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Examining Whether Government Environmental Regulation Promotes Green Innovation Efficiency—Evidence from China's Yangtze River Economic Belt

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Abstract: Based on the panel data of 11 provinces and cities in the Yangtze River Economic Belt from 2005 to 2018, this paper uses the SBM-DEA efficiency model with undesired output to measure the green innovation efficiency of the Yangtze River Economic Belt. The panel Tobit empirical analysis model was used to quantitatively analyze the impact of three different forms of government environmental regulations on the efficiency of green innovation. The research results show that the government's mandatory environmental regulations and government financial subsidies for green innovation technology are two regulatory methods that positively promote the efficiency of regional green innovation, but government investment in environmental governance has a negative impact on the efficiency of regional green innovation. Then the study found that this negative impact has a significant inflection point effect: when it exceeds a certain threshold, the negative impact turns into a positive effect. At the same time, the impact of environmental regulations on the efficiency of green innovation has significant regional heterogeneity, and the three environmental regulations have a greater impact on downstream provinces and cities.

Keywords: environmental regulation; green innovation efficiency; SBM-DEA efficiency model

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1. Introduction

Since the reform and opening up of China's economy, it has experienced a long period of rapid development and achieved remarkable economic development, but behind the rapid economic growth is huge resource consumption and environmental pollution. Domestic and international experience shows that the development path of high energy consumption and high pollution leading to high growth is not sustainable. In this context, the Chinese government has been committed to properly handling the relationship between economic development and environmental protection and enhancing the capacity of sustainable economic development. In 2018, Xi Jinping emphasized the need to build a resource-saving and environment-friendly green development system. Then, as one of the regions with the strongest comprehensive strength and the largest strategic support role in China, the Yangtze River Economic Belt, as a super basin spanning 11 provinces and cities in the east and west of China, had a GDP in 2020 that accounted for nearly half of the national GDP. However, due to the development of heavy industry, the region has seen rapid growth in energy and resource consumption, environmental pollution, and water and soil erosion.

For this reason, the 19th Report of the Communist Party of China and the Outline of the Yangtze River Economic Belt Development Plan clearly put forward the construction plan of "grasping big protection and not big development" to strengthen environmental regulations and thus promote the green development of the Yangtze River Economic Belt. Technological innovation is a prerequisite for green development [1]. Compared with the traditional production efficiency, green innovation efficiency, which is similar to eco-efficiency, can better reflect the quality of economic development and the impact of resources on the environment. The concept of green innovation efficiency involves reducing the use of natural resources, reducing the emissions of pollutants into the environment, and reducing the amount of waste generated [2,3]. Compared with eco-efficiency, green innovation efficiency emphasizes the importance of R&D investment and the application of green technology on the input side. However, can environmental regulation lead to increased green innovation efficiency? How are the two related, and through what channels can this influence be exerted? An accurate answer to this question is of crucial relevance and theoretical value for the green development of the Yangtze River Economic Belt and for the choice of China's future economic development model.

Scholars have done a lot of research around this research topic, and based on different perspectives, scholars obtain different research conclusions or even diametrically opposed views. The current research can be divided into two main directions. The first is the one-way relationship, in which environmental regulations enhance or reduce the efficiency of green innovation efficiency. Jeffe argues that although environmental regulation has an incentive effect on green innovation efficiency, it brings benefits to firms, but the direction is unclear [4]. Thomas et al. argued that environmental regulation policies have increased the need for firms to enhance environmental management behaviors, such as treating sewage and cleaning polluted wastewater [5]. This increases the cost expenditure of following environmental policies and squeezes out the investment in productivity-enhancing R&D. The empirical results show that environmental regulations significantly inhibit the improvement of green production efficiency. The second, the non-linear relationship, the impact of environmental regulation on green innovation efficiency, is not a unidirectional linear relationship. Deng Feng et al., Zang Chunqiu, Jiang Fuxin et al., Li Ling et al., and others confirmed that the impact of environmental regulation on the green total factor productivity of enterprises has an inverted "U" relationship [6–9].

Furthermore, when the intensity of environmental regulation reaches a certain threshold value, environmental regulation helps enterprises green the relationship between environmental regulation, and the green total factor productivity is inverted. However, the relationship becomes negative after a certain threshold value is exceeded. In the study of the relationship, Li Yang et al. found that the impact of environmental regulations on green innovation efficiency has a coexistence of short-term inhibition and long-term promotion [10]. Furthermore, Lanjouwjo et al., found no significant correlation between the increased emission reduction expenditure of environmental regulations and green technology innovation [11]. There was no evidence of a correlation between green technology innovation productivity and environmental regulation.

The above studies have enriched the research content and direction of environmental regulation and green innovation efficiency. However, there are also certain shortcomings. First, there is the green innovation efficiency measurement method. At present, there are controversies in the measurement methods; in particular, some important non-expected output indicators have not been included in the measurement index system, so there is some space for improvement. Second, the definition of environmental regulation is controversial. The vast majority of researchers define environmental regulation as the introduction of environmental policies by government departments and the more frequent use of environmental pollution fines, environmental taxes, and other measures. Environmental regulation laws are not simply defined as a single punishment by the government in the market but can only be used as a means of environmental regulation. At present, government agencies are also beginning to use indirect environmental regulation methods, such as financial subsidies for enterprises to develop advanced green technologies. The logic mechanism of the two impacts on green total factor productivity is not consistent.

Therefore, conflating them may not accurately describe the logical relationship between environmental regulation and green innovation efficiency, which is obviously not conducive to the rational use of environmental regulation policies by the government. Based on these arguments, this paper measures the green total factor production efficiency with the help of the SBM-DEA modeling method. Additionally, the study explores the relationship between environmental regulation and green innovation efficiency from two dimensions of environmental governance inputs and environmental market penalties, respectively, starting from the differences of environmental regulation tools and expecting to provide some reference for choosing a reasonable and effective regulation organization and policy dynamic adjustment.

2. Theoretical Analysis

Environmental regulation is a general term for the environmental protection policies and implementation tools enacted by government and related departments to solve the environmental problems associated with economic growth. In the early days, the Chinese government used more direct means, such as fines for environmental pollution, and direct financial investment in environmental pollution control to achieve the goal of reducing environmental pollution. At present, the Chinese government has also begun to pay attention to indirect means, such as green subsidy policies and environmentally friendly technology R&D subsidy policies. According to the standard of government participation in environmental pollution governance, we divide environmental regulation into two parts: direct environmental regulation and indirect environmental regulation. The content of the theoretical analysis is also carried out in accordance with this classification.

2.1. Government Directly Intervenes in Environmental Governance

The government directly intervenes in environmental governance by introducing environmental regulations and policies and directly undertaking environmental pollution control and restoration.

First, the government enforces environmental regulation measures directly. This measure includes pollutant emission standards, environmental audits, and emission tax collection. The public goods attribute of environmental resources determines the typical externality characteristic of environmental pollution. The existing insurmountable limitations of the market mechanism to address environmental pollution through property rights definition and integration provide room for governmental environmental regulation. Environmental regulation is ensured through public power and thus has a strong binding capacity. However, it has a different impact on the efficiency of firms' green production.

On the one hand, such regulation is conducive to the improvement of green production efficiency. Based on Michael Porter's hypothesis, which is that strict environmental regulations can induce efficiency and encourage innovations that help improve commercial competitiveness [12], Scherer et al., Han Jing, and Han Xianfeng et al. argue that the introduction of these environmental regulation policies is conducive to forcing enterprises to improve their existing production processes, optimize management procedures, and invest more R&D funds to promote the development of innovative green technologies, thus enhancing overall green production efficiency [13–15]. However, on the other hand, Collop and Roberts and Cary argue that harsh environmental regulations increase the cost of environmental pollution control, which reduces the scale of green innovation investment and is not conducive to the improvement of overall green production efficiency [16,17].

Second, the government directly undertakes environmental pollution controls and restoration. The government's sharing of responsibility for corporate environmental pollution management also has two different directions of influence on the impact of corporate green production efficiency. On the one hand, the government's increased investment in pollution management can make up for the lack of pollution management investment at the enterprise end, so enterprises can shift more resources to the research and development of green production technology, which helps to improve the overall green production efficiency. On the other hand, the government's commitment to pollution control investment may also cause enterprises to reduce pollution control investment. Enterprises will expand their own production scale and bring more pollution, which is ultimately not conducive to the improvement of green innovation efficiency.

2.2. Government Indirectly Intervenes in Environmental Governance

In this case, the government does not directly participate in environmental governance activities but guides enterprises to develop and adopt environmentally friendly technologies through targeted financial subsidies. The government's indirect environmental regulation through financial subsidies may have two effects on the production efficiency of green innovation. On the one hand, the government's green subsidy policy is conducive to improving the efficiency of green innovation. Government financial subsidies reduce the cost and risk of R&D of environmentally friendly technologies, thus motivating enterprises to increase their confidence in innovation investment, which is conducive to enhancing green innovation capacity and green innovation efficiency [18]. On the other hand, the government's green subsidy policy may also be detrimental to the improvement of green innovation efficiency of enterprises. Excessive reliance on government financial subsidies to carry out technology research and development activities may reduce the scale of investment in research and development funds for the purpose of enterprise development, which reduces the competitiveness of enterprises and will eventually be eliminated by the market [19–21].

Overall, the relationship between environmental regulation and green innovation efficiency is shown in Figure 1.

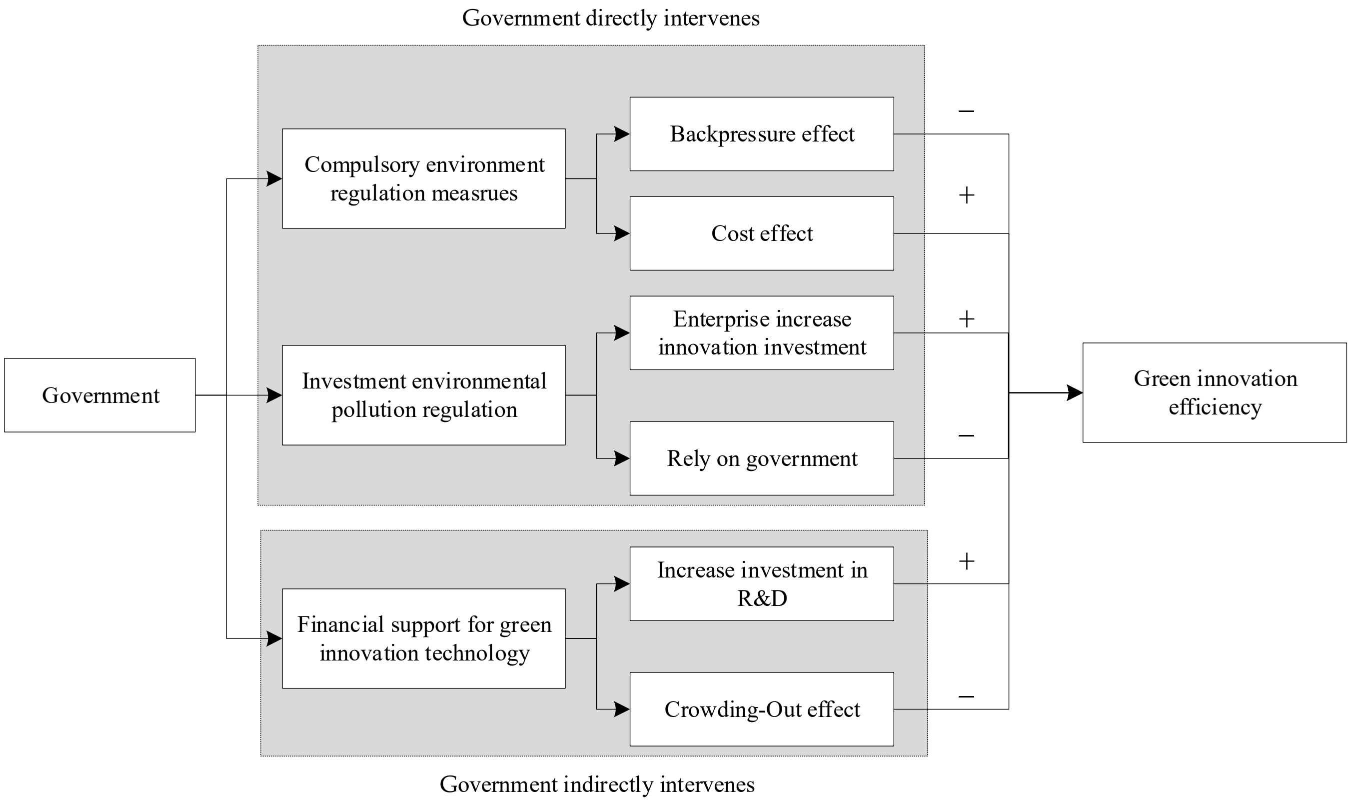

Figure 1. The relationship between government environmental regulations and green innovation efficiency.

3. Research Design and Empirical Model

3.1. Research Method

3.1.1. SBM-DEA Efficiency Model

The basic principle of data envelopment analysis (DEA) is to construct a nonparametric envelope frontier from the spatial data of decision units, and all the points on the frontier are valid, while those placed outside the frontier are invalid. The non-radial and non-angular SBM model overcomes the influence of traditional CCR and BCC models that do not consider input–output slack variables on the reliability of model estimation [22,23]. Adding the slack variables to the objective function can effectively solve the problem of efficiency measures that contain pollution variables. The basic idea is as follows.

Suppose the number of decision units in a system is n, and each decision unit contains three variables: input (X), desired output (Y^g), and undesired decision output (Y^b). Define the matrix of X, Y^g, and Y^b as follows:

$$X = [x_1, x_2, x_3, \ldots, x_n] \in R_{m\times n}$$

$$Y^g = \left[y_1^g, y_2^g, y_3^g, \ldots, y_n^g\right] \in R_{s1\times n}$$

$$Y^b = \left[y_1^b, y_2^b, y_3^b, \ldots, y_n^b\right] \in R_{s2\times n}$$

Among them, $X > 0$, $Y^g \geq 0$, $Y^b \geq 0$ define the production possible set as

$$p = \{(x, y^g, y^b) \mid x \geq X\lambda, y^g \leq Y^g\lambda, y^b \geq Y^b\lambda, \lambda \geq 0\}$$

The linear programming form of the SBM model is as follows:

$$\rho* = \min \frac{1 - \frac{1}{m}\sum\limits_{i=1}^{m} \frac{s_i^{-1}}{x_{i0}}}{1 + \frac{1}{s_1+s_2}\sum\limits_{s_2}^{s_1} \frac{s_r^g}{y_{r0}^g} + \left(\sum\limits_{r=1}^{s_2} \frac{s_r^b}{y_{r0}^b}\right)}$$

$$s.t.\begin{cases} x_0 = X\lambda + s^{-1} \\ y_0^g = Y^g\lambda - s^g \\ y_0^b = Y^b\lambda + s^b \\ \lambda, s^{-1}, s^g, s^b \geq 0 \end{cases}$$

In the above formula, $0 \leq \rho^* \leq 1$ and for s^{-1}, s^g, s^b are strictly decreasing. The s represents the slack variable. The s^{-1}, s^g, s^b represent excessive input, insufficient expected output, and excessive undesired output, respectively; λ represents the weight of each variable. Objective function (ρ^*) expresses the deviation of input and output from the optimal state. The decision-making unit is the most effective only when there is no redundancy or deficiency in input and output.

3.1.2. The Data of Green Innovation Efficiency

According to the suggestion of Yang Shuwang et al., this paper selects R&D talent full-time equivalent and R&D internal funding expenditure as input variables [24]. Scientific researchers and funding are the most direct guarantee of innovation input and output. In terms of innovation output, the number of patent applications granted is more indicative of the quality of innovation output than the number of patent applications accepted. The three industrial wastes (industrial waste gas, wastewater emissions, and industrial solid waste output) are important sources of environmental pollution. With the entropy method used by Yi Ming et al., the three industrial wastes are synthesized into an environmental pollution index to serve as non-desired outputs [1]. As a result, the input variables become two, and the output variables are two, which meets the limitation of the number of indicators by DEA method when the number of decision units is 11. The overall data were obtained from the China Statistical Yearbook (2005–2019), the China Statistical Yearbook of Science and Technology (2005–2019), and the China Statistical Yearbook of Environment (2015–2019).

3.2. Empirical Model

The Tobit regression model is a restricted dependent variable regression model, first proposed by James Tobin, and the Undesirable-SBM measures green innovation efficiency at 0–1, which is truncated data. Tobit regression is more efficient and unbiased. The basic model setup is as follows.

$$Y = \begin{cases} Y* & = \beta X + \mu(Y* > 0) \\ 0 & (Y* < 0) \end{cases}$$

In the above formula, Y^* is the truncated dependent variable. Y is the value of green innovation efficiency tendency. X is a vector of independent variables, β a vector of parameters, and μ is a random interference term.

When $Y^* > 0$, the Tobit model based on the impact of environmental regulation on the productivity of green innovation is as follows.

$$GTFP_{i,t} = \beta_i + \beta_2 ERE_{i,t} + \beta_3 X_{i,t} + \varepsilon_{i,t}$$

The $GTFP_{i,t}$ represents the green innovation efficiency of each province of the Yangtze River economy in different years, as measured by Undesirable-SBM. The *ERE* represents government environmental regulation measures, and based on the previous analysis, this paper selects government-mandatory environmental regulation (*ERE1*); government financial subsidies for innovation (*ERE2*); and government environmental governance (*ERE3*), respectively. The X represents other control variables that affect the efficiency of green innovation, representing the random disturbance term.

3.3. Variable Selection and Source

Green innovation is a complex process in which multiple subjects and factors act together [24]. With the help of previous scholars' studies, this paper defines the following important independent variables as a way to discover the impact of government regulation on green production efficiency.

3.3.1. Government Regulation Variables (*ERE*)

Three main dimensions are chosen to measure the level of government environmental regulation. The first is the level of government compulsory environmental regulation (*ERE1*). In this paper, we choose to use the amount of emission fees collection as a proxy variable for the level of compulsory government regulation as a percentage of government revenue. The second is government innovation financial subsidies (*ERE2*) This paper chooses the ratio of local government innovation subsidies to the scale of local fiscal expenditures to measure this indicator. The third is government environmental governance (*ERE3*). Drawing on the idea of Yang Shuwang et al., this paper selects government pollution control investment as a percentage of the scale of local government fiscal expenditure to measure the intensity of government environmental governance investment [24].

3.3.2. Industrial Structure (Str)

In a general sense, regional green development relies on the tertiary industry rather than the secondary industry. Ruiji Pun et al. and Weiqi Tang argue that the service industry in China is ineffective in influencing green development, and the degree of ineffectiveness is deepening [25,26]. This paper chooses the share of the value added from the tertiary industry to the GDP as a proxy scalar of industrial structure so as to examine how exactly the industrial structure affects the green production efficiency.

3.3.3. The Degree of Market Openness (Open)

The opening to the outside world introduces advanced foreign technology and undertakes international industrial transfer, and the relatively low strength of environmental controls can also lead to the entry of international pollution, which brings a heavy environmental burden while enhancing the level of innovation and development, especially for the middle and upper reaches of the Yangtze River Economic Belt provinces [27]. Brunnermeier, however, argues that the demand for green products and fierce competition in the international market is conducive to the improvement of green production efficiency [28]. In this section, FDI to regional GDP ratio is chosen as an alternative indicator.

3.3.4. Maturity of Technology Market (Tech)

The more mature the technology market is, the more it is conducive to accelerating the transformation of innovation results, activating the regional innovation atmosphere and improving the overall regional innovation capacity [29]. The maturity of the technology market is expressed using the turnover of the regional technology market.

3.3.5. Regional Factor Endowment (RFE)

Regional factor endowment lays the foundation for local green innovation development, and Xiao Quan et al. (2021) argue that the richer the regional factor endowment, the higher the level of local innovation development and the higher the level of green production efficiency. This paper mainly uses the ratio of local fixed asset investment stock to regional employees as a proxy variable for regional factor endowment.

The descriptive statistics for the variables and data are shown in Table 1.

Table 1. Descriptive statistics of variables.

Variables Name	Variables	Obs	Mean	Std
Green innovation efficiency	*GTFP*	165	0.7112	0.228
	ERE1	165	0.0121	0.039
Government regualtion	*ERE2*	165	0.0281	0.011
	ERE3	165	0.0131	0.024
Industrial structure	*Str*	165	0.5019	0.1395
The degree of market openness	*open*	165	0.0651	0.046
Maturity of the technology market	*Tech*	165	12.0981	4.099
Regional factor endowment	*RFE*	165	89.0761	12.701

The data were mainly obtained from the overall data from the China Statistical Yearbook (2005–2019), the China Statistical Yearbook of Science and Technology (2005–2019), and the China Statistical Yearbook of Environment (2005–2019). The data of 11 provinces and cities in the Yangtze River Economic Zone from 2005 to 2019 were selected to verify the impact of environmental regulation on the efficiency of green innovation. The results of the analysis were obtained from Stata 14.0.

4. Empirical Results and Discussion

4.1. Basic Regression Results

The results of the Tobit regression analysis with green innovation efficiency as the dependent variable, using the panel Tobit mixed-effects model, the panel Tobit fixed-effects model, and the panel Tobit random-effects model, are shown in Table 2. The results of the F-test significantly reject the assumption that the mixed-effects model is not different from the fixed-effects model, and the empirical evidence of the panel Tobit fixed-effects model should be accepted. The results of the Hausman test also significantly reject the panel Tobit random-effects model. Therefore, the panel Tobit fixed-effects model is selected in the empirical analysis section to analyze the effect of environmental regulation on the green innovation effect in the Yangtze River Economic Belt.

Table 2. Baseline regression results of environmental regulation and green innovation efficiency.

Explanation Variables	Panel Tobit Fixed-Effects Model		
ERE1	0.0169 *** (4.098)		
ERE2		0.0189 ** (2.402)	
ERE3			−0.0207 *** (−3.098)
Str	0.0197 (1.201)	0.0201 (1.191)	0.0196 (1.313)
open	2.911 ** (2.402)	2.981 *** (3.107)	3.092 *** (3.215)
Tech	0.0012 *** (3.091)	0.0009 *** (3.129)	0.0015 *** (2.764)
RFE	0.0233 *** (5.019)	0.0216 *** (3.201)	0.0219 *** (4.019)

Note: (1) The numbers in brackets are the t statistics corresponding to the regression coefficient; ***, ** indicate they have passed the significance test at the 1%, 5% confidence levels, respectively, with the same interpretations below. (2) The empirical results of the panel Tobit random-effects model and panel Tobit mixed effects model are not reported due to space limitation.

According to the above table, firstly, there is a positive relationship between the cost of emissions (*ERE1*) and green innovation, which also indicates that the government's use of sewage charges to regulate the environment is conducive to improving the efficiency of local green production. This is because the government's sewage charges raise the production costs of polluting firms and reduce their production profits. In this context, enterprises are more willing to change their innovative activities to reduce the amount of emissions, reduce the scale of pollution emissions, and reduce pollution costs, thereby gaining a competitive advantage in the market and thus improving green production efficiency. Second, the government's science and technology innovation input-based (*ERE2*) environmental regulation is also conducive to enhancing green production efficiency. This shows that, at this stage, the positive impact of government innovation investment on enterprises' green production efficiency is greater than the negative impact. Additionally, government investment in environmental science and technology R&D helps alleviate enterprises' shortage of R&D funds, reduce R&D risks, and thus improve green production efficiency. The scale of the crowding-out effect of enterprises' own innovation input brought by the government's science and technology innovation input is not yet large enough to affect the overall green production efficiency enhancement. Finally, government environmental governance inputs (*ERE3*), on the contrary, are not conducive to the improvement of green production efficiency. This is because government environmental governance inputs lead to higher environmental governance costs, which inhibit other government inputs, especially government investments in R&D, which is not conducive to the improvement of green production efficiency. This partly proves the existence of Porter's hypothesis.

For the other control variables, the direction and sign of the effects of all control variables are as expected, except that there is no significant correlation between industrial structure (*Str*) and green production efficiency. First, the degree of openness to the outside world (open) contributes to green production efficiency. This is also consistent with Brunnermeier's study, where the introduction of regional foreign investment helps to enhance local innovation competition and improve the level of local science and technology innovation [28]. Second, the maturity of the technology market (*Tech*) helps to enhance local green production efficiency. A well-developed technology transfer market helps establish a good innovation R&D atmosphere, which in turn helps accelerate the innovation results into the practical application process, thus promoting green innovation efficiency. Third, regional factor endowment (*RFE*) helps to enhance local green production efficiency. This is the same as the findings of Xiao Quan et al., mainly because the higher the regional factor endowment and the richer the resources held by enterprises, the higher the green production efficiency improvement brought by innovation [30]. Finally, there is no significant correlation between industrial structure and green production efficiency. The possible reason for this is that there is currently a non-green development trend in the tertiary industry in the Yangtze River Economic Zone, which means that even if the tertiary industry accounts for a higher share, it does not translate into green production efficiency improvement [25].

4.2. Inflection Point Effect of Environmental Regulation on Green Production Efficiency

The current research literature has found that the impact of environmental regulation on green innovation efficiency is not a unidirectional impact, but there is an obvious inflection point when certain conditions are reached [24]; that is, the impact of environmental regulation on green production efficiency can vary significantly with the degree of regulation, and the direction of its impact changes. In order to verify the existence of this influence mechanism, this section introduces three different quadratic terms of environmental regulation variables and continues to use the panel Tobit fixed-effects model to estimate the Tobit model based on the impact of environmental regulation on green innovation productivity as follows (when truncating the dependent variable *GTFP* > 0).

$$GTFP_{i,t} = \beta_i + \beta_2 ERE_{i,t} + \beta_3 ERE^2{}_{i,t} + \beta_4 X_{i,t} + \varepsilon_{i,t}$$

The specific results are shown in Table 3. It can be found that the sign before the quadratic term of *ERE3* changes. The sign of the first term is negative, but the sign before the second term is positive. The result shows that environmental regulation by means of environmental fines may have an inverted U-shaped impact on green innovation efficiency, which also confirms the Porter hypothesis. This also proves that the Porter Hypothesis exists in the Yangtze River Economic Belt. In the short-term environmental pollution control is not conducive to the improvement of green production efficiency of enterprises; this is because short-term environmental pollution control raises the cost of environmental management and increases the tax burden on enterprises, which is not conducive to the competitive advantage of enterprises in the market. However, in the long run, this means it is still conducive to the improvement of green production efficiency, probably because the "compensation effect" brought by the improvement of the environment and the increase in innovation output covers the "cost effect", allowing enterprises to obtain additional economic benefits. This is conducive to the improvement of green innovation efficiency. In contrast, no change is found in the sign of the quadratic terms of *ERE1* and *ERE2*, which indicates no inflection point of green innovation subsidies and environmental management inputs on green innovation productivity in the region during the sample period.

4.3. The Impact of Environmental Regulation on the Heterogeneity of Green Innovation Production Efficiency

Are there heterogeneous effects of inter-regional differences? In order to verify whether heterogeneity exists, this study divides the Yangtze River economic belt into three categories according to the criteria of "upstream, midstream and downstream": upstream provinces include Chongqing, Sichuan, Guizhou, and Yunnan; midstream provinces are Jiangxi, Hubei, and Hunan; downstream provinces are Shanghai, Jiangsu, Zhejiang, and Anhui. The panel Tobit fixed-effects model continues to be used for the empirical estimation of the existence of the effect of environmental regulation on the heterogeneity of green innovation production efficiency. The specific results are shown in Table 4.

According to the results shown in Table 4, the impact of environmental regulations on green innovation productivity in the upstream, midstream, and downstream provinces remains similar to the overall empirical results, controlling for other variables. First, the positive relationship between emission costs (*ERE1*) and green innovation is still present. Still, significant differences in intensity emerge, with downstream provinces having the largest situation of emission costs on green innovation efficiency, followed by midstream provinces and the smallest in the west. Secondly, government science and technology innovation input-based (*ERE2*) environmental regulation is also beneficial to enhance green production efficiency. Moreover, the intensity of the impact appears to be significantly different, with government science and technology support in upstream provinces producing the largest effect on green innovation efficiency, followed by midstream provinces and the smallest in the west. Finally, there is still a negative correlation between government environmental governance inputs (*ERE3*) and green innovation efficiency. Additionally, there are significant differences in the degree of impact, with the upstream provinces having the greatest impact and the downstream provinces having the least.

Table 3. Inflection point effect of environmental regulation on green production efficiency.

Explanation Variables	Panel Tobit Fixed-Effects Model		
ERE1	0.0138 *** (4.098)		
ERE2		0.0215 ** (2.116)	
ERE3			−0.0214 *** (−3.401)
ERE1^2	0.0141 *** (3.701)		
ERE2^2		0.0191 *** (3.064)	
ERE3^2			0.0221 *** (3.081)
Other variables	YES	YES	YES
Constant	0.0871 * (2.169)	0.7601 (1.6319)	−0.193 * (−1.703)

Note:(1) The numbers in brackets are the t statistics corresponding to the regression coefficient; ***, ** and * indicate that they have passed the significance test at the 1%, 5% and 10% confidence levels, respectively, with the same interpretations below. (2) *ERE1*^{2}, *ERE2*^{2}, *ERE3*^{2} represent the squares of *ERE1*, *ERE2*, *ERE3* respectively.

Table 4. Inflection point effect of environmental regulation on green production efficiency.

Explanation Variables	Panel Tobit Fixed-Effects Model		
	Upstream	Midstream	Downstream
ERE1	0.0106 *** (3.112)	0.0127 ** (2.237)	0.0203 *** (4.103)
ERE2	0.0112 ** (2.039)	0.0176 *** (3.149)	0.0204 *** (2.971)
ERE3	−0.0304 *** (−2.411)	−0.0181 ** (−2.364)	−0.0135 *** (−3.429)
Other variables	YES	YES	YES

Note: (1) The numbers in brackets are the t statistics corresponding to the regression coefficient; *** and ** indicate that they have passed the significance test at the 1% and 5% confidence levels, respectively, with the same interpretations below. (2) Regression equation variables for all variables were not included in the table due to space limitations. The three different environmental regulation variables were included in Equation (3) separately for the panel Tobit fixed-effects model, and the results are summarized in the table.

There are two possible reasons for the heterogeneous impact results: first, there are differences in the degree of perfection of relevant systems in different provinces. Compared with upstream and midstream provinces, the degree of economic development, green innovation resources, and market mechanisms is sounder in downstream provinces, so it is easier for enterprises in downstream provinces to obtain more advanced green production technologies. Moreover, due to the sound market and public management mechanisms, enterprises in downstream provinces have higher pollution costs and stronger regulation. This leads enterprises to choose cleaner but more efficient green production technologies, obtaining higher economic returns. Second, different provinces are at different stages of economic development. Compared with the middle and upper reaches of the provinces, the downstream provinces have already moved past the stage of extensive pollution treatment, and there is not much pressure on pollution management. In contrast, the middle and upstream provinces are under very high pressure for pollution treatment and environmental protection, which requires a lot of investment in environmental pollution treatment, which crowds out other government funds for improving green production efficiency.

5. Discussion

Research on the relationship between environmental regulation and green innovation efficiency has become an important research topic. However, the current related research also has two certain shortcomings. In particular, there are research limitations in how to accurately measure green innovation efficiency and the impact of different environmental regulations on green innovation efficiency.

5.1. Research Implications

This study addresses these issues in an attempt to understand the relationship between the different environmental regulations and green innovation efficiency. To this end, two main contributions are made in terms of research implications.

First, this study addresses the measurement problem of green innovation efficiency by using the SBM-DEA method. The concept of green innovation efficiency involves reducing the use of natural resources, reducing the emissions of pollutants into the environment and reducing the amount of waste generated. Traditional DEA methods cannot solve the slackness problem caused by the unintended output. This study addresses the slackness problem by using the SBM-DEA method. The data using the SBM-DEA method show that the higher the level of production technology, the higher the efficiency of green innovation, which is also in line with the connotation of high-quality development in the general sense.

Second, this study expands the conceptual scope of environmental regulation, and empirical research methods are used to verify the impact of different environmental regulations on the efficiency of green innovation, as well as the heterogeneity of this impact. Environmental regulations cannot be simply defined as direct government enforcement of environmental regulation laws. More and more indirect environmental regulatory measures, such as financial subsidies to companies that adopt clean technologies, are also being adopted by the government. Direct or indirect environmental regulations have different logical mechanisms for the impact of green innovation efficiency. When environmental compulsory and government financial subsidies are used as proxy indicators of environmental regulation, government environmental regulation is conducive to improving green innovation efficiency. Conversely, the relationship between government regulation and green innovation efficiency becomes negative when the government environmental investment variable is used. The subsequent empirical results show that the impact of environmental regulation on the efficiency of green innovation is not linearly related but presents an obvious "U" shape. Further empirical results show that the relationship has obvious spatial heterogeneity, which shows that environmental regulation in downstream provinces and cities has a greater positive impact on green production efficiency. Relatively, the degree of positive impact in the middle and upper reaches of the province is small. Previous studies have focused more on analyzing the impact of a single environmental regulation, which may not be conducive to grasping the overall impact of environmental regulation on green innovation efficiency. This research extends the literature on the relationship between environmental regulation and green innovation efficiency in empirical insights.

5.2. Practical Implications

In terms of practical relevance, the province and city governments, which lie in the Yangtze River Economic Belt, may find this research useful in two parts. First, in the short term, governments could adopt compulsory environmental regulation and financial subsidies to improve local green innovation efficiency. First, it can reduce the R&D risks associated with enterprises' green innovation development and enhance their innovation enthusiasm. Second, the government's financial subsidies can also play the role of leading relevant enterprises to adopt more green innovation technologies, which will help to improve local green innovation efficiency. Third, this can expand the intensity and quality of government investment in environmental governance to enhance the efficiency of green innovation in the long term. It can increase the intensity of environmental governance investment, strive to cross the influence inflection point, and put the government's environmental governance investment into enhancing the efficiency of green innovation. It can also improve the government's environmental governance input towards quality. The quality of the government's environmental governance investment can be adjusted to ensure that each project, especially major projects, has a reasonable proportion of ex-ante protection, ex-post control, and governance subjects to improve the efficiency of energy-saving and environmental protection spending. It also needs to strengthen supervision to enhance the efficiency of using environmental protection funds.

5.3. Limitations and Future Research

As with any research, the present study is constrained by certain limitations [31,32]. This research also has some limitations. First, this research only discusses the mechanism of the impact of different environmental regulations on green production efficiency through theoretical deduction, but it does not verify these mechanisms through empirical methods. In future studies, we will introduce micro-panel data at the enterprise level located in the Yangtze River Economic Belt to empirically verify the internal mechanism of the impact of environmental regulations on the efficiency of green innovation. Second, we found evidence that the impact of environmental regulations on the efficiency of green innovation has significant regional heterogeneity. However, we have only given possible reasons for the heterogeneous impact of environmental regulations on green innovation efficiency. The above reasons have not been confirmed by empirical work. In future studies, we will combine micro-enterprise data and macro-provincial data and use the panel fixed-effect empirical model to find the reasons for the heterogeneity of the impact of environmental regulations on green innovation efficiency.

6. Conclusions

Based on the panel data of 11 provinces and cities in the Yangtze River Economic Belt from 2005 to 2018, this paper uses the SBM-DEA efficiency model with undesired output to measure the green innovation efficiency of the Yangtze River Economic Belt. It used the panel Tobit empirical analysis model to quantitatively analyze the impact of three different forms of government environmental regulations on the efficiency of green innovation. The research results are as follows. (1) The overall results show that the impact of different environmental regulation instruments on the green innovation productivity of the study sample is not consistent, and the government compulsory environmental regulation measures and government financial subsidies for technological innovation are conducive to the improvement of its green innovation productivity, but the government environmental pollution input is not conducive to the improvement of this indicator. (2) There is an inflection point for the impact of environmental pollution control measures on green innovation productivity, and when this inflection point is exceeded, environmental pollution control measures will improve green innovation efficiency. (3) There is significant regional heterogeneity in the impact of environmental regulation on green innovation efficiency. This heterogeneity is mainly manifested by the fact that different environmental regulation instruments have a greater impact on downstream provinces, and the different degrees of institutional perfection and different economic development stages may be the reasons for this heterogeneity.

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