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Original Research

Impacts of Heterogenous Environmental Regulations on Green Innovation of New Energy Firms: Empirical Evidence from China

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Abstract

As a strategic emerging industry, the new energy industry can promote green and low-carbon development. While the impact of environmental regulations on green innovation has been widely discussed, the underlying mechanism of heterogeneous environmental regulations affecting green innovation in new energy companies has not yet attracted attention. The dataset of this study covers the panel data of A-share new energy companies listed in Shanghai and Shenzhen from 2012 to 2020. The two-way fixed-effect model is used to draw the conclusion that command-and-control environmental regulation(CCR) and market investment-oriented environmental regulation(MIR) promote the green innovation of new energy firms. Compared with CCR, MIR exerts a stronger and more significant incentive impact on the green innovation of firms. Besides, firms' investment in R&D has a partial mediation effect between CCR and green innovation, and firms' production cost has a partial mediation effect between MIR and green innovation. Furthermore, through the heterogeneity test of firms, the results indicate that both types of environmental regulations substantially encourage the green innovation of large-scale and state-owned firms. Therefore, the government should give full play to the incentive effects of environmental regulations, select environmental regulation tools scientifically and formulate the optimal combination of environmental regulations.

Keywords: environmental regulations, green innovation, mediation effect, two-way fixed-effect model

Introduction

In recent years, environmental sustainability has become the most urgent issue in global economic development [1, 2]. Against globalization and integration, all countries are actively groping their ways of sustainable development. Since China ushered in the new era, its economy has shifted from high-speed to high-quality growth. The extensive economic development mode, featured by high input, high consumption and low output, would prejudice the ecological environment and hinder the sustainable development of China's economy [3], so it is not suitable for China's economic development any more. China's

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Energy Development in the New Era, issued by the State Council in 2022, states: "In the face of increasingly severe global issues, China has established the concept of human community with a shared future, and will promote the comprehensive transformation of economic and social green development. While promoting clean and low-carbon energy development at home, China will take an active part in global energy governance and work with other countries to speed up the promotion of global energy's sustainable development." China's energy development strategy greatly influences global energy and environmental conditions [4, 5].

New energy is characterized by low environmental pollution, abundant resource reserves and high recyclability [6]. Thus a growing number of countries have launched new energy development strategies to promote the development of new energy and transform the energy structure [4]. China boasts the most prosperous wind power, hydropower and solar energy resources, making it a natural place to drive a revolution in green energy technology. Since 2010, China's new energy industry has been developing rapidly [7]. In particular, its competitiveness in wind power and photovoltaic industries has been significantly improved. The proportion of photovoltaic modules, wind turbines, gearboxes and other critical components in the global market has increased to 70%. In China, wind and photovoltaic power have also become the primary sources of newly-installed power generation equipment and newly-increased generation capacity, accounting for over 78% and 55%, respectively, in 2022. The cumulative installed capacity has exceeded 700 million kW. China has formed the world's largest market and user of new energy.

The key to the rapid development of China's new energy industry and its firm foothold in the market in a short period lies in the continuous green innovation of various firms in the industry. Green innovation is also known as ecological, environmental, or sustainable innovation [8]. There is no clear definition of green innovation in academia. Based on the studies of scholars, green innovation is defined in this paper as firms carrying out innovation activities for the purpose of environmental protection and improving their products, crafts, technology or systems to reduce pollution, control emissions, save energy, and recycle waste to ultimately achieve the goal of environmentally sustainable development [9-12]. Green innovation can not only encourage firms to reduce pollution and use resources effectively, but also accelerate the transformation of production mode, improve production efficiency and firm competitiveness [13, 14]. In addition, green innovation plays a vital role in achieving energy efficiency, environmentally sustainable and green development in the world [15-17].

However, green innovation has double externalities [9, 18]. Apart from the spillover effect from innovation itself, external environmental costs will also cause externality, which means green innovation of firms will reduce their negative impacts on the external environment and positively impact society. However, firms cannot get corresponding returns when they bring benefits to the external environment, and the externality cannot achieve Pareto optimality, which results in inefficient of optimal allocation of resources [19, 20]. Therefore, it is difficult for firms to maintain their enthusiasm for green innovation only through market regulation. Government intervention is needed to address the externality to ensure firms continuously provide green products or services through innovation [1, 21, 22]. Environmental regulations are an effective tool for government intervention. Eiadat et al. define government environmental regulation as a set of characteristics for government environmental policies aimed at mitigating a firm's impact on the natural environment and creating a context where a firm will engage in environmental innovation [23]. At present, China's environmental governance has reached a critical moment. Standard regulatory tools include environmental tax, sewage charge, environmental administrative penalties, and investment in pollution control [24, 25].

The new energy firms are an important driving force for China's green and low-carbon development, as well as an important subject for China to build a market-oriented green technology innovation system, which can achieve a balance between environmental performance and innovation development. As a typical green technology firm, new energy firms are an important indicator of the level of green innovation in a country or region, and their green innovation performance should be more widely and deeply explored. Strict environmental regulations can ensure firms' motivation for green innovation [26, 27], but there is little direct evidence to prove that environmental regulation has a positive effect on green innovation in new energy enterprises. Therefore, this paper attempts to reveal this potentially important mechanism and clarify the relationship between environmental regulation and green innovation in new energy enterprises by taking new energy enterprises as the research object. Scholars generally divide formal environmental regulations promulgated by government into government-based and market-based [28-31]. Nevertheless, the definitions of market-based environmental regulations in existent literature are broad, with the result that the market-based environmental regulations are further refined into market-investment-based environmental regulations in this paper. Based on this, we study how the command-and-control and market investment-oriented environmental regulations affect the green innovation of new energy firms. Moreover, this paper further analyses the influencing mechanism of the two types of environmental regulations from different perspectives and their different impacts on the green innovation of firms of different scales and ownership. This study has important theoretical and practical significance for promoting pollution control and environmental protection at the level of green innovation, and thus for building a low-carbon and safe energy system and driving green development.

The rest of this paper is divided into the following sections: Section 2 is about literature review and theoretical analysis, Section 3 presents the research data and methods, Section 4 includes baseline regression and robustness testing, Section 5 further explores the mediation effects and heterogeneity analysis, and the conclusions and policy recommendations are summarized in Section 6.

Literature Review and Theoretical Hypothesis

Literature Review

Regarding the impacts of environmental regulations on firm innovation, in the short term, the neoclassical school of economists believe that environmental regulations would inhibit the innovation capacity of firms and lower their productivity and competitiveness, which is called the "compliance cost effect". On the one hand, environmental regulations could increase the pressure on firms to govern the environment and lead to additional production costs [26, 32]. On the other hand, with limited funds, firms might lose the opportunity to invest in other profitable projects to comply with laws and regulations, resulting in opportunity costs [29, 33]. Some scholars uphold this view. For example, based on the British manufacturing industry research object, Kneller and Manderson find that environmental regulations have no positive effect on total R&D [34]. Wu et al. find that Governmental Direct Environmental Regulations (GDER) hurt innovation investment [35]. Moreover, Tang et al. find that Command-and-Control Regulations (CCR), represented by China's eleventh Five-Year Plan environmental regulation, would inhibit the efficiency of firms' green innovation [36].

However, in the medium and long term, Porter et al. [37, 38] believe that appropriate environmental regulations could encourage firms to carry out more innovative activities, improve their productivity, and offset the extra costs brought by environmental protection, namely the "innovation compensation effect". That opinion is known as the "Porter Hypothesis" and has been accepted in different industries of different countries [39-43]. Some other scholars study the impacts of different environmental regulations on green innovation. For instance, Wang et al. take Chinese A-share companies listed from 2010 to 2019 as examples and find that both command-oriented and market-oriented environmental regulations could stimulate firms to carry out green technology innovation [44]. Based on the panel data of Chinese high-tech firms from 2012 to 2017, Sun et al. discover that compared with command-and-control environmental regulations, market-incentive and voluntary environmental regulations played a more significant role in stimulating firm innovation [45]. Zhang et al. take city of Xi'an (China) as a case study. The result shows that market-based and voluntary environmental regulations are more effective than command-and-control environmental regulations in stimulating green innovation [46]. Fang et al. adopt the spatial Durbin model and conclude that market-incentive environmental regulations could promote regional green technology innovation. In contrast, command-and-control environmental regulations would suppress regional green technology innovation [47]. Through questionnaire surveys, Peng et al. discover that compared with incentive-based environmental regulations, the control-based environmental regulations have a more significant impact on the intention of green innovation [48]. In addition to the compliance cost and innovation compensation effects, some scholars conduct the research from a dynamic perspective. It is found that there is a "U" shaped relationship between environmental regulations and firm innovation [26, 49, 50].

Aside from studies on the direct impacts of environmental regulations on firms' green innovation, a few scholars hold different views on the influencing mechanism of environmental regulations. Sun et al. take innovation input as a mediation variable to study the influence of heterogeneous environmental regulations on technology innovation [45]. Zhong et al. find that environmental responsibility mediates the impacts of environmental regulations on firms' green innovation [51]. Zhang et al. explore how command-and-control and market-based environmental regulations influence green product and process innovation through external knowledge [52]. Zhu et al. deem that environmental regulations could indirectly influence the technological innovation of China's iron and steel firms through human capital effect, enterprise size effect, profit margin effect and executive environmental awareness effect [25]. It can be seen that different scholars have different views on the mediating variables affecting the relationship between environmental regulation and firms' green innovation.

In conclusion, the results of the existing studies on the relationship between environmental regulations and firms' green innovation have been relatively mature, but there are several shortcomings. Firstly, based on different research subjects, measurement methods and data selection, the evaluation of the incentive effects of different types of environmental regulations on green innovation varies greatly, and uniform conclusions have not yet been obtained and need to be further developed. Secondly, most of the existing literature focuses on manufacturing firms or heavily polluting firms, and little literature takes new energy firms as research objects. As new energy firms are advanced manufacturing clusters with the task of green and low-carbon innovation, the impact of environmental regulation on green innovation in new energy firms should be given some academic attention. Finally, most existing literature studies the direct effect of environmental regulations on firms' green innovation. Only a few studies focus on the mediation effect, and in particular, there is a paucity of studies that include firm R&D investment and firm production costs as mediating variables.

Based on this, this paper has the following marginal contributions: (1) In terms of research objects, this paper focuses on the green innovation capacity of new energy firms, and aims to provide the necessary empirical evidence to complement the previous literature. (2) In terms of influencing mechanisms, the R&D investment and production cost of firms are introduced as the mediation variables of command-and-control and market investment-oriented environmental regulations, respectively, in this paper to study how two different types of environmental regulations indirectly affect green innovation of new energy firms through different mechanisms. (3) Regarding model selection, the panel two-way fixed model is first selected in this research, and the dummy variables of year and industrial characteristics are added. Then, considering constrained dependent variables, the panel Tobit is selected for testing. Finally, considering the problem of endogeneity, the 2SLS model is selected for testing to ensure the robustness of the conclusions in this paper.

Theoretical Hypothesis

The command-and-control environmental regulations refer to laws, regulations, policies and systems formulated by legislation or administrative departments that aim to manage polluters by administrative means directly and require their emissions to meet a certain standard [52]. The government has taken strict environmental measures to impose administrative penalties on firms' pollution behavior and limit their pollutant emissions, so the measures are highly binding [36]. New energy firms usually pay sewage charge in response to stringent regulations [53]. However, that is only a stopgap measure. In the long run, it would continuously increase their pollution treatment cost [3, 54]. As a result, firms are forced to maximize the output within the permitted pollution emission range by improving their production process, product quality, or productivity level [25]. Alternatively, they would use professional technology to purify the pollutants before discharge and improve their pollution control ability to solve the increasing external costs. Innovation is inevitable whether firms improve production technology or their pollution control ability. To ensure sustainable development, they must intensify green innovation to alleviate the additional environmental costs caused by environmental regulations.

H1: Command-and-control environmental regulations can promote new energy firms to make green innovations.

Market investment-oriented environmental regulations are a positive subsidy-oriented incentive measure adopted by the government. By increasing firms' investment in industrial pollution control, the environmental costs will be internalized to reduce pollution [46]. According to the market failure theory, innovation activities have spillover effects and externalities [55], which lead to a low level of R&D and inhibit firms' green innovation capacity [50]. As one of the means to adjust market failures, market investment-oriented environmental regulations can provide corresponding financial support for new energy firms, remove firms' constraints of limited internal resources [56], reduce their marginal cost of R&D investment, and thus promote the advancement of green technology [57]. Based on the theory of industrial organization, firm innovation is featured by long cycles and uncertainty. New energy firms are cautious about disclosing R&D information, which results in information asymmetry and moral hazard between new energy firms and investors. Market investment-oriented environmental regulations represent the government's strong support for the new energy industry. They are also a signal of the government's incredible attention to this industry [58], thus attracting market investors to invest in the green innovation activities of new energy firms [59]. Those regulations also reduce the uncertainty of green innovation, disperse the innovation risks of firms [50], and stimulate firms' enthusiasm for green innovation.

H2: Market investment-oriented environmental regulations can promote new energy firms to make green innovations.

Different types of environmental regulations have significantly different impacts on firms' green innovation capacity. Although command-and-control environmental regulations are highly coercive and can achieve the goal of environmental improvement quickly, it is difficult to implement those regulations and quantify the outcome. More than that, the unified environmental standards applied to all firms fail to consider the heterogeneity among firms and are subject to human factors of governmental departments. In comparison, market-based environmental regulations are an optimal resource allocation scheme formulated according to the market mechanism. They can give firms high flexibility and autonomy [48]. Implementing those regulations featuring strong consistency and coherence is relatively easy. Therefore, the implementation effect of market-incentive environmental regulations is more effective than that of command-and-control environmental regulations.

H3: Compared with the command-and-control type, market investment-oriented environmental regulations have more significant impacts on the green innovation of new energy firms.

With the increasing intensity of command-and-control environmental regulations and the increasing environmental punishment conducted by the government, new energy firms will be unable to meet the green quality standards of products and maintain sustainable development if they only stay the original production technology. Thus, firms can deal with the crisis only if they increase R&D input to acquire advanced technology and knowledge [60]. Based on the "endogenous growth theory", R&D input is the source of firm innovation and economic growth [61]. R&D input encourages firms to develop new technologies and transform them into tangible objects, thus playing an essential and decisive role in their green innovation capacity. In addition, increasing R&D investment can enhance firm researchers' awareness of green innovation [44] and transform green innovation capacity from thought to action and from theory to practice [62]. In summary, even though command-and-control environmental regulations can affect firms' green innovation in many ways, the most direct influencing mechanism is stimulating firms to increase R&D investment to improve their green innovation capacity.

H4: R&D investment plays a mediation role between command-and-control environmental regulations and green innovation of new energy firms.

The infrastructure of the new energy industry is relatively expensive, with high operation and maintenance costs. At this point, the government's financial support is needed to alleviate the financial pressure on the new energy firms to a certain extent. Government environmental investment can indirectly encourage firm innovation by reducing costs [63, 64]. Market incentive environmental regulations enable firms to independently choose pollution control methods and coordinate economic benefits and pollution control costs. In other words, if the government undertakes part of the cost as compensation [25], the production cost of new energy firms will be reduced equivalently [19]. Reducing production costs can narrow the gap between the returns on green innovation activities of new energy firms and the highest social income level and improve the returns on green innovation activities so that new energy firms' green innovation will be boosted. Moreover, firms will have extra money to hire high-tech talents for green innovation activities. Market investment-oriented environmental regulations can improve new energy firms' green innovation capacity by reducing production costs.

H5: Firms' production costs play a mediation role between market investment-oriented environmental regulations and new energy firms' green innovation.

The research framework of this paper is shown in Fig. 1, which summarizes the influencing mechanism of heterogeneous environmental regulations on new energy firms' green innovation.

Data and Methodology

Sample and Data

A-share new energy firms listed in Shanghai and Shenzhen from 2012 to 2020 are chosen as research objects in this paper. The data after 2012 is selected because, in 2012, the 18th National Congress incorporated ecological civilization in the five-sphere integrated plan for building socialism with Chinese characteristics for the first time. Since then, China's green governance has ushered in a new era. So far, there has not been a standard classification of new energy firms used by all major databases and securities companies. In line with the main business and scope disclosed in the annual report, the listed companies whose business involves wind power, solar power, new energy vehicles and other keywords related to new energy are selected in this paper. The new energy firms selected in this paper can be roughly divided into three types. The first type of firms are engaged in new energy vehicles, including research, production, and sales of new energy vehicles; the second type engages in new energy power generation projects, including electric field construction and operation projects of wind power, solar power and other new energy. The third type works on new energy products, including lithium batteries, solar cells and their anode, cathode raw materials, special equipment for new energy power generation, and new energy vehicle parts.

In this paper, firms that meet the following

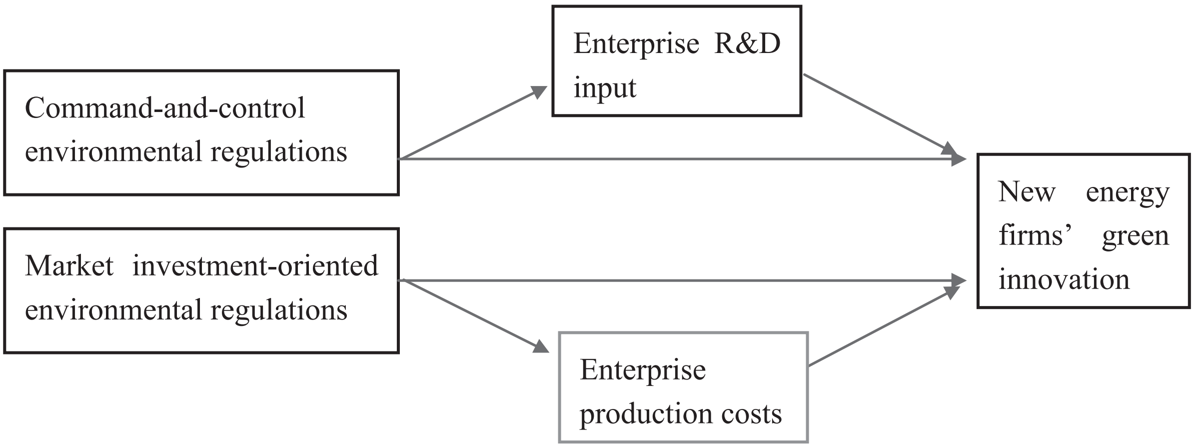

Fig. 1. Influencing mechanism.

requirements are excluded: (1) ST and *ST firms; (2) firms with a severe lack of indicator data after 2012; (3) firms that were listed after 2012; and (4) firms with a small proportion of business income from the new energy industry. Eventually, 78 new energy firms are chosen as the research samples. Regarding data sources, the number of patent applications and grants come from the State Intellectual Property Office (SIPO) and CNRDS databases, the cases of environmental administrative penalty come from China Environmental Yearbook, and the investment in industrial pollution control comes from China Environmental Statistical Yearbook. Other relevant data come from the listed firms' annual reports, RESSET and CSMAR databases.

Variable Selection

Explained Variables

Green innovation capability (GI): Green patents are the direct embodiment of green innovation achievements of new energy firms. Green patents are defined according to the "Green List of National Patent Classification", published by the World Intellectual Property Organization (WIPO) in 2010. The complete catalogue of environment-friendly patents is recognized as green patents. In this paper, some scholars' index construction methods are used for reference [65-68], and the number of green patent applications is selected for logarithmic processing. Because the number of patent applications is closer to the invention time and is less affected by human factors of patent institutions, it can better reflect the innovation capability of new energy firms in the current period. In the robustness test, the number of green patents is used to ensure the robustness of regression results.

Explanatory Variables

Command-and-control environmental regulations (CCR): They are China's most widely used means of environmental regulations. The commonly-used means cover laws and regulations and environmental administrative punishment. This paper references some scholars' index construction methods [44, 60, 69]. The ratio of the number of environmental administrative penalty cases where the new energy firms are located to the total number in the whole country is used as the index to measure the CCR. The greater the intensity of environmental regulations, the stronger the environmental law enforcement, the more importance the local government attached to environmental protection, and the more cases of environmental administrative punishment there would be in a region.

Market investment-oriented environmental regulations (MIR): By using this type of environmental regulation, investment in environmental governance can form fixed assets, including investment in environmental-friendly technology and investment in environmental governance facilities. This paper references some scholars' index construction methods [60, 70]. The investment in the industrial pollution control of the region where the new energy firms are located is used as the index to measure the market investment-oriented environmental regulations. Logarithmic processing is performed on the index. The greater the intensity of the environmental regulations, the more attention the local government pays to environmental protection, and the greater the investment in industrial pollution control would be.

Mediation Variable

Enterprise R&D investment (RD): The ratio of new energy firms' R&D expenditure to operating income is used as the measurement index.

Enterprise production cost (Cost): The ratio of net new energy fixed assets to operating income is used as the measurement index.

Control Variables

Relevant literature on environmental regulations and firms' green innovation capability is used for reference in this paper [32, 36, 44]. The following indexes are selected as the control variables: Enterprise Growth Ability (Growth), Enterprise Size (Size), Financial Leverage Capacity (Lev), Cash Holding Level (Cash), Return on Equity (Roe), Board Size (Board), Ratio of Independent Directors (Ind) Duality (Dual) and Shareholding Ratio of the First Shareholder (Top 1).

The specific definitions of the variables above and the calculation methods are shown in Table 1.

Model Construction

Direct Effect

In order to test the research hypotheses H1-H3, the following model is constructed in this paper:

$$GI_{it}=\alpha_0+\alpha_1 CCR_{it}+\delta control_{it}+\mu_i+v_t+\varepsilon_{it} \quad (1)$$

$$GI_{it}=\beta_0+\beta_1 MIR_{it}+\delta control_{it}+\mu_i+v_t+\varepsilon_{it} \quad (2)$$

Wherein, i represents new energy firms, t represents time, the explained variable GI refers to firm green innovation, the explanatory variable CCR refers to command-and-control environmental regulations, MIR refers to market investment-oriented regulations, control refers to control variables, u refers to industrial individual fixed effect, v refers to time-fixed effect, and ε_{it} refers to the random error term.

Mediation Effect

In order to test research hypotheses H4-H5, the follwing model is constructed in this paper:

Table 1. Definitions and Explanations of the Variables.

Variable Types	Variable Name	Variable Symbol	Definitions of Variables
Explained Variables	Green innovation	GI	The natural log of (number of green patent applications +1)
Explanatory Variables	Command-and-control environmental regulations	CCR	Number of environmental administrative penalty cases in the region where the firms are located/total environmental penalty cases in the country
	Market investment-oriented environmental regulations	MIR	In (investment in local industrial pollution control)
Mediation Variables	R&D input	RD	Enterprise R&D expenditure/revenue
	Enterprise production cost	Cost	Net fixed assets/operating income
Control Variables	Enterprise growth ability	Growth	Business income of the current year/business income of the previous year[1]
	Enterprise size	Size	The natural log of the firm's ending total assets
	Financial leverage capability	Lev	Ending total liabilities /ending total assets
	Cash holding level	Cash	Net cash flows/total assets from business activities
	Return on equity	Roe	Net profit of the current period/ending net assets
	Board size	Board	The natural log of the number of directors on the board
	The ratio of independent directors	Ind	Number of independent directors/number of directors on the board
	Duality	Dual	If the chairman and general manager are the same person, the value will be 1. Otherwise, it is 0.
	The shareholding ratio of the first shareholder	Top1	The number of shares held by the largest shareholder/the total share capital of the firm.

$$RD_{it}=\omega_0+\omega_1 CCR_{it}+\delta control_{it}+\mu_i+v_t+\varepsilon_{it} \quad (3)$$

$$GI_{it}=\theta_0+\theta_1 CCR_{it}+\theta_2 RD_{it}+\delta control_{it}+\mu_i+v_t+\varepsilon_{it} \quad (4)$$

Wherein, RD represents firm R&D input. In model (3), ω_1 represents the impacts of command-and-control environmental regulations on firm R&D input. Based on model (1), R&D input is added to model (4) to study the influencing mechanism of command-and-control environmental regulations on green innovation of new energy firms with firm R&D input as the mediation variable.

$$cost_{it}=\gamma_0+\gamma_1 MIR_{it}+\delta control_{it}+\mu_i+v_t+\varepsilon_{it} \quad (5)$$

$$GI_{it}=\varphi_0+\varphi_1 MIR_{it}+\varphi_2 Cost_{it}+\delta control_{it}+\mu_i+v_t+\varepsilon_{it} \quad (6)$$

Wherein, Cost represents firm production cost. In model (5), γ_1 represents the influences of market investment-oriented environmental regulations on firm production cost. In model (6), production costs are added based on model (2) to study the influencing mechanism of market investment-oriented environmental regulations on firm green innovation with firm production cost as the mediating cost.

Results and Discussion

Description Analysis

The descriptive statistics of each variable are shown in Table 2. First, the mean number of green patent applications of new energy firms is 2.559, which indicates that the average level of sample firms' green innovation capability is relatively low. The minimum value is 0, the maximum value is 6.351, and the standard deviation is 1.418, indicating significant differences in the green innovation capability among new energy firms. Second, the standard deviation of command-and-control environmental regulations is 0.106, and that of market investment-oriented environmental regulations is 0.878, indicating that the intensity of these two environmental regulations has little difference among new energy firms. Other control variables are consistent with those in the existing literature and thus will not be listed in detail due to word limitation.

Correlation Analysis

Spearman correlation coefficients of the main core variables are tested, and the results are shown in Table 3. It can be seen that the correlation coefficient between CCR and MIR is 0.384 and that between MIR regulations and production costs is -0.270, both of which show a weak correlation. The absolute values of all other

Table 2. Descriptive Statistical Results of Sample Variables.

Variable	Obs	Mean	Std. dev.	Min	Max
GI	702	2.559186	1.417744	0	6.350886
CCR	702	0.0756574	0.1061475	0.0002984	0.6089993
MIR	702	12.51416	0.8781862	7.971431	14.16367
RD	702	0.0466025	0.0393104	0.0001464	0.4671569
Cost	702	0.7011963	0.9124485	0.0210898	7.582394
Growth	702	0.2125451	0.9089206	-0.687207	22.09865
Size	702	22.87553	1.329472	19.55133	26.80596
Lev	702	0.5122131	0.2182469	0.0573579	2.861043
Cash	702	0.0379635	0.0642506	-0.7617281	0.2574131
Roe	702	0. 05969	0.1440276	-1.791829	0.492641
Board	702	2.175661	0.1917971	1.609438	2.890372
Ind	702	0.3654882	0.0470736	0.2857143	0.6
Dual	702	0 .0002022	0.0142186	0	1
Top1	702	0.3296896	0.1549168	0.052777	0.752535

Table 3. Correlation analysis of Main Variables.

Variable	GI	CCR	MIR	RD	Cost
GI	1.0000				
CCR	0.0180	1.0000			
MIR	0.0302	0.3844	1.0000		
RD	0.1627	0.1163	-0.0151	1.0000	
Cost	-0.0933	-0.0570	-0.2699*	-0.1014*	1.0000

correlation coefficients are less than 0.2, so the models have no severe multicollinearity problem.

Baseline Results

According to the panel data test, the models' fixed-effect and random-effect regressions are superior to the mixed regression. According to the Hausman test, fixed-effect regression is superior to random-effect regression. Therefore, fixed-effect models are used for individual and time effects of fixed industries. The results are shown in Table 4. The dependent variable is the number of green patent applications of new energy firms. Columns (1) and (2) respectively represent the impacts of command-and-control and market investment-oriented environmental regulations on the green innovation capability of new energy firms, which corresponds to equations (1) and (2) in model construction.

The results show that the two types of environmental regulation tools have promoted the innovation of new energy firms to varying degrees. The opinion proposed by the "Porter Effect" that strict environmental regulations can promote firm innovation has been confirmed in the new energy firms in China. The effect of command-and-control environmental regulations on green innovation of new energy firms is positive at the significant level of 5%, and the regression coefficient is 0.867, which indicates that the harsher the local government's environmental administrative punishment is, the more beneficial it will be to stimulate new energy firms' enthusiasm for green innovation. The effect of market investment-oriented environmental regulations on green innovation of new energy firms is positive at the significant level of 1%, and the regression coefficient is 0.166, which shows that the greater the local government's investment in pollution control is, the greater the green innovation capability of new energy firms will be. Moreover, compared with command-and-control environmental regulations, market investment-oriented regulations have more significant impacts on the green innovation of firms. Thus, hypotheses H1 to H3 have been verified.

As for the control variables, the impact of firm size on green innovation of new energy firms is positive at

Table 4. Regression results of the influence of different environmental regulations on green innovation of new energy firms.

Variable	(1)	(2)
	GI	GI
CCR	0.8669**	
	(0.4210)	
MIR		0.1660***
		(0.0522)
Growth	0.0253	0.0110
	(0.0473)	(0.0470)
Size	0.5653***	0.5687***
	(0.0479)	(0.0476)
Lev	0.6258**	0.6298**
	(0.2951)	(0.2939)
Cash	0.4768	0.6096
	(0.8485)	(0.8389)
Roe	0.4948	0.4274
	(0.3188)	(0.3181)
Board	-0.0397	-0.0583
	(0.2956)	(0.2933)
Ind	0.2424	0.2329
	(1.0588)	(1.0524)
Dual	0.0358	0.0443
	(0.1031)	(0.1023)
Top1	-0.9358***	-0.8411***
	(0.2953)	(0.2961)
_cons	-10.5041***	-12.5852***
	(1.1659)	(1.3899)
Time fixed effects	yes	yes
Individual fixed effects	yes	yes
N	698	698
R^2	0.412	0.417
adj. R^2	0.391	0.396

Standard errors in parentheses
* $p<0.1$, ** $p<0.05$, *** $p<0.01$

the significant level of 1%, which shows that the larger the firm size, the stronger the risk-taking ability, and the more potent its green innovation capability. The influence of financial leverage on the green innovation of new energy firms is positive at the significant level of 5%, which shows that the higher the debt ratio of firms, the more it can stimulate the green innovation of firms. The influence of the shareholding ratio of the first shareholder on green innovation of new energy firms is negative at the significant level of 1%, which indicates that the more concentrated the shareholding of firms, the more unfavorable they are to the green innovation of firms. Other control variables have no significant effects on the green innovation of new energy firms.

Robustness Tests

Substitution of Variable Measurement Index

To make the research conclusion more convincing, the explanatory variable of the number of green patent applications is replaced by the number of green patent grants. The results are shown in columns (1) and (2) of Table 5, where GI1 represents the number of green patent grants. It has been found that whether the number of green patent applications or the number of green patent grants is taken as the measurement index of green innovation, both command-and-control and market investment-oriented environmental regulations have a significantly positive effect on green innovation of new energy firms, further validating the hypotheses H1 to H3.

Substitution of Measurement Model

The explained variable of green patent contains a partially observed value of 0, and the observed value can only be greater than or equal to 0 and belongs to the limited dependent variable with the left tail broken distribution. Therefore, the fixed-effect panel Tobit model is adopted for testing. The results are shown in columns (3) and (4) of Table 5. No matter which measurement model is selected, command-and-control and market investment-oriented environmental regulations play a significantly positive role in new energy firms' green innovation, further validating hypotheses H1 to H3.

Problem of Endogeneity

Environmental regulations are based on the macro data of the province where the firms are located. In contrast, green innovation is based on microdata at the firm level. Hence, there is no bidirectional causal relationship in theory. However, in practice, each variable might have measurement errors, which could cause the problem of endogeneity. To avoid the problem of endogeneity, the lag period of the command-and-control and market investment-oriented environmental regulations is selected as the instrumental variables, respectively, and is tested through weak instrumental variables. The two-stage least square method (2sls) is used to re-estimate equations (1) and (2). The results are in columns (5) and (6) of Table 5. It is found that the coefficient symbol of each explanatory variable did not change significantly, which indicated that the endogeneity problem did not affect the estimated results of baseline regression.

Table 5. Robustness Test Results.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	Substitution variable		Substitution model		Endogenous test	
	GI1	GI1	GI	GI	GI	GI
CCR	1.0578***		0.9705**		1.9171**	
	(0.3803)		(0.4062)		(0.8524)	
MIR		0.1447***		0.1652***		1.1726***
		(0.0473)		(0.0249)		(0.3328)
Growth	0.0293	0.0144	0.0251***	0.0108	0.0293	-0.0325
	(0.0427)	(0.0426)	(0.0091)	(0.0081)	(0.0194)	(0.0341)
Size	0.4621***	0.4621***	0.5883***	0.5879***	0.6125***	0.6706***
	(0.0432)	(0.0432)	(0.0783)	(0.0734)	(0.0514)	(0.0617)
Lev	0.7477***	0.7512***	0.7084*	0.7212*	0.6750**	0.6667*
	(0.2666)	(0.2663)	(0.4221)	(0.4359)	(0.3088)	(0.3842)
Cash	0.5526	0.7432	0.5456	0.6985	0.4820	0.1848
	(0.7666)	(0.7602)	(0.5993)	(0.5441)	(0.9798)	(1.1529)
Roe	0.2035	0.1446	0.5240***	0.4533***	0.4354*	-0.0119
	(0.2880)	(0.2883)	(0.1294)	(0.1691)	(0.2643)	(0.4334)
Board	-0.0121	-0.0481	-0.0315	-0.0592	-0.0979	0.1189
	(0.2670)	(0.2658)	(0.4718)	(0.4911)	(0.3017)	(0.3800)
Ind	0.0117	-0.0532	0.1253	0.1271	0.5599	1.4489
	(0.9565)	(0.9537)	(0.7431)	(0.7248)	(1.1030)	(1.3561)
Dual	0.0493	0.0641	0.0333	0.0459	-0.0165	-0.0413
	(0.0932)	(0.0927)	(0.0363)	(0.0367)	(0.1103)	(0.1413)
Top1	-0.6431**	-0.5678**	-0.9409***	-0.8548***	-0.9122***	-0.1567
	(0.2668)	(0.2683)	(0.3036)	(0.2973)	(0.3362)	(0.4484)
_cons	-8.6496***	-10.3105***			-11.8883***	-28.9033***
	(1.0533)	(1.2596)			(1.3011)	(5.1530)
Time fixed effects	yes	yes	yes	yes	yes	yes
Individual fixed effects	yes	yes	yes	yes	yes	yes
N	698	698	698	698	620	620
R^2	0.415	0.416			0.413	0.068
adj. R^2	0.394	0.396			0.390	0.032

Standard errors in parentheses
* $p<0.1$, ** $p<0.05$, *** $p<0.01$

Further Analysis

Analysis of Mediation Effect

The above research results show that both command-and-control and market investment-oriented environmental regulations significantly positively affect the green innovation of new energy firms. In this paper, the influencing mechanisms of the two types of environmental regulations on green innovation of new energy firms will be further explored, and the mediation effect test results are shown in Table 6.

Columns (1) and (2) in Table 6 represent the influencing mechanism of command-and-control

Table 6. Regression Results of the Mediation Effect Model.

Variable	(1)	(2)	(3)	(4)
	RD	GI	Cost	GI
CCR	0.0472***	0.6965*		
	(0.0137)	(0.4221)		
MIR			-0.1894***	0.1432***
			(0.0343)	(0.0533)
Rd		3.6121***		
		(1.1799)		
Cost				-0.1202**
				(0.0585)
Growth	-0.0007	0.0277	-0.0705**	0.0026
	(0.0015)	(0.0470)	(0.0309)	(0.0471)
Size	-0.0045***	0.5814***	-0.0192	0.5664***
	(0.0016)	(0.0479)	(0.0313)	(0.0475)
Lev	-0.0288***	0.7299**	-0.0157	0.6280**
	(0.0096)	(0.2953)	(0.1930)	(0.2932)
Cash	-0.0858***	0.7868	-1.2470**	0.4596
	(0.0276)	(0.8494)	(0.5510)	(0.8401)
Roe	-0.0050	0.5129	-0.7890***	0.3325
	(0.0104)	(0.3169)	(0.2089)	(0.3207)
Board	0.0345***	-0.1644	-0.3273*	-0.0976
	(0.0096)	(0.2966)	(0.1926)	(0.2932)
Ind	0.1059***	-0.1402	-1.3519*	0.0703
	(0.0344)	(1.0597)	(0.6913)	(1.0529)
Dual	-0.0011	0.0399	0.1366**	0.0607
	(0.0033)	(0.1025)	(0.0672)	(0.1023)
Top1	0.0119	-0.9786***	0.2908	-0.8061***
	(0.0096)	(0.2938)	(0.1945)	(0.2959)
_cons	0.0466	-10.6725***	4.6996***	-12.0201***
	(0.0379)	(1.1600)	(0.9129)	(1.4136)
Time fixed effects	yes	yes	yes	yes
Individual fixed effects	yes	yes	yes	yes
N	698	698	698	698
R^2	0.204	0.420	0.399	0.420
adj. R^2	0.176	0.398	0.378	0.399

Standard errors in parentheses
* $p<0.1$, ** $p<0.05$, *** $p<0.01$

environmental regulations on green innovation of new energy firms, corresponding to Equations (3) and (4) in model construction. According to column (1), command-and-control environmental regulations (ω_1 = 0.047, p<0.01) can significantly promote firm R&D investment. According to column (2), after introducing the R&D input variable, both command-and-control environmental regulations (θ_1 = 0.697, p<0.1) and firm R&D input (θ_2 = 3.612, p<0.01) have a significant positive effect on green innovation of new energy firms. It indicates that with increasing the intensity of command-and-control environmental regulations, new energy firms will indirectly increase R&D investment to improve their green innovation capability. $\omega_1 \times \theta_2$ gets 0.1704, indicating that each unit increase in the intensity of command-and-control environmental regulations will increase the intensity of R&D investment by 0.0472 units and increase the intensity of green innovation by 0.1704 units. $\omega_1 \times \theta_2/(\theta_1 + \omega_1 \times \theta_2)$ gets 19.66%, indicating that 19.66% of the command-and-control environmental regulations indirectly promotes the green innovation capability of firms by increasing R&D investment.

Columns (3) and (4) in Table 6 represent the influencing mechanism of market investment-oriented environmental regulations on green innovation

Table 7. Regression Results of Heterogeneous Scale.

Variable	(1)	(2)	(3)	(4)
	large-scale firms		small-scale firms	
	GI	GI	GI	GI
CCR	1.0351*		0.5766	
	(0.5705)		(0.6280)	
MIR		0.2765***		0.0170
		(0.0637)		(0.0861)
Growth	0.0343	0.0122	-0.0760	-0.0843
	(0.0480)	(0.0468)	(0.1597)	(0.1596)
Size	0.7093***	0.7425***	0.4951***	0.4939***
	(0.0773)	(0.0757)	(0.1263)	(0.1265)
Lev	0.9107*	1.1061**	0.5274	0.5094
	(0.4851)	(0.4723)	(0.4143)	(0.4147)
Cash	0.7089	0.8816	0.3559	0.4793
	(1.2582)	(1.2209)	(1.1474)	(1.1411)
Roe	0.3089	0.1447	0.7806	0.8008
	(0.4048)	(0.3965)	(0.5348)	(0.5350)
Board	-0.3902	-0.4909	0.4536	0.4720
	(0.3519)	(0.3390)	(0.5683)	(0.5695)
Ind	0.7385	0.3222	-0.0884	-0.1515
	(1.4452)	(1.4097)	(1.7637)	(1.7728)
Dual	0.0753	0.0462	-0.0453	-0.0288
	(0.1538)	(0.1501)	(0.1412)	(0.1402)
Top1	-0.6290	-0.4037	-0.4137	-0.3730
	(0.4923)	(0.4826)	(0.4141)	(0.4131)
_cons	-13.7320***	-17.6739***	-9.9140***	-10.0885***
	(1.8687)	(2.0632)	(3.1882)	(3.3915)
Time fixed effects	yes	yes	yes	yes
Individual fixed effects	yes	yes	yes	yes
N	312	312	385	385
R^2	0.444	0.472	0.231	0.230
adj. R^2	0.404	0.434	0.180	0.178

Standard errors in parentheses
* p<0.1, ** p<0.05, *** p<0.01

of new energy firms, corresponding to equations (5) and (6) in model construction. It can be seen from column (3) that market investment-oriented environmental regulations (γ_1 =-0.189, p<0.01) has a significantly negative effect on the production cost of firms. From column (4), it can be seen that after introducing the variable of production cost, the market investment-oriented environmental regulations (φ_1 = 0.143, p<0.01) have a significantly positive effect on firms' green innovation and production cost (φ_2 =-0.120, p<0.05) has a significantly negative effect on firms' green innovation. It indicates that with increasing the intensity of the market investment-oriented environmental regulations, new energy firms can indirectly improve their green innovation capability by reducing production costs. $\gamma_1 \times \varphi_1$ gets 0.0227, indicating that each unit increase in the intensity of market investment-oriented environmental regulations

Table 8. Regression Results of Heterogeneous Ownership of Firms

Variable	(1)	(2)	(3)	(4)
	state-owned firms		non-state-owned firms	
	GI	GI	GI	GI
CCR	1.6088**		0.5669	
	(0.7841)		(0.4891)	
MIR		0.2236***		0.1706**
		(0.0756)		(0.0673)
Growth	-0.0853	-0.0980	-0.0088	-0.0178
	(0.2368)	(0.2337)	(0.0512)	(0.0507)
Size	0.7229***	0.7343***	0.5527***	0.5564***
	(0.0695)	(0.0688)	(0.0678)	(0.0674)
Lev	0.0757	0.1036	0.2867	0.2700
	(0.4846)	(0.4789)	(0.4088)	(0.4064)
Cash	2.6138*	3.1645**	0.3697	0.4883
	(1.5107)	(1.4551)	(1.0286)	(1.0185)
Roe	0.5651	0.6518*	0.3012	0.1308
	(0.3896)	(0.3819)	(0.4737)	(0.4731)
Board	0.0468	0.0901	-0.8042	-0.7666
	(0.4231)	(0.4177)	(0.4918)	(0.4884)
Ind	-0.0312	-0.3693	-0.8461	-0.6924
	(1.8770)	(1.8468)	(1.4654)	(1.4582)
Dual	-0.3512	-0.5356**	0.1510	0.1709
	(0.2595)	(0.2612)	(0.1209)	(0.1197)
Top1	0.5811	0.5915	-1.3356***	-1.2503***
	(0.6481)	(0.6402)	(0.3456)	(0.3455)
_cons	-14.7313***	-17.6775***	-7.8816***	-10.2223***
	(1.7486)	(2.0920)	(1.9867)	(2.2110)
Time fixed effects	yes	yes	yes	yes
Individual fixed effects	yes	yes	yes	yes
N	202	202	496	496
R^2	0.577	0.587	0.385	0.391
adj. R^2	0.528	0.539	0.355	0.362

Standard errors in parentheses
* p<0.1, ** p<0.05, *** p<0.01

will reduce the production cost of firms by 0.1894 units and increase the green innovation of firms by 0.0227 units. $\gamma_1 \times \varphi_1/(\varphi_2 + \gamma_1 \times \varphi_1)$ gets 13.71%, indicating that 13.71% of market investment-oriented environmental regulations indirectly promotes the green innovation capability of firms by reducing the production costs.

Effects Based on Firm Size

In this paper, the ending total assets of the new energy firms are used to measure the firm scale. New energy firms whose scale is larger than the sample mean are classified as large-scale firms, and vice versa. Columns (1) and (3) in Table 7 represent the regression results of the influence of command-and-control environmental regulations on green innovation of large- and small-scale firms, respectively, and columns (2) and (4) represent the regression results of the influence of market investment-oriented environmental regulations on green innovation of large- and small-scale firms, respectively. According to the results, the government's environmental administrative punishment and pollution control investment only have a significant promoting effect on large-scale firms but not on small-scale firms, which has been confirmed by Borsatto et al. [71]. That may be due to innovation activities' high cost and risk [25]. Large-scale firms have abundant resources and anti-risk ability, so they invest extra funds in green innovation to alleviate the pressure of external environmental costs [72]. However, small-scale firms often lack operating funds and invest less in green innovation. At the same time, the internal control system of large-scale firms is relatively perfect. They can view issues from a long-term perspective and choose green innovation to solve the problem fundamentally.

Effects Based on Firm Ownership

This paper divides new energy firms into state-owned and non-state-owned firms. Columns (1) and (3) in Table 8 show the regression results of the impacts of command-and-control environmental regulations on green innovation of state-owned and non-state-owned firms, respectively, and columns (2) and (4) show the regression results of the impacts of market-incentive environmental regulations on green innovation of state-owned and non-state-owned firms, respectively. The government's environmental administrative punishment and pollution control investment have a significantly more significant promoting effect on state-owned firms than non-state-owned firms. That may be because the government owns or controls state-owned firms, and the government's will power determines the behavior of state-owned firms. Therefore, state-owned firms are the critical implementation objects of the government's environmental regulation [51] and receive more financial support and subsidies than non-state-owned firms. In addition, state-owned firms have strong policy implementation capabilities and bear corporate social responsibility in fulfilling government policy commitments [68, 73]. They will pursue comprehensive benefits of the economy, greenness and society, can lower investors' pessimistic expectations of firms, and can obtain external investors' support. Therefore, state-owned firms' green innovation is significantly influenced by environmental regulations. In comparison, non-state-owned firms are less subject to governmental intervention and suffer less stress from environmental regulations. Short-term profit maximization makes non-state-owned firms not priorities green innovation, so they have less motivation for green innovation.

Conclusion and Policy Implications

Green innovation is the pursuit of the green ecological benefits of energy cleaning and emission reducing, by which firms are committed to maximizing comprehensive economic and environmental benefits [64]. How to implement environmental regulations well to promote green innovation of new energy firms has become a hot topic. Therefore, based on the panel data of A-share new energy firms listed in Shanghai and Shenzhen from 2012 to 2020, we divide environmental regulations into command-and-control and market investment-oriented environmental regulations, take the number of green patent applications as the measurement index of green innovation, and use a two-way fixed-effect model to investigate the impacts of the two types of environmental regulations on green innovation of new energy firms. The results show that: (1) both types of environmental regulations can promote green innovation of new energy firms to a different degree. Compared with command-and-control environmental regulations, market investment-oriented environmental regulations have a more substantial impact on the green innovation of firms. This conclusion is still valid after a series of robustness tests, including the substitution of the measurement index of variables, change of measurement model and treatment of the endogeneity problem. (2) Enterprise R&D input plays a partial mediation role between command-and-control environmental regulations and the green innovation of new energy firms. 19.66% of the command-and-control environmental regulations can indirectly promote the green innovation capability of firms by increasing R&D investment. The production cost of firms plays a partial mediation role between market investment-oriented environmental regulations and the green innovation of new energy firms, and 13.71% of market investment-oriented environmental regulations can indirectly promote the green innovation capability of firms by reducing production costs. (3) Both types of environmental regulations have different promoting effects on the green innovation of new energy firms because of different firm sizes and ownership. CCR and MIR have a significant promoting effect on the green innovation of large-scale firms. Thus, the "Porter Hypothesis" has been verified. However, environmental regulations' effects on small-scale firms are insignificant, indicating that small-scale firms follow the cost effect. Moreover, compared with non-state-owned firms, environmental regulations play a more significant role in promoting the green innovation of state-owned firms, which indicates that environmental regulations are more effective in the green innovation of state-owned new energy firms.

The conclusions of this paper have the following implications for the effective implementation of environmental regulations and green innovation of new energy firms:

(1) The incentive role of environmental regulations in green innovation should be brought into full play. Although environmental regulations may bring external pressure to new energy firms in the short term, in the long term, environmental regulations will induce firms to solve externalities through green innovation. Therefore, it is necessary to increase environmental administrative penalties on new energy firms, force them to increase research and development investment to promote green innovation, increase investment in pollution control of new energy firms, and provide policy support and financial subsidies for green innovation to alleviate the problem of limited green innovation resources due to increased pollution control costs. Besides, it is necessary to establish a sound external environment for new energy firms, continue to promote the construction of a market economy, improve the market-oriented green technology innovation system, improve the level of human capital, establish standard personnel training institutions and incentive mechanism, and guide the society to advocate green innovation atmosphere, so that environmental regulations can better play the innovation compensation effect.

(2) It is necessary to improve the policy system of environmental regulations further and formulate the optimal combination of environmental regulations. China's market system and firms' green innovation concept are improving, and command-and-control environmental regulations still prevail. It has been found in this paper that the promotion effect of market investment-oriented environmental regulations is superior to that of command-and-control regulations. Market-based environmental regulations enable firms to have a high degree of autonomy and to flexibly adjust operational strategies to alleviate the external pressure of compliance costs. Moreover, market-based regulations are more conducive to firms' green innovation than direct regulations such as environmental penalties. Therefore, relevant government departments should reduce the intensity of direct intervention, attach importance to using environmental tools based on economic means, promote the application of market-based environmental regulations, and gradually prioritize market-based environmental regulations. Meanwhile, governmental departments should give full play to the respective advantage of different environmental regulations, achieve synergy and complementarily, and give play to the promoting effects of various environmental regulations on green innovation of new energy firms.

(3) Implementing environmental regulations should be tailored to the case rather than by a "one-size-fits-all" approach. Targeted strategies should be adopted based on the actual situation of firms. It has been concluded in this paper that environmental regulations have different effects on the green innovation of new energy firms because of different firm sizes and ownership, and they have more significant impacts on large-scale and state-owned firms. Therefore, the proportion of large-scale new energy firms can be appropriately increased to promote state-owned firms to enter the new energy field. Government departments should reasonably design environmental regulations, pay close attention to the impact of environmental regulations on different types of firms, and formulate specific situations according to the attributes of different firms. The intensity of environmental regulations and supervision can be appropriately strengthened for new energy firms with solid innovation capability. At the same time, firms should be ensured to carry out green innovation activities within the range of bearable pressure. As an intermediary between firms and investors, the government should actively provide positive information for the capital market, alleviate the information asymmetry between new energy firms and investors, and attract more investors to invest in green innovation to improve further the level of green innovation in the field of new energy. Meanwhile, the government should also pay attention to the compliance costs brought by small-scale and non-state-owned firms, help firms reduce external costs of controlling environmental pollution, encourage them to increase investment in green innovation research and development, and guarantee the healthy green development of new energy firms in China.

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Conflict of Interest

The authors declare no conflict of interest.

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