is the random error term, i denotes province, and t denotes year.

3.2.2 Direct Effect Analysis

To verify the direct effect of market-incentivized environmental regulation on green innovation in energy enterprises, a direct effect analysis was conducted. The results show that in Model 1, which does not include control variables, the regression coefficient for market-incentivized environmental regulation (ERI) is positive at the 5% significance level, indicating that for each unit increase in market-incentivized environmental regulation, green innovation in energy enterprises increases by 0.206 units. Model 2 presents the regression results after adding control variables, where the impact of market-incentivized environmental regulation on green innovation in energy enterprises remains positive. Hypothesis H1, that market-incentivized environmental regulation has a significant promotional effect on green innovation in energy enterprises, is supported.

Table 3: Baseline Regression Results

	(1)	(2)
	GL	**GL**
ERI	0.206**	0.215**
	[2.37]	[2.47]
BDS		1.174***
		[4.25]
IDP		0.0197**
		[2.58]
SBS		0.157
		[0.58]
BM		-0.0112
		[-0.08]
PB		-0.00180
		[-0.40]
Age		0.637
		[1.41]
Individual Fixed Effects	0.286	-5.231***
Time Fixed Effects	[1.59]	[-3.34]
N	1114	1114
R^2	0.710	0.717

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

3.2.3 Robustness Tests

(1) Using Lagged Explanatory Variables. Market-incentivized environmental regulation may have a lagged effect on green innovation in energy enterprises. Therefore, this paper lags the explanatory variable by one and two periods and performs regression analysis separately, as detailed in columns (1) and (2) of Table 4. The coefficients for ERI lagged by one and two periods are both positive at the 5% significance level. The results indicate that market-incentivized environmental regulation has a significant promotional effect on green innovation in energy enterprises, consistent with the baseline regression results, confirming the robustness of the findings.

(2) Sample Data Screening. Extreme values may affect the baseline regression results. Therefore, the sample was winsorized at 1% and 5% levels, and the regressions were re-run, as shown in columns (3) and (4) of Table 4. After excluding extreme values, the regression coefficient for ERI remains significantly positive at the 5% level, consistent with the baseline regression results.

Table 4: Robustness Test

	(1)	(2)	(3)	(4)
	GL	**GL**	**GL**	**GL**
L.ERI	0.258**			
	[2.54]			
L2.ERI		0.310**		
		[2.38]		
L.GL				
ERI			0.205**	0.194**
			[2.32]	[2.23]
BDS	1.287***	1.401***	1.158***	1.253***
	[3.86]	[3.86]	[4.17]	[4.85]
IDP	0.0219**	0.0222**	0.0177**	0.0216**
	[2.40]	[2.19]	[2.10]	[2.39]
SBS	0.125	0.190	-0.0791	0.0227
	[0.41]	[0.58]	[-0.25]	[0.07]
BM	-0.0850	0.0201	-0.116	-0.164
	[-0.46]	[0.09]	[-0.64]	[-0.87]
PB	-0.00286	-0.00376	-0.0207	-0.0269
	[-0.28]	[-0.59]	[-1.03]	[-1.05]
Age	0.562	0.993	1.237**	0.883**
	[0.92]	[1.20]	[2.36]	[2.08]
Individual Fixed Effects	Yes	Yes	Yes	Yes
Time Fixed Effects	Yes	Yes	Yes	Yes
N	909	758	1114	1114
R^2	0.720	0.682	0.690	0.642

3.2.4 Heterogeneity Test

Coastal vs. Non-Coastal Regions

Due to differences in environmental policies and economic development across regions, the influence mechanism on green innovation in energy enterprises also exhibits certain regional characteristics. Based on this, this paper further divides the sample into coastal and non-coastal regions to explore the differences in regional effects. Coastal regions include Tianjin, Hebei, Liaoning, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, and Guangdong; the remaining areas are classified as non-coastal regions. See Table 5, where column (1) shows coastal regions and column (2) shows non-coastal regions.

Table 5: Heterogeneity Test

	(1)	(2)
	GL	GL
ERI	0.0782	0.371***
	[0.69]	[2.72]
BDS	1.614***	0.380
	[4.75]	[0.86]
IDP	0.0306**	0.00726
	[2.49]	[0.67]
SBS	-0.0178	0.423
	[-0.05]	[1.14]
BM	-0.257	0.0643
	[-0.89]	[0.34]
PB	-0.0223	0.000188
	[-0.85]	[0.04]
Age	-1.874	0.857*
	[-1.61]	[1.70]
N	404	710
R^2	0.643	0.748

The insignificant impact of market-incentivized environmental regulation on green innovation in energy enterprises in coastal regions may stem from the particularities of their economic structure and policy environment. On one hand, coastal regions underwent industrial upgrades earlier, and energy enterprises already possess certain green technology reserves, leaving limited marginal incentive space for policy. On the other hand, market mechanisms in coastal regions are mature, and enterprises face diverse external pressures, diluting the policy signals of environmental regulation. Additionally, coastal enterprises have ample R&D resources and a tendency towards risk aversion, making them less sensitive to short-term policy fluctuations and more reliant on long-term technological accumulation rather than immediate policy responses, further weakening statistical significance.

The significant effect in non-coastal regions is closely related to regional latecomer advantages and policy gaps, meaning market-incentivized environmental regulation yields policy dividends for them. Non-coastal energy enterprises typically have lower technological starting points and stronger path dependence. Market-incentivized policies directly break the “high pollution - low cost” equilibrium, creating significant expectations for innovation returns. Simultaneously, local governments in non-coastal areas often strengthen policy coordination through targeted support, lowering the barriers to enterprise transformation. Coupled with less competitive pressure in the region, policy signals become a core trigger for innovation, and enterprises can more easily achieve green catching-up through rapid application of mature technologies, making the policy effects significantly evident both statistically and practically.

4. Research Conclusions

This paper takes listed energy companies on the Shanghai and Shenzhen A-share markets from 2012 to 2022 as the research sample, empirically examines the direct impact of market-incentivized environmental regulation on green innovation in energy enterprises, and focuses on the heterogeneous effects between coastal and non-coastal regions. The findings are as follows:

First, market-incentivized environmental regulation has a significantly positive overall promotional effect on green innovation in energy enterprises, verifying the applicability of the Porter Hypothesis in the energy industry. Market-incentivized tools internalize environmental costs through price signals, effectively stimulating the green innovation vitality of enterprises, exhibiting a "policy dividend" attribute.

Second, the innovation-promoting effect of market-incentivized environmental regulation exhibits significant regional heterogeneity: in non-coastal regions, the regulation has a significant driving effect on green innovation in energy enterprises; while in coastal regions, this promotional effect is not significant. This difference reflects the profound influence of factors such as regional economic development stage, market maturity, and policy coordination capacity on the transmission efficiency of regulation. Non-coastal regions, leveraging policy gaps and latecomer advantages, see regulatory signals as a core driver of innovation. Coastal regions, due to earlier green technology reserves and mature market mechanisms, experience a relatively weaker marginal incentive effect from regulation.

4.1 Policy Recommendations

Based on the above conclusions, this paper proposes the following policy recommendations:

At the government level: A system for precise, regionally differentiated policy implementation should be established to fully release the innovation dividends of market-incentivized environmental regulation.

First, for non-coastal regions, strengthen foundational transformation support. Non-coastal regions are the main arena where market-incentivized environmental regulation exerts its innovation-promoting effect. Governments should increase green technology subsidies, build regional common technology R&D platforms, and promote the rapid diffusion and application of mature green technologies within the region. Simultaneously, improve the green finance infrastructure, lower the financing threshold for corporate green innovation, and assist non-coastal energy enterprises in achieving "green catching-up."

Second, for coastal regions, deepen market mechanism and policy coordination. The marginal effect of market-incentivized environmental regulation in coastal regions is weakening. The policy focus should shift from "incremental incentives" to "activating existing stock." On the one hand, deepen the construction of the carbon finance market, using methods like carbon allowance auctions and carbon derivative product innovation to provide sustained economic incentives for enterprises already possessing green technology reserves. On the other hand, strengthen environmental information disclosure requirements, promote the implementation of ESG investment concepts, and guide capital markets to form differentiated pricing based on corporate green performance, forcing enterprises to continuously optimize their environmental performance.

Third, establish a mechanism for inter-regional policy coordination and experience sharing. Encourage cross-regional cooperation between coastal and non-coastal regions in areas such as green technology, management experience, and policy tools, leveraging the technology spillover effects of coastal regions to enhance the overall green innovation capability of non-coastal regions.

At the enterprise level: Enterprises should proactively identify and respond to policy signals, integrating green innovation into long-term strategic planning. Enterprises in non-coastal regions should fully utilize the policy dividend period, accelerate the introduction of green technologies and independent R&D, and seize the first-mover advantage in transformation. Enterprises in coastal regions, based on their existing technological reserves, need to continuously optimize environmental performance, proactively engage with carbon markets and green finance tools, and transform environmental compliance capabilities into competitive market advantages.

4.2 Limitations and Future Outlook

This study has the following limitations: First, the sample mainly focuses on listed energy enterprises, with insufficient coverage of small, medium, and non-listed enterprises. Future research could expand the sample scope to enhance the generalizability of the conclusions. Second, it only considers market-incentivized environmental regulation as a single dimension, without incorporating command-and-control regulation, public participation regulation, or their interactive effects. Subsequent research could construct a multi-dimensional environmental regulation framework to compare the driving mechanisms of different policy combinations. Furthermore, the analysis of regional heterogeneity only divides regions into coastal and non-coastal categories. Future research could refine this further to the provincial or urban agglomeration level to

explore the impact of more micro-level regional characteristics on policy effects.

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Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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