

Article

How Do Environmental Regulation and Decentralization Interactively Affect the Green Productivity of the Construction Industry? Evidence from China

Zhao Yang ^{1,*} and Hong Fang ²

¹ School of Urban Economics & Management, Beijing University of Civil Engineering and Architecture, Beijing 102616, China

² School of Economics & Management, Beihang University, Beijing 100191, China; fanghong@buaa.edu.cn

* Correspondence: yangzhao@bucea.edu.cn

Abstract: In this paper, based on the spatial panel data of 30 provinces in China from 2008 to 2019, the relationship between environmental regulation (ER), environmental decentralization (ED) and the green total factor productivity of the construction industry (hereafter GTFPCI) was investigated through the spatial Dobbins model, and the heterogeneity of the relationship between three environmental regulations and the GTFPCI under different environmental decentralization intensities was studied through a threshold panel model. The results showed that the three environmental regulations had different degrees of impact on the GTFPCI, among which market-based environmental regulations (MERs) played the most obvious role. Environmental regulation and environmental decentralization have spillover effects on the GTFPCI in surrounding provinces. On the whole, with the increasing intensity of environmental decentralization, environmental regulation plays a stronger positive role in promoting the GTFPCI. However, through a threshold analysis, it was seen that the regulatory impact of different environmental regulations on the GTFPCI are heterogeneous in different ranges of environmental decentralization intensity.

Keywords: GTFPCI; spillover effects; heterogeneous; threshold analysis



Citation: Yang, Z.; Fang, H. How Do Environmental Regulation and Decentralization Interactively Affect the Green Productivity of the Construction Industry? Evidence from China. *Sustainability* **2024**, *16*, 6138. <https://doi.org/10.3390/su16146138>

Academic Editor: Patrik Söderholm

Received: 24 May 2024

Revised: 5 July 2024

Accepted: 12 July 2024

Published: 18 July 2024



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1. Introduction

The construction industry has played a great role in promoting the development of China's national economy. The booming construction industry has provided jobs for tens of thousands of Chinese people and contributed a lot to China's gross domestic product (GDP). However, the construction industry consumes a lot of energy and produces greenhouse gases and other pollutants in the production process. According to research, the construction industry accounts for 25% of global CO₂ emissions and 40% of energy consumption [1]. The total carbon emission of China's construction industry in the whole process reached a staggering 4.93 billion tons in 2018, accounting for 51.3% of China's total carbon emission and 14.9% of the world's total carbon emission [2]. China's construction industry has great emission reduction potential. At the Paris Conference on Climate Change, China committed to reducing CO₂ emissions per unit of GDP by 60–65% compared with 2005 and achieving a proportion of non-fossil energy in energy consumption of about 20% by 2030. In order to achieve these goals, it is urgent for the construction industry to achieve sustainable development [3]. In the face of the huge resource consumption and greenhouse gas emissions caused by the development of the construction industry, China's relevant departments must issue relevant policies to improve the energy conservation and emission reduction efficiency of the construction industry and promote the green development of the construction industry. Environmental problems have become a major issue hindering the green development of China's construction industry. Therefore, this paper brings environmental factors into the framework of traditional total factor investigation and

calculates the green total factor productivity of the construction industry (hereafter the GTFPCI) to reflect the green production of the construction industry.

In previous studies, it has been found that environmental regulation (ER) can improve energy efficiency and regulate environmental problems. It regulates and supervises economic production activities and promotes the green and sustainable development of production activities. Environmental regulation makes the regulated subjects improve their production efficiency and create more energy-saving and environmental protection products, thus bringing “innovation compensation” [4,5]. Common environmental regulations include command-controlled environmental regulation (CER), market-based environmental regulation (MER) and voluntary environmental regulation (VER) [6]. The regulatory impacts of different types of environmental regulation on enterprise production activities are heterogeneous [7]. Policies such as the regulations on the energy conservation of civil buildings and the comprehensive work plan for energy conservation and emission reduction in the 13th five-year plan issued by China in recent years have stipulated the production energy conservation and pollution emission of the construction industry. China has also increased its investment in environmental pollution control. The total investment has increased from 238.8 billion CNY in 2005 to 953.9 billion CNY in 2017. The government expects to achieve the goal of environmental protection and promoting green development by increasing investment in pollution control, but the results are not ideal. The Chinese government began to reform its environmental management system, emphasizing that governments at all levels cooperate with each other to jointly fulfill their responsibilities for environmental protection, and the core issue is the decentralization of environmental management power, that is, environmental decentralization.

The effectiveness of ER on environmental protection depends on the supervision and implementation of relevant departments, and the effect of government environmental supervision at all levels is affected by the authority distribution of environmental management affairs, that is, by environmental decentralization (ED) [8]. Is there heterogeneity in the effect of environmental decentralization on the production activities of the construction industry through different types of environmental regulations? In addition, there are obvious differences in economic and environmental conditions between different regions of China. Will this situation lead to significant differences in green total factor productivity of construction industry in various regions? In order to answer these questions, this paper establishes some related models to explore the relationship among the ER, ED and GTFPCI and provides theoretical support and relevant policy suggestions for the sustainable development of China's construction industry.

The innovations of this paper are the following: (1) This paper studies the heterogeneity of the interaction between different ERs and EDs on the GTFPCI. (2) The spatial Dobbins model was used to calculate the spillover effects of the ED and ER on the GTFPCI under different geographical distances. (3) The threshold model was used to calculate the impact of the three ERs on the GTFPCI under different ED intensities.

The contents of the remaining sections of the article are as follows. Section 2 is a literature review, Section 3 is an introduction of the calculation methods and data sources used, Section 4 is the empirical regression conducted and Section 5 is the proposed policy suggestions.

2. Literature Review

The issues of green total factor productivity, environmental regulation and environmental decentralization are one of the focuses of academic attention. The research on enterprise productivity has a long history. In the early days, researchers usually used single-factor indicators such as the number of products produced per capita per unit time to measure enterprise productivity. In 1954, the connotation of total factor productivity was first put forward in Hiram Davis's productivity accounting [9]. The connotation emphasizes that it is unscientific to use only one index to measure the productivity of enterprises, and the calculation process of productivity needs to include all input and output indicators.

In recent years, researchers realized that when investigating production activities, they should not only pay attention to the desirable output, such as economic growth, but also add the analysis of undesirable output indicators, such as carbon emissions. Therefore, the concept of green total factor productivity has been put forward. Its connotation is the productivity of sustainable development of enterprises obtained by bringing the indicators reflecting environmental problems in production activities into the evaluation index system [10]. Pittman (1983) first incorporated undesirable output into the index system and calculated green total factor productivity by using a data envelopment analysis model [11]. Since then, green total factor productivity has been applied to evaluate the efficiency of various industries [12–15].

Many studies have shown that environmental regulation is a measure that plays an important role in production efficiency and pollutant emission. The existing relevant literature is mainly divided into “green paradox” and “forced emission reduction”. The concept of a “green paradox” was put forward by Sinn (2008) [16]. He believed that fossil energy miners would reduce the impact of stricter environmental regulation in the foreseeable future by accelerating mining, which would make pollution more serious. Reyer (2010) believed that if the government issued incentive policies to encourage the development of clean energy, it would reduce the cost of fossil energy exploitation, but would accelerate fossil energy exploitation and bring more pollution [17]. Through research, Ploeg and Withagen (2012) found that unreasonable policy setting, ineffective implementation of policies and non-uniformity of local policies were the three main reasons for the “green paradox” [18]. Fünfgelt and Schulze (2016) believed that the government’s environmental regulation made enterprises increase production costs and reduce their share of enterprise innovation costs, which was not conducive to enterprises improving their productivity and reducing pollutant emissions [19]. These theories have been confirmed in relevant studies [20,21].

However, most researchers support the view of “forced emission reduction”. American scholar Porter (1991) put forward the famous “Porter Hypothesis” in 1991 [22]. He believed that the means of government environmental regulation would force enterprises to transform, upgrade and improve their production technology, so as to improve their production efficiency and reduce pollutant emissions, although enterprises would put production costs into production in the short term. However, in the long-term production process, this would bring higher profits and compensate the early investment, which is the “innovation compensation theory”. Porter and Linde (1995) further complemented the “Porter Hypothesis” [23]. They believed that environmental regulation would force enterprises to achieve the “win-win” goal of improving productivity and protecting the environment. Since then, many scholars have empirically verified Porter’s hypothesis, but their conclusions have been different. Some studies found that although environmental regulation makes enterprises reduce pollutant emissions, it also leads to the reduction in enterprise production efficiency [24–27], while other studies confirmed the existence of the “innovation compensation theory”, whereby reasonable environmental regulation enables enterprises to improve production efficiency, reduce pollutant emissions, obtain more profits in long-term production activities and achieve the “win-win” goal of protecting the environment and increasing profits [28–33].

Previous studies have proven that the rationality of environmental regulation and the degree of policy implementation determine whether environmental regulation can play a positive role in the sustainable production of enterprises [34–37], and the key issue affecting the formulation and implementation of environmental policies is environmental decentralization [38,39], which refers to a central government delegating the power of environmental supervision and governance to local governments. Local governments formulate and implement environmental laws and regulations by themselves, and local governments need to assume the responsibility of environmental protection in economic construction [40,41]. Many scholars have obtained different research results on whether environmental decentralization can effectively improve the efficiency of environmental pro-

tection. The research results can mainly be divided into two aspects: decentralization will reduce pollution and increase pollution. Some scholars believe that the centralized management model is conducive to improving the efficiency of environmental management. The central government can formulate environmental policies and provide environmental services, which can avoid the problem of pollution transfer caused by different environmental policies in different regions [42,43]. More and more scholars believe that when the central government decentralizes the power of environmental control, regional governments have more autonomy in environmental management, which will improve the efficiency of environmental monitoring and management, and local governments will reduce the generation of pollutants by improving environmental standards [44,45]. There is heterogeneity between different regions. Decentralization is conducive to local governments to better deal with regional environmental problems [46].

It can be seen from the above analysis that the characteristics of high energy consumption and high pollution of the construction industry determine that more government environmental supervision is needed in its production activities. The degree of ED and the intensity of ER affect its development; however, there is no previous literature that analyzed and synthesized the ER, ED and GTFPCI into a unified framework. No scholar has studied the relationship between them and the impact of the interaction of environmental regulation and environmental decentralization on the GTFPCI. Therefore, this paper examines the relationship between three environmental regulations and the GTFPCI through a linear model and examines the direct impact and spatial spillover impact of environmental regulation, environmental decentralization and their interaction on the GTFPCI through a spatial Dobbins model. A threshold model was used to calculate the impact of the three environmental regulations on the GTFPCI when the environmental decentralization was at different threshold intervals.

3. Methods and Data Sources

3.1. Methods and Data Sources Used to Calculate the GTFPCI

3.1.1. Method of Calculating the GTFPCI

The data envelopment analysis (DEA) model was proposed by Charnes et al. (1978) [47]. The theory behind the DEA model is to envelop input and output data. If the decision-making unit (DMU) is located on the data envelopment surface, its value is 1 and efficiency is the highest. The closer the value is to 0, the lower the efficiency. However, the traditional DEA model cannot add undesirable indicators in the calculation of an efficiency value, and production activities will produce a large number of undesirable outputs such as greenhouse gases. If only input and desirable output are calculated in the evaluation of production efficiency, the calculation results will lose objectivity. In order to solve this problem, Tone (2001) perfected the DEA model and proposed the SBM—DEA model, so that the calculation of economic production efficiency (2001) could include undesirable output indicators [48]. The specific calculation formula is the following:

$$\beta_0^* = \min \frac{1 - \frac{1}{m} \sum_{i=1}^m \frac{s_{i0}^-}{x_{i0}}}{1 + \frac{1}{s_1 + s_2} \left(\sum_{r=1}^{s_1} \frac{s_{r0}^y}{y_{r0}} + \sum_{r=1}^{s_2} \frac{s_{r0}^d}{d_{r0}} \right)} \quad (1)$$

$$x_0 = X\lambda + s_0^-$$

$$y_0 = Y\lambda - s_0^y$$

$$d_0 = D\lambda + s_0^d \quad s_0^- \geq 0, s_0^y \geq 0, s_0^d \geq 0, \lambda \geq 0$$

In the formula, β_0^* represents the calculated efficiency value, X , Y and D represent the set of input, desirable output and undesirable output, respectively, vectors s_0^- and s_0^d represent the excess value of the input and undesirable output, respectively, vector s_0^y is the slack variable of the desirable output, and subscript 0 represents the DMU currently being calculated, where λ is the weight vector.

3.1.2. Indicator Data Source for Calculating the GTFPCI

The calculation indicators and data sources used in the SBM-DEA are shown in Table 1:

$$C_{\text{dir}} = \sum Q_i \times NCV_i \times A_i \times O_i \times \frac{44}{12} + W1 \times \beta1 + W2 \times \beta2 \quad (2)$$

Table 1. Data sources used for calculations.

Type of Indicator	Indicator	Unit	Data Source
Input	Total assets	CNY billion	China Statistics Yearbook On Construction (2009–2020) [49]
	Number of employees	10,000 persons	
	Technical equipment	CNY/person	
Desirable output	Standard coal	10,000 tons	China Energy Statistical Yearbook (2009–2020) [50]
	Total profit	CNY billion	China Statistics Yearbook On Construction (2009–2020) [49]
	Floor space of buildings completed	Million square meters	
Undesirable output	CO ₂ emissions	10 thousand tons	CO ₂ emission calculated according to Formula (2)

The meanings and sources of symbols and numbers in the formula are shown in Table 2.

Table 2. Data sources of the CO₂ emission calculation formula.

Indicator	Unit	Data Sources
<i>i</i>	Types of energy	China Energy Statistical Yearbook (2009–2020) [50]
<i>Q</i>	Energy consumption	
<i>NCV</i>	Low calorific value	
<i>A</i>	Carbon emission factor	General Principles for Calculation of the Comprehensive Energy Consumption (GB/T 2589-2008) [51], 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventory [52]
<i>O</i>	Carbon oxidation rate	
44/12	Carbon conversion coefficient	
<i>W1</i>	Electricity consumption	China Statistics Yearbook On Construction (2009–2020) [49]
<i>W2</i>	Heat consumption	
$\beta1$	Electric energy carbon emission factor	China Building Energy Consumption Research Report (2018) [53]
$\beta2$	Carbon emission factor of heat	

3.2. Index Introduction and Data Source of the Regression Model

3.2.1. Environmental Regulation

(1) Command-controlled environmental regulation

CER refers to the relevant mandatory commands or punishment measures implemented by an environmental department to protect the environment. Previous studies usually use the number of new environmental regulations issued in that year as the strength measurement standard of the CER [54], but some scholars believe that the newly issued laws and regulations may not be effectively implemented [55], so this paper used the number of environmental administrative punishment cases of the government every year as the strength measurement standard of the CER.

(2) Market-based environmental regulation (MER)

MER refers to a government regulating the production activities of enterprises through market means to achieve the purpose of reducing pollution. Referring to the previous research [56], this paper took the pollutant discharge fees of each region as an index to measure the intensity of the MER.

(3) Voluntary environmental regulation (VER)

VER refers to an environmental regulation in which the public spontaneously participates in environmental protection activities and reports the environmental damage of enterprises, so as to standardize the behavior of enterprises. Referring to the previous research literature [7], this paper used the number of written reports received by the Ministry of Ecology and Environment (China) as the index to measure the intensity of the VER.

In order to compare the impact of the three environmental regulations, the data on the three environmental regulations were standardized.

3.2.2. Environmental Decentralization

Referring to a previous study [39], the author took the personnel distribution of local environmental protection systems at all levels as the standard to measure environmental decentralization. The specific calculation formula is the following:

$$ED_{it} = \frac{LEP_{it}/LPOP_{it}}{NEP_t/NPOP_t} \times [1 - (GDP_{it}/GDP_t)] \quad (3)$$

where LEP_{it} and NEP_t , respectively, represent the number of staff in region i and national environmental protection systems in year t , $LPOP_{it}$ and $NPOP_t$, respectively, represent the population of the region i and country in year t , $[1 - (GDP_{it}/GDP_t)]$ is an economic reduction coefficient to eliminate the endogenous problem of economic development and environmental decentralization, and GDP_{it} and GDP_t , respectively, represent the GDP of the regional i and country in year t .

3.2.3. Data Source of the Regression Model

The data source of the three environmental regulation indicators and environmental decentralization indicators was the China Environmental Yearbook (2009–2020) [57]. The control variable set $X_{i,t}$ in the above model included research and test development funds (R&D), gross domestic product (GDP) and foreign direct investment (FDI). The data sources of the control variables were the China Statistical Yearbook [58]. To address the issue of inaccurate evaluation efficiency caused by inflation and other factors, this study utilized the GDP deflator method to convert all relevant economic indicators into 2008 data. According to data released by the People's Bank of China, the exchange rate of the CNY to USD in 2008 was CNY/USD = 0.147. The descriptive statistics for the variables utilized in this paper are presented in Table 3.

Table 3. Descriptive statistics of all variables included in this paper.

Indicator	Unit	Mean	S.D.	Min	Max
Total assets	CNY billion	415.088	428.371	4.068	2722.064
Number of employees	10,000 persons	146.565	166.599	5.480	811.030
Technical equipment	CNY/person	13,429.691	8654.852	3069.000	91,231.000
Standard coal	10,000 tons	93.495	66.986	3.766	275.551
Total profit	CNY billion	16.376	18.579	1.146	116.177
Floor space of buildings completed	Million square meters	114.569	144.015	17.397	768.239
CO ₂	10 thousand tons	6.51	8.52	0.080	60.097
CER	Ten thousand	0.055	0.072	0.003	0.308
MER	CNY billion	0.507	0.493	0.025	2.019
VER	Ten thousand	0.704	0.513	0.045	2.026
ED	None	0.975	0.505	0.324	2.579
R&D	CNY billion	0.901	1.172	0.018	4.519
FDI	CNY billion	4.059	12.035	0.030	64.121
GDP	CNY billion	2499.252	1987.970	225.820	8216.320

3.3. The Basic Regression Model

In this paper, in order to study the linear relationship between the ER and GTFPCI, the author first established a linear model as follows, in which β_n is the correlation coefficient, ER is the environmental regulation and $X_{i,t}$ is the set of control variables. i , t and n , respectively, represent regions, years and descriptions of environmental regulations, α_i and v_t are the fixed effects of individual and time, respectively, and $\varepsilon_{i,t}$ is the heterogeneous error term.

$$GTFPCI_{it} = \beta_1 + \beta_2 CER_{it} + \beta_3 MER_{it} + \beta_4 VER_{it} + \beta_5 X_{it} + \alpha_i + v_t + \varepsilon_{it} \quad (4)$$

According to previous studies, there may be a nonlinear relationship between environmental regulation and productivity [59]. Therefore, this paper added the investigation of the relationship between the quadratic term of environmental regulation and the GTFPCI. The research model is the following:

$$GTFPCI_{it} = \beta_1 + \beta_2 CER_{it} + \beta_3 MER_{it} + \beta_4 VER_{it} + \beta_5 CER_{it}^2 + \beta_6 MER_{it}^2 + \beta_7 VER_{it}^2 + \beta_8 X_{it} + \alpha_i + v_t + \varepsilon_{i,t} \quad (5)$$

Considering that the impact of the ER on the GTFPCI may lag, this paper established the following two models by delaying all independent variables by one year to compare with the previous two models, to study the effect of the ER on the GTFPCI. In the new model, the author also treated the control variables with a lag of one year in order to avoid the two-way causal effect between the control variables and the GTFPCI [5].

$$GTFPCI_{it} = \beta_1 + \beta_2 CER_{it-1} + \beta_3 MER_{it-1} + \beta_4 VER_{it-1} + \beta_5 X_{it-1} + \alpha_i + v_{t-1} + \varepsilon_{it-1} \quad (6)$$

$$GTFPCI_{it-1} = \beta_1 + \beta_2 CER_{it-1} + \beta_3 MER_{it-1} + \beta_4 VER_{it-1} + \beta_5 CER_{it-1}^2 + \beta_6 MER_{it-1}^2 + \beta_7 VER_{it-1}^2 + \beta_8 X_{it-1} + \alpha_i + v_{t-1} + \varepsilon_{it-1} \quad (7)$$

3.4. Spatial Durbin Model

3.4.1. The Design of the Spatial Durbin Model

Spillover effect is an objective phenomenon in economic production and the embodiment of economic externality. It refers to the external impact of economic production. The impact of spatial spillover effect should be considered when studying issues related to an economic environment [60]. The spatial Durbin model can calculate the spillover effects of environmental regulation and environmental decentralization from the two dimensions of time and space. This paper established a spatial Durbin model, and the model is the following:

$$\begin{aligned} GTFPCI_{it} = & \beta_1 + \beta_2 CER_{it} + \beta_3 MER_{it} + \beta_4 VER_{it} + \beta_5 CER_{it}^2 + \beta_6 MER_{it}^2 + \beta_7 VER_{it}^2 + \\ & \beta_8 ED_{it} + \beta_9 CER_{it} \times ED_{it} + \beta_{10} MER_{it} \times ED_{it} + \beta_{11} VER_{it} \times ED_{it} + \beta_{12} \sum_{j=1}^N W_{ij} CER_{jt} + \\ & \beta_{13} \sum_{j=1}^N W_{ij} MER_{jt} + \beta_{14} \sum_{j=1}^N W_{ij} VER_{jt} + \beta_{15} \sum_{j=1}^N W_{ij} ED_{jt} + \beta_{16} \sum_{j=1}^N (W_{ij} CER_{jt} ED_{jt}) + \\ & \beta_{17} \sum_{j=1}^N (W_{ij} VER_{jt} ED_{jt}) + \beta_{18} \sum_{j=1}^N (W_{ij} MER_{jt} ED_{jt}) + \beta_{19} X_{i,t} + \alpha_i + v_t + \varepsilon_{i,t} \end{aligned} \quad (8)$$

3.4.2. Construction of a Spatial Weight Matrix

To carry out the analysis of spatial econometrics, we first had to calculate the spatial weight matrix. This paper used a 0–1 spatial weight matrix, distance reciprocal weight matrix and distance threshold weight matrix to investigate the spatial spillover effect.

The 0–1 spatial weight matrix is defined as the following:

$$W_{ij} = \begin{cases} 1, & i \neq j \text{ and regions } i \text{ and } j \text{ have shared borders} \\ 0, & i = j \text{ or regions } i \text{ and } j \text{ do not have shared borders} \end{cases} \quad (9)$$

The reciprocal distance weight matrix is defined as Formula (9), where d_{ij} is the distance between regions i and j .

$$W_{ij} = \begin{cases} \frac{1}{d_{ij}}, & i \neq j \\ 0, & i = j \end{cases} \quad (10)$$

The distance threshold value weight matrix is defined as Formula (10), where d is the threshold critical value.

$$W_{ij} = \begin{cases} 1, & dij \leq d \text{ and } i \neq j \\ 0, & dij > d \text{ or } i = j \end{cases} \quad (11)$$

3.4.3. Calculation of a Moran Index

The Moran index is an effective method for measuring spatial auto-correlation. Its value is between -1 and 1 . If there is a positive correlation, the value is greater than 0 . If there is a negative correlation, the value is less than 0 . The closer the Moran index value is to -1 or 1 , the stronger the spatial correlation. The closer the Moran index value is to 0 , this indicates that there is no spatial auto-correlation. The global Moran index formula is the following:

$$I_{morans} = \frac{n \sum_{i=1}^n \sum_{j=1}^n W_{ij} (x_i - \bar{x})(x_j - \bar{x})}{S^2 \sum_{i=1}^n \sum_{j=1}^n W_{ij}} \quad (12)$$

where $S^2 = \sum_{i=1}^n (x_i - \bar{x})^2$ is the sample variance and $\bar{x}$ is the sample average.

The Moran index of region i is calculated as the following:

$$I_i = \frac{(x_i - \bar{x})}{S^2} \times \sum_{j=1}^n W_{ij} (x_j - \bar{x}) \quad (13)$$

3.5. Threshold Panel Model

Based on previous studies [61,62], this paper establishes dynamic threshold panel models (14)–(16) with the ED as the threshold variables to study the effects of three ERs on the GTFPCI under different ED intensities. The dynamic threshold model could make up for the endogenous shortcomings between the variables of the traditional threshold model, and the evaluation results were more reasonable. The dynamic threshold panel model is the following:

$$GTFPCI_{i,t} = \beta_0 + \beta_1 CER_{i,t} \times I(ED \leq c) + \beta_2 CER_{i,t} \times I(ED > c) + \beta_3 X_{i,t} + \alpha_i + v_t + \varepsilon_{it} \quad (14)$$

$$GTFPCI_{i,t} = \beta_0 + \beta_1 MER_{i,t} \times I(ED \leq c) + \beta_2 MER_{i,t} \times I(ED > c) + \beta_3 X_{i,t} + \alpha_i + v_t + \varepsilon_{it} \quad (15)$$

$$GTFPCI_{i,t} = \beta_0 + \beta_1 VER_{i,t} \times I(ED \leq c) + \beta_2 VER_{i,t} \times I(ED > c) + \beta_3 X_{i,t} + \alpha_i + v_t + \varepsilon_{it} \quad (16)$$

4. Discussion

4.1. Analysis of the Green Total Factor Productivity of China's Construction Industry

In this study, based on the relevant panel data, the SBM-DEA model was used to calculate the GTFPCI. The panel data spanned from 2008 to 2019, including 30 provinces in China. The calculation results are shown in Table 4. According to the different geographical locations of China's provinces, the author divided China's 30 provinces into three regions: eastern, central and western.

Table 4. Green total factor productivity of China’s construction industry.

	Province	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Mean	S.D.
Eastern region	Beijing	1	1	1	1	1	1	1	1	1	1	1	1	1.000	0.000
	Tianjin	1	1	1	1	1	1	1	1	1	1	1	1	1.000	0.000
	Hebei	0.781	0.872	0.836	1	1	1	1	1	1	1	1	1	0.957	0.076
	Liaoning	0.711	0.88	0.827	0.827	0.864	0.874	0.904	0.958	0.993	0.976	0.993	1	0.901	0.084
	Shanghai	1	1	1	1	1	1	1	1	1	1	1	1	1.000	0.000
	Jiangsu	0.601	0.836	0.744	1	0.812	1	1	0.936	0.891	0.934	0.977	1	0.894	0.120
	Zhejiang	1	1	1	1	1	1	1	1	1	1	1	1	1.000	0.000
	Fujian	0.673	0.73	0.756	0.54	0.639	0.654	0.763	0.763	0.75	0.83	0.854	0.799	0.729	0.085
	Shandong	0.969	0.806	0.809	0.934	0.859	0.865	0.934	0.896	0.886	0.901	0.833	0.97	0.889	0.054
	Guangdong	0.527	0.504	0.525	0.569	0.607	0.602	0.654	0.667	0.676	0.733	0.745	0.731	0.628	0.082
Middle region	Hainan	0.671	0.773	0.751	0.512	0.762	0.651	0.603	0.594	0.578	0.569	0.602	0.568	0.636	0.082
	Shanxi	0.65	0.648	0.668	0.647	0.615	0.675	0.726	0.704	0.681	0.669	0.641	0.637	0.663	0.029
	Anhui	0.651	0.765	0.766	0.504	0.545	0.571	0.588	0.586	0.588	0.576	0.646	0.6	0.616	0.077
	Jiangxi	0.649	0.522	0.799	0.589	0.54	0.649	0.824	0.741	0.699	0.656	0.643	0.711	0.669	0.089
	Henan	0.698	0.525	0.61	0.635	0.657	0.695	0.728	0.796	0.889	0.814	0.896	0.933	0.740	0.122
	Hubei	0.696	0.756	0.778	0.6	0.594	0.639	0.746	0.853	0.863	0.886	1	0.924	0.778	0.125
	Hunan	1	1	1	1	1	1	1	1	1	1	1	1	1.000	0.000
	Jilin	0.656	0.633	0.604	0.588	0.886	0.578	0.725	0.557	0.524	0.569	0.549	0.51	0.615	0.100
Western region	Heilongjiang	0.59	0.752	0.545	0.533	0.794	0.776	0.737	0.685	0.722	0.631	0.645	0.664	0.673	0.083
	Inner Mongolia	0.638	0.607	0.693	0.611	0.711	0.796	0.727	0.662	0.824	1	0.918	1	0.766	0.136
	Guangxi	0.683	0.688	0.621	0.666	0.622	0.661	0.615	0.705	0.755	0.756	0.776	0.523	0.673	0.069
	Chongqing	0.711	0.798	0.661	0.704	0.726	0.66	0.842	0.922	0.899	0.9	0.843	0.876	0.795	0.094
	Sichuan	0.633	0.697	0.728	0.513	0.573	0.592	0.786	0.773	0.556	0.518	0.815	0.675	0.655	0.102

Table 4. Cont.

	Province	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Mean	S.D.
Western region	Guizhou	0.589	0.623	0.612	0.648	0.649	0.654	0.631	0.628	0.639	0.75	0.789	0.722	0.661	0.058
	Yunnan	0.651	0.626	0.684	0.727	0.727	0.793	0.536	0.795	0.508	0.509	0.577	0.708	0.653	0.099
	Shaanxi	0.7	0.717	0.719	0.712	0.568	0.777	0.787	0.734	0.506	0.794	0.574	0.786	0.698	0.092
	Gansu	0.57	0.544	0.537	0.662	0.635	0.676	0.412	0.667	0.661	0.608	0.576	0.595	0.595	0.072
	Qinghai	0.566	0.586	0.646	0.563	0.568	0.623	0.631	0.639	0.646	0.635	0.645	0.574	0.610	0.034
	Ningxia	0.604	0.621	0.692	0.656	0.705	0.684	0.501	0.714	0.738	0.715	0.645	0.65	0.660	0.062
	Xinjiang	0.47	0.54	0.469	0.504	0.517	0.537	0.602	0.555	0.536	0.569	0.489	0.451	0.520	0.043
	East	0.812	0.855	0.841	0.853	0.868	0.877	0.896	0.892	0.889	0.904	0.909	0.915	0.876	0.030
	Middle	0.699	0.734	0.711	0.634	0.701	0.693	0.759	0.728	0.746	0.725	0.753	0.747	0.719	0.033
	West	0.620	0.660	0.670	0.661	0.663	0.668	0.632	0.713	0.658	0.680	0.672	0.652	0.662	0.022
	National	0.711	0.751	0.743	0.724	0.748	0.751	0.763	0.783	0.766	0.774	0.781	0.774	0.756	0.021

Table 4 shows the results: the GTFPCI in Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, Hubei and other places was high, while the energy efficiency of Gansu, Qinghai, Xinjiang and other provinces was low. Among them, the GTFPCI in Beijing, Tianjin, Shanghai, Zhejiang and Hunan was 1 from 2008 to 2019. The efficiency values of these five provinces constitute the frontier of data envelopment. A vertical comparison in each province showed that the productivity values of the provinces Guangdong, Henan and Inner Mongolia showed an obvious upward trend, and the efficiency values of other provinces did not fluctuate significantly from 2008 to 2019.

Through the horizontal comparison of the average value of the GTFPCI in 30 provinces, it was found that the efficiency value varied greatly among provinces, with the highest being 1 and the lowest being only 0.520, which indicates that the provinces with low efficiency value had great room for improvement, while the average value of the GTFPCI in the east, middle and west showed a decreasing trend and great difference of 0.876, 0.719 and 0.662, respectively. The efficiency value of the eastern region was greater than the national average efficiency value, while the efficiency value of the central and western regions was less than the national average efficiency value. The possible reasons for the above results are the following: the economic foundation, talents, capital, production technology and construction maturity of the eastern region were better than those of the central and western regions, which made the allocation and utilization of construction production factors in the eastern provinces more efficient and reasonable. Thus, the GTFPCI in the eastern region was generally high. Although the central and western regions enjoyed the policy dividends of a “central rise” and “western development”, respectively, their economic development levels were still far from that in the eastern region. In particular, Gansu, Qinghai, Xinjiang and other provinces with low efficiency were in the western region, and there were serious low-efficiency problems in the production of the construction industry in these provinces, which needed to be improved.

4.2. Estimation Result of the Basic Model

In this paper, the annual GTFPCI in each province was used as the dependent variable and three different types of ER were used as the independent variable to explore the linear and nonlinear relationships between the current and lagging ER and the GTFPCI; the results are shown in Table 5. The results of AR (2) estimation and the Sargan test indicated the absence of second-order sequence correlation in random error terms, with all R² values exceeding 0.65, suggesting a high level of model fitting.

(1) Relationship between the CER and GTFPCI: The CER and GTFPCI in the current period were not significant in the regression of the two models, which showed that the impact of the CER in the current period on the GTFPCI was small and can be ignored. The regression results of the one-year lag model show that there was a significant positive correlation between the lag term of the CER and GTFPCI, and this correlation is a U-shaped relationship rather than a linear relationship (the coefficient of the first-order term is negative, and the coefficient of the square term is positive). With the increase in CER from 0.003, the GTFPCI first decreased and then increased, which shows that the government’s mandatory policy can promote the improvement in GTFPCI only after it is promulgated for a period of time and reaches a certain intensity. Therefore, the government should promulgate environmental regulations with appropriate intensity, increase punishment and promote technical improvement in the construction industry.

(2) Relationship between the MER and GTFPCI: The MER in the current period and MER in the lag period have an inverted U-shaped relationship with the GTFPCI (the coefficient of the first order is positive, and the coefficient of the square order is negative). The GTFPCI first increased and then decreased with the increase in MER, and the relationship between the MER in the lag period and GTFPCI was more significant than that in the current period. The above relationship shows that due to the regulatory role of the market, the MER has a more significant impact on the GTFPCI in the lag period. To a certain extent, the increase in MER intensity will “force” enterprises to carry out reform,

so that the GTFPCI will increase. Once the MER intensity exceeds a specific value, the construction industry has to invest more funds in pollution control, which will reduce the production investment of other items in the construction industry, resulting in the reduction in total factor productivity.

(3) Relationship between the VER and GTFPCI: The current VER and lag VER were positively correlated and linear with the GTFPCI. The masses reflect the environmental problems caused by enterprise production to the government through letters and other means. The government will manage enterprise production under the pressure of public opinion, so as to promote the improvement in the GTFPCI.

Table 5. Dynamic panel regression results.

Variable	No Lag		One-Year Lag	
	Linear Model	Square Term Model	Linear Model	Square Term Model
CER	−0.207 (−1.31)	−0.909 (−1.36)	−0.118 (−1.18)	−1.755 ** (−2.07)
CER ²		0.756 (1.04)		0.637 *** (3.09)
MER	0.119 (1.07)	2.352 ** (2.07)	0.167 ** (2.63)	3.344 *** (3.50)
MER ²		−0.109 ** (−2.59)		−0.101 *** (−2.80)
VER	0.006 * (1.82)	0.146 (1.15)	0.092 ** (2.51)	0.300 (0.06)
VER ²		−0.090 (−1.55)		−0.024 (−0.89)
R&D	0.300 ** (2.40)	0.410 ** (2.00)	0.022 * (1.85)	0.040 * (1.88)
GDP	0.015 * (1.73)	−0.020 * (−1.77)	0.003 (0.03)	0.000 (0.38)
FDI	0.134 * (1.80)	0.256 * (1.90)	0.039 * (1.88)	0.042 (0.12)
Constant	0.048 *** (3.89)	0.091 *** (3.28)	−0.001 *** (−3.03)	−0.112 *** (−3.10)
R ²	0.654	0.747	0.705	0.819
Diagnostic test	Statistic	p-value	Statistic	p-value
AR (1)	−3.190	0.000	−1.600	0.000
AR (2)	0.251	0.8012	0.546	0.584
Sargan test	13.712	0.3195	17.798	0.401
Wald test	5522.73 ***	0.000	7440.42 ***	0.000

Note: The data in parentheses are the Z-values, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Based on the above research, it was found that the relationship between the three environmental regulations and China's GTFPCI are different. Among them, the relationship between the GTFPCI and MER in the current period and lag period passed the 5% significance test, which shows that among the three environmental regulations, the MER has the most far-reaching impact on the GTFPCI.

Among the three control variables, only R&D showed a significant positive strong correlation with the GTFPCI in the regression results of all models, which shows that the impact of scientific research investment on the GTFPCI is very far-reaching. Although the

other three control variables had a certain impact on the GTFPCI of the current period, they had a weak impact on the GTFPCI of subsequent years.

4.3. Spatial Correlation Test

Referring to previous studies, in this paper, the 0–1 weight matrix (W1), reciprocal geographical distance weight matrix (W2) and four distance threshold matrices were used to calculate the Moran index of the GTFPCI. The calculation results are shown in Table 6. From the results, all Moran indexes were greater than 0 and most Moran indexes passed the significance test, which shows that the GTFPCI had obvious positive spatial correlation in all years and under all threshold conditions. Under different weight matrices, the Moran index showed an increasing trend with the increase in years, which showed that the relationship between the construction industry in various provinces became closer and closer, and the correlation was also increasing, which is similar to the results of previous studies [63].

Table 6. Calculation results of the Moran index.

Year	Indicator	W1	W2	W500KM	W1000KM	W1500KM	W2000KM
2008	Moran's I	0.237 ***	0.531 ***	0.215 **	0.207 *	0.165 *	0.098
	Z-value	2.985	2.543	2.554	3.850	1.970	2.400
2009	Moran's I	0.254 ***	0.345 ***	0.222 ***	0.198 *	0.176 *	0.093
	Z-value	2.006	2.333	2.897	2.218	2.156	2.563
2010	Moran's I	0.263 ***	0.365 ***	0.233 ***	0.201 *	0.195 *	0.098
	Z-value	2.638	2.537	3.789	3.287	2.140	4.044
2011	Moran's I	0.269 ***	0.397 ***	0.240 **	0.211 **	0.199 *	0.100
	Z-value	3.655	2.165	1.678	2.276	3.569	1.345
2012	Moran's I	0.273 ***	0.412 ***	0.257 **	0.236 **	0.220 *	0.113 *
	Z-value	2.689	3.469	2.861	3.700	2.264	3.321
2013	Moran's I	0.305 ***	0.473 ***	0.297 *	0.256 **	0.237 *	0.123 *
	Z-value	3.573	1.269	2.708	4.176	2.975	3.809
2014	Moran's I	0.325 ***	0.489 ***	0.301 *	0.272 **	0.258 **	0.138
	Z-value	2.678	2.826	4.174	3.618	2.973	2.772
2015	Moran's I	0.332 ***	0.501 ***	0.311 ***	0.283 **	0.279 *	0.155 **
	Z-value	1.497	2.379	3.561	2.360	2.539	3.367
2016	Moran's I	0.357 ***	0.546 ***	0.324 *	0.307 *	0.293 *	0.175 *
	Z-value	2.604	2.847	3.698	2.991	2.503	1.197
2017	Moran's I	0.373 ***	0.550 ***	0.338 **	0.314 **	0.302 *	0.186
	Z-value	2.316	3.437	2.913	3.864	3.965	4.032
2018	Moran's I	0.385 ***	0.563 ***	0.350 ***	0.330 **	0.317 *	0.194 *
	Z-value	2.289	2.443	3.113	3.147	3.369	2.443
2019	Moran's I	0.404 ***	0.587 ***	0.368 *	0.351 ***	0.335 **	0.207 *
	Z-value	2.289	2.581	2.442	2.113	3.912	3.447

Note: ***/**/* significant at 1%, 5% and 10%, respectively.

In this paper, Moran index scatter charts for 2008 and 2019 were drawn according to the 0–1 weight matrix. The role of the Moran scatter chart was to investigate the correlation of the GTFPCI among provinces, which was divided into four quadrants according to different correlation relations. When a province was in the first or third quadrant, this

indicated that the province had a positive spatial auto-correlation, while when a province was in the second or fourth quadrant, this indicated that the province had a negative spatial auto-correlation. If the provinces were evenly distributed in the four quadrants, this indicated that there was no spatial correlation among the provinces.

As can be seen from Figures 1 and 2, most provinces were distributed in the first and third quadrants, which shows that most provinces had a positive spatial auto-correlation relationship of the GTFPCI. When the GTFPCI in these provinces was high, neighboring provinces would be affected, resulting in an increase in total factor productivity. By comparing Figures 1 and 2, it can be seen that the provinces originally in the second quadrant in Figure 1 were transferred to the first or third quadrant in Figure 2, and the total number of provinces in the second and fourth quadrants in Figure 2 was less than that in Figure 1, which shows the improvement in spatial agglomeration. The rise in the number of provinces exhibiting positive spatial auto-correlation suggests that the construction industry's production was increasingly influenced by neighboring provinces. Enterprises should draw on the advanced experiences of neighboring provinces to enhance their own green production efficiency.

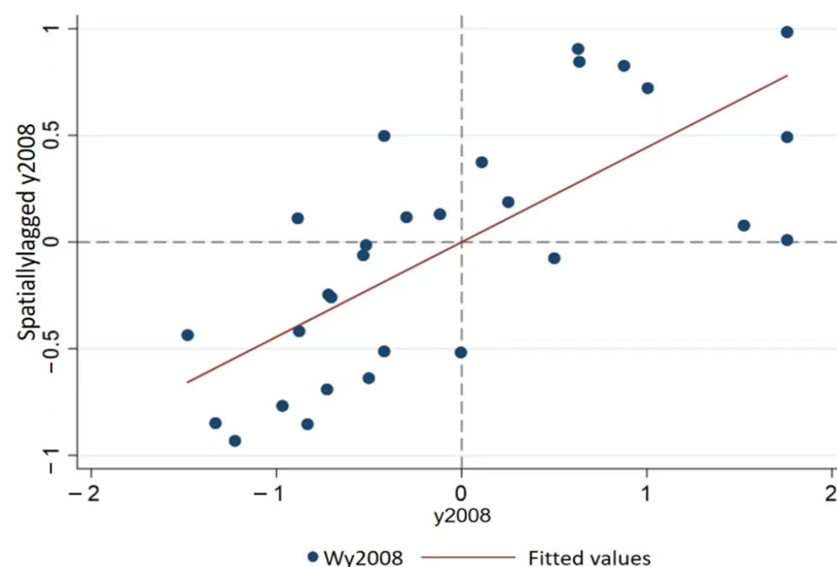


Figure 1. Moran index chart in 2008.

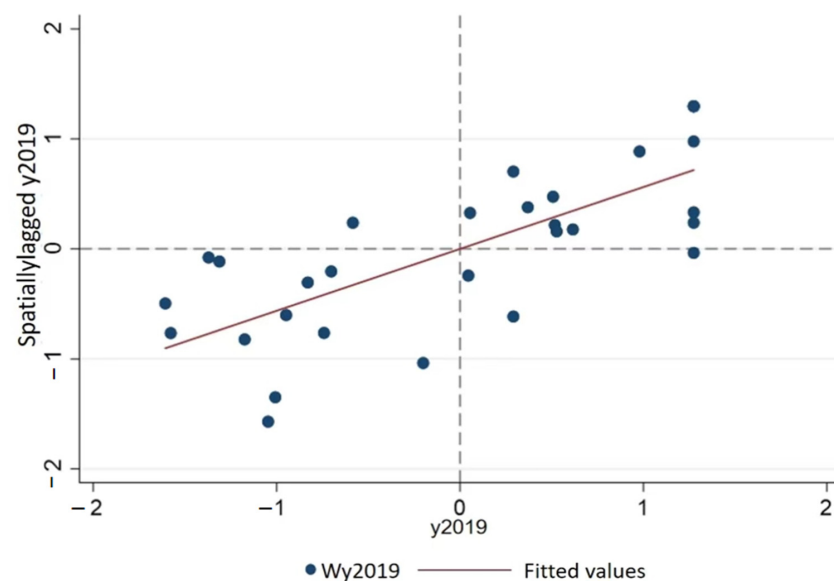


Figure 2. Moran index chart in 2019.

4.4. Estimation Results of the Spatial Effect

In the spatial weight matrix based on these six values in Table 7, the coefficients of W^*CER and W^*MER are negative, while W^*CER^2 and W^*MER^2 are positive, and these results are highly significant, indicating that the GTFPCI in one region was obviously affected by the CER and MER in adjacent regions, presenting a “U” relationship. The relationship between the GTFPCI and VER in adjacent areas also presented a “U” shape, but it was significant only in a few models, and this significance was poor. The reason for this result may be that under the increasingly strict policies such as local fines and charges, many construction enterprises with backward production and high pollution moved to adjacent areas, which reduced the GTFPCI of the adjacent areas to a certain extent. However, with the continuous improvement in local regulatory mechanisms, enterprises will choose to adopt technological innovation and other ways to reduce operating costs and the amount of pollutant discharge fees. However, because the impact of the VER on the local GTFPCI was indirect and the lag was obvious, the impact of the VER in adjacent areas was not obvious.

Table 7. The regression results of the moderating effect.

Variable	W_1	W_2	W_{500KM}	W_{1000KM}	W_{1500KM}	W_{2000KM}
CER	−0.909 **	−0.847 **	−0.902 **	−0.904 *	−0.912	−0.910
	(−3.36)	(−2.25)	(−2.40)	(−1.65)	(−1.37)	(−1.41)
CER^2	1.756 **	1.659 **	1.772 **	1.740 *	1.766 *	1.763 *
	(2.04)	(2.27)	(2.09)	(1.73)	(1.84)	(1.85)
MER	0.352 *	0.395 *	0.312	0.356 *	0.280	2.76
	(1.67)	(1.83)	(1.58)	(1.69)	(1.40)	(1.38)
MER^2	−0.109 **	−0.120 ***	−0.097 **	−0.105 **	−0.077 **	−0.075 **
	(−2.59)	(−3.73)	(−2.55)	(−2.58)	(−2.21)	(−2.16)
VER	−0.146	−0.138 *	−0.133 *	−0.136	−0.103	−0.110
	(−1.15)	(−1.71)	(−1.08)	(−1.01)	(−1.03)	(−1.55)
VER^2	0.090	0.080	0.080	0.085	0.055	0.060
	(1.55)	(1.31)	(1.30)	(1.40)	(1.06)	(1.03)
W^*CER	−1.496 **	−1.401 **	−1.479 **	−1.605 **	−1.495 *	−1.632 *
	(−2.58)	(−2.43)	(−2.66)	(−2.00)	(−1.89)	(−1.95)
W^*CER^2	4.634 **	4.373 **	4.650 **	4.955 *	4.634 *	5.206 *
	(2.57)	(2.53)	(2.68)	(1.88)	(1.88)	(1.77)
W^*MER	−0.289 ***	−0.257 ***	−0.279 ***	−0.274 **	−0.285 **	−0.330 **
	(−3.07)	(−2.91)	(−2.96)	(−2.01)	(−2.03)	(−2.37)
W^*MER^2	0.089 ***	0.077 ***	0.085 ***	0.080 **	0.088 **	0.097 *
	(3.58)	(3.45)	(3.48)	(2.54)	(2.58)	(1.72)
W^*VER	−0.005 *	−0.007 **	0.005 *	−0.009 *	−0.007	−0.003
	(−1.70)	(−2.14)	(1.82)	(−1.81)	(−1.13)	(−1.06)
W^*VER^2	0.025 **	0.023 **	0.014 **	0.029	0.025 *	0.027
	(2.09)	(2.18)	(2.57)	(1.07)	(1.89)	(0.98)
ED	0.028 ***	0.031 ***	0.029 **	0.051 *	0.029 ***	0.035 ***
	(3.38)	(3.85)	(2.43)	(1.66)	(3.56)	(3.71)

Table 7. Cont.

Variable	W ₁	W ₂	W _{500KM}	W _{1000KM}	W _{1500KM}	W _{2000KM}
CER*ED	0.119 **	0.108 **	0.050 *	0.784 *	0.736 *	0.256 **
	(2.65)	(2.65)	(1.76)	(1.82)	(1.66)	(1.74)
MER*ED	0.014 **	0.042 ***	0.007 **	0.005 ***	0.027 ***	0.004 **
	(2.67)	(3.51)	(2.38)	(3.18)	(3.50)	(2.25)
VER*ED	0.045 *	0.004 **	0.009 *	0.015 *	0.005 *	0.003 *
	(1.69)	(1.68)	(1.83)	(1.69)	(1.68)	(1.83)
W*ED	−0.001 *	−0.002 *	−0.001 *	−0.002 *	−0.002 *	−0.000 *
	(−1.69)	(−1.71)	(−1.75)	(−1.65)	(−1.80)	(−1.82)
W*CER*ED	0.002 **	0.002 **	0.004 **	0.002 **	0.002 **	0.000 **
	(2.73)	(2.72)	(2.52)	(2.66)	(2.67)	(2.22)
W*MER*ED	0.016 ***	0.016 ***	0.015 ***	0.016 ***	0.016 ***	0.014 ***
	(3.71)	(3.70)	(3.57)	(3.73)	(3.71)	(3.68)
W*VER*ED	0.030 *	0.030 *	0.028 *	0.029 *	0.030 *	0.004
	(1.80)	(1.82)	(1.65)	(1.81)	(1.81)	(0.60)
R&D	0.140 ***	0.300 ***	0.203 ***	0.235 ***	0.159 ***	0.345 ***
	(3.78)	(3.96)	(3.16)	(3.64)	(4.89)	(4.78)
GDP	0.017 ***	0.023 ***	0.035 ***	0.028 ***	0.036 ***	0.057 ***
	(4.60)	(4.03)	(4.89)	(4.86)	(4.65)	(4.53)
FDI	0.134 ***	0.123 ***	0.278 ***	0.333 ***	0.456 ***	0.037 ***
	(3.00)	(3.24)	(3.61)	(−3.12)	(3.09)	(3.08)
Constant	−1.467	−1.488	−1.276	−1.507	−1.506	−0.559
	(−0.85)	(−0.86)	(−0.73)	(−0.89)	(−0.87)	(−0.34)
Spatial rho	0.725 ***	0.749 ***	0.729 ***	0.680 ***	0.661 ***	0.680 ***
	(10.11)	(10.74)	(9.90)	(8.84)	(9.51)	(27.57)
Variance sigma ²	0.003 ***	0.003 ***	0.005 ***	0.006 ***	0.010 ***	0.004 ***
	(3.63)	(3.73)	(3.64)	(3.38)	(3.36)	(3.72)

Note: The data in brackets are the Z-values, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The estimated coefficients of the ED are positive, which shows that the improvement in environmental decentralization was conducive to the improvement in the GTFPCI to a certain extent, better mobilizing the subjective initiative, promoting enterprise reform and achieving sustainable development, which is similar to the results of previous studies [45]. The W*ED estimation coefficient was negative, which indicates that the increase in the ED value in this region reduced the GTFPCI in adjacent regions. This is because with the increase in the ED value in this region, the environmental supervision in this region became strict, which made some highly polluting construction enterprises choose to migrate to adjacent regions, resulting in the decline in the GTFPCI in adjacent regions.

The estimated coefficients of the interaction terms of the three types of ERs and ED were positive and significant at the 5% confidence level, which shows that with the improvement in the degree of environmental decentralization, the decentralization of rights improved the autonomy of local governments, could better fulfill the responsibility of environmental supervision and played a better regulatory role in the production activities of construction enterprises, The estimated coefficient of MER*ED was the largest and most significant at a level of 1%, which indicates that the collection of pollutant discharge fees most effectively promoted the green and sustainable production of the construction

industry, and the decentralization of regulatory power made the collection and verification of pollutant discharge fees by local governments more efficient. The estimated coefficients of W^*CER^*ED , W^*VER^*ED and W^*MER^*ED were positive, which shows that the spillover effect of their interaction on the GTFPCI in other regions was positive. Environmental decentralization positively regulated the spatial spillover effect of the CER at a confidence significance level of 5%, which means that the improvement in environmental regulations and the enhancement of environmental supervision in the surrounding areas put great pressure on local construction enterprises, so that enterprises could carry out independent research and development and improve their GTFPCI, so as to avoid being punished or paying huge environmental charges. Under the confidence significance level of 1%, environmental decentralization positively regulated the spatial spillover effect of the MER. The economic incentive environmental regulation is to collect pollutant discharge fees from enterprises, so as to encourage enterprises to improve their technology. Due to technology spillover, it will promote the improvement in the GTFPCI in adjacent areas. The spatial spillover effect of the VER had limited impact on the GTFPCI of other adjacent areas and could not drive the progress of the GTFPCI in adjacent areas.

4.5. Dynamic Threshold Model Regression Results

In relevant studies, it was found that there is a certain threshold effect on the regulatory effect of environmental decentralization on the GTFPCI and environmental regulation in some industries. In order to verify whether this law also existed in the construction industry, this paper established a panel threshold model for analysis. Before threshold regression, the number and size of relevant thresholds needed to be calculated. The calculation results are shown in Tables 8 and 9.

Table 8. Results of threshold effect tests.

Model	Threshold Variable	Model	F-Statistic	p-Value	Critical Value		
					10%	5%	1%
CER	ED	Single threshold	40.12	0.0000	20.870	34.927	50.253
		Double threshold	51.70	0.0333	27.596	38.504	60.615
MER	ED	Single threshold	31.09	0.0267	18.9282	22.212	36.886
		Double threshold	16.19	0.1000	18.2879	22.877	32.799
VER	ED	Single threshold	16.07	0.2433	25.951	33.513	62.794
		Double threshold	4.58	0.7833	20.0249	27.838	41.464

Table 9. Threshold estimators and confidence intervals.

Model	Threshold Variable	Threshold Number	Threshold Estimator	95% Confidence Interval
CER	ED	Single threshold	0.5275	[0.4281, 0.5318]
	ED	Double threshold	0.8562	[0.8389, 0.8567]
MER	ED	Single threshold	0.6239	[0.6208, 0.6302]

In Table 8, the single threshold and double threshold tests of environmental decentralization on the CER passed at the significance level of 5%, and the thresholds were 0.5275 and 0.8562, respectively. The single threshold effect of the ED on MER regulation passed the test of the 1% significance level, but the double threshold test did not pass, which indicates that there was a threshold in Formula (15), and it can be seen in Table 9 that the threshold was 0.6239. The single threshold test and double threshold test of environmental decentralization on the VER regulation failed, which indicates that there was no threshold.

Table 10 shows that when $ED \leq 0.5275$, the impact of the CER on the GTFPCI was positive at the confidence level of 1%, and the correlation coefficient was 0.173, indicating that the increase in CER intensity led to the increase in the GTFPCI. When $0.5275 < ED \leq 0.8562$, the impact of the CER on the GTFPCI was positive at the confidence level of 1%, but the correlation coefficient increased to 0.336, which means that with the increase in the ED, the impact of the CER on the GTFPCI also increased. When $0.8562 < ED$, the impact of the CER on the GTFPCI was negative at the 1% confidence level, which shows that when the ED was greater than a certain value, the CER had a negative impact on the GTFPCI. One possible reason is that when environmental monitoring is too harsh, enterprises have to spend a lot of money on rectification. The available funds for construction production activities are reduced, so the green production efficiency is reduced.

Table 10. Threshold model regression results.

Model 1		Model 2	
Variable	Double Threshold Model	Variable	Double Threshold Model
CER ($ED \leq 0.5275$)	0.173 *** (4.83)	MER ($ED \leq 0.6239$)	0.441 *** (3.90)
CER ($0.5275 < ED \leq 0.8562$)	0.336 *** (4.74)	MER ($0.6239 < ED$)	0.562 *** (8.73)
CER ($0.8562 < ED$)	−0.541 *** (−3.56)		
R&D	0.333 *** (3.19)	R&D	0.376 *** (3.57)
GDP	0.015 * (1.72)	GDP	0.035 * (1.66)
FDI	0.157 ** (2.32)	FDI	0.213 *** (2.45)
Constant	0.186 *** (6.50)	Constant	0.233 *** (7.80)
Within R2	0.5735	Within R2	0.6899
F test	33.24 ***	F test	54.97 ***
F test all vi = 0	18.86 ***	F test all vi = 0	25.57 ***

Note: The data in brackets are the Z-values ***/**/* significant at 1%, 5% and 10%, respectively.

When the $ED \leq 0.6239$, the impact of the MER on GTFPCI was positive at the confidence level of 1%, and the correlation coefficient was 0.441, which indicates that when the ED value was within this interval, the regulatory effect of the CER on GTFPCI was positive. The intensity of environmental decentralization and economic incentive environmental regulation cooperate with each other to make the production activities of the construction industry move toward green and sustainable development. When $0.6239 < ED$, the impact of the MER on the GTFPCI was positive at the 1% confidence level, and the correlation coefficient became 0.562. In this range, the degree of environmental decentralization is high, and the increase in the number of environmental supervisors in various provinces makes environmental supervision and sewage charge collection more efficient, which can better promote construction enterprises to improve production technology and produce green and energy-saving products.

5. Conclusions

This paper synthesized the construction industry panel data of 30 provinces in China from 2008 to 2019 into three models, the linear regression model, spatial Dobbin model and dynamic threshold panel model, to investigate the effects of the ER and ED on the GTFPCI. Based on the results obtained, the following policy suggestions are put forward:

(1) The GTFPCI has obvious regional differences and strong spatial auto-correlation. The average productivity of the eastern, central and western regions decreased in turn, which indicates that the GTFPCI was affected not only by the local economy, science and technology and policies, but also by the spillover effects of various factors in adjacent regions. When formulating relevant construction policies, the Chinese government should adjust measures to local conditions and take into account the economic development level, scientific and technological level, and spatial layout of different regions. Especially in

the western region, the government should formulate relevant policies to reduce the gap with the eastern and central construction industries, protect the environment and achieve sustainable development. The western construction industry should also strengthen its production technology exchange with the eastern and central construction industries, actively improve its production technology, and achieve the “win-win” goal of improving production and protecting the environment.

(2) The impact of the three environmental regulations on the production activities of China’s construction industry was heterogeneous. The CER, MER, VER were shown to have a U-shaped, inverted U-shaped and linear positive correlation with GTFPCI, respectively, which indicates that the heterogeneity of the impact mechanism of different environmental regulations on the GTFPCI and the three environmental regulations should be adjusted in an appropriate intensity range to jointly promote the improvement in the GTFPCI. The GTFPCI will be directly affected by local environmental regulations and the spillover effect of environmental regulations in adjacent areas. When relevant environmental regulatory policies are issued in adjacent areas, a region should also keep up with the situation and issue and implement environmental regulations suitable for the region. Among the three environmental regulations, the MER has the most obvious impact on the GTFPCI. Local governments need to consider the inverted U-shaped relationship between the two and set the collection standard of a pollutant discharge fee in the most reasonable range, so as to “force” enterprises to carry out technological reform and achieve sustainable development. At the same time, local governments should improve their environmental supervision systems and encourage the public to report and expose corporate pollution.

(3) The regression results of the linear regression model and spatial Dobbin model showed that the interaction between the ER and ED was positive, which indicates that the ED plays a positive regulatory role between the ER and GTFPCI as a whole. However, the interaction between environmental regulation and the ED in adjacent areas had a negative spillover effect on this area, which shows that the combination of ER and ED in adjacent areas will have a great negative impact on the GTFPCI in this area. In short, the central government must delegate environmental related rights to local governments to a certain extent, but control the scale of decentralization. When facing the impact of environmental decentralization and environmental regulation in adjacent areas, local governments should also respond in time, formulate corresponding environmental policies for different types of ER and jointly promote the improvement in the GTFPCI.

Author Contributions: Z.Y. proposed the original concept and methods and finished the first draft. H.F. supervised the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: The research was funded by projects of Beijing University of Civil Engineering and Architecture, project numbers 05080923006, X23020, and 05080924003.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Umberto, B. Clarifying the new interpretations of the concept of sustainable building. *Sustain. Cities Soc.* **2013**, *8*, 72–78. [CrossRef]
2. China Association of Building Energy Efficiency. China Building Energy Consumption Research Report. 2020. Available online: <https://www.cabee.org/site/content/24020.html> (accessed on 1 June 2022).
3. Chen, J.; Shen, L.; Song, X.; Shi, Q.; Li, S. An empirical study on the CO₂ emissions in the Chinese construction industry. *J. Clean. Prod.* **2017**, *168*, 645–654. [CrossRef]

4. Chakraborty, P.; Chatterjee, C. Does environmental regulation indirectly induce upstream innovation? New evidence from India. *Res. Policy* **2017**, *46*, 939–955. [\[CrossRef\]](#)
5. Rubashkina, Y.; Galeotti, M.; Verdolini, E. Environmental regulation and competitiveness: Empirical evidence on the Porter Hypothesis from European manufacturing sectors. *Energy Policy* **2015**, *83*, 288–300. [\[CrossRef\]](#)
6. Liu, Y.; Li, Z.; Yin, X. The effects of three types of environmental regulation on energy consumption—Evidence from China. *Environ. Sci. Pollut. Res.* **2018**, *25*, 27334–27351. [\[CrossRef\]](#) [\[PubMed\]](#)
7. Ren, S.; Li, X.; Yuan, B.; Li, D.; Chen, X. The effects of three types of environmental regulation on eco-efficiency: A cross-region analysis in China. *J. Clean. Prod.* **2018**, *173*, 245–255. [\[CrossRef\]](#)
8. Li, H.; Zhou, L.A. Political turnover and economic performance: The incentive role of personnel control in China. *Public Econ.* **2005**, *89*, 1743–1762. [\[CrossRef\]](#)
9. Lewis, A. *Economic Development with Unlimited Supplies of Labor*; Manchester School of Economics and Social Studies: Manchester, UK, 1954.
10. Yang, X.; Jia, Z.; Yang, Z. How does technological progress impact transportation green total factor productivity: A spatial econometric perspective. *Energy Rep.* **2021**, *7*, 3935–3950. [\[CrossRef\]](#)
11. Pittman, R.W. Multilateral comparisons with undesirable outputs. *Econ. J.* **1983**, *93*, 883–891.
12. Chen, Y.; Miao, J.; Zhu, Z. Measuring green total factor productivity of China's agricultural sector: A three-stage SBM-DEA model with non-point source pollution and CO₂ emissions. *J. Clean. Prod.* **2021**, *318*, 128543. [\[CrossRef\]](#)
13. Cao, X.; Deng, M.; Li, H. How does e-commerce city pilot improve green total factor productivity? Evidence from 230 cities in China. *J. Environ. Manag.* **2021**, *289*, 112520. [\[CrossRef\]](#) [\[PubMed\]](#)
14. Feng, C.; Huang, J.-B.; Wang, M. Analysis of green total-factor productivity in China's regional metal industry: A meta-frontier approach. *Resour. Policy* **2018**, *58*, 219–229. [\[CrossRef\]](#)
15. Shi, X.; Li, L. Green total factor productivity and its decomposition of Chinese manufacturing based on the MML index: 2003–2015. *J. Clean. Prod.* **2019**, *222*, 998–1008. [\[CrossRef\]](#)
16. Sinn, H.W. Public policies against global warming: A supply side approach. *Int. Tax Public Financ.* **2008**, *15*, 360–394. [\[CrossRef\]](#)
17. Reyer, G. Too much oil. *Work. Pap.* **2010**, *57*, 79–102.
18. Ploeg, F.; Withagen, C. Is there really a green paradox? *J. Environ. Econ. Manag.* **2012**, *64*, 342–363. [\[CrossRef\]](#)
19. Fünfgelt, J.; Schulze, G.G. Endogenous environmental policy for small open economies with transboundary pollution. *Econ. Model.* **2016**, *57*, 57294–57310. [\[CrossRef\]](#)
20. Dirckinck-Holmfeld, K. The options of local authorities for addressing climate change and energy efficiency through environmental regulation of companies. *J. Clean. Prod.* **2015**, *98*, 175–184. [\[CrossRef\]](#)
21. Hancevic, P.I. Environmental regulation and productivity: The case of electricity generation under the CAAA-1990. *Energy Econ.* **2016**, *60*, 131–143. [\[CrossRef\]](#)
22. Porter, M.E. America's Green Strategy. *Sci. Am.* **1991**, *4*, 1–5.
23. Porter, M.E.; Linde, C.V.D. Toward a New Conception of the Environment-Competitiveness Relationship. *J. Econ. Perspect.* **1995**, *4*, 97–118. [\[CrossRef\]](#)
24. Brunnermeier, S.B.; Cohen, M.A. Determinants of environmental innovation in US manufacturing industries. *Environ. Econ. Manag.* **2003**, *45*, 278–293. [\[CrossRef\]](#)
25. Wagner, M. On the relationship between environmental management, environmental innovation and patenting: Evidence from German manufacturing firms. *Res. Policy* **2007**, *36*, 1587–1602. [\[CrossRef\]](#)
26. Chintrakarn, P. Environmental regulation and US states' technical inefficiency. *Econ. Lett.* **2008**, *100*, 363–365. [\[CrossRef\]](#)
27. Albrizio, S.; Kozluk, T.; Zipperer, V. Environmental policies and productivity growth: Evidence across industries and firms. *Environ. Econ. Manag.* **2017**, *81*, 209–226. [\[CrossRef\]](#)
28. Li, C.; Wei, W. Empirical study of environmental regulation in northwest China on TFP (total factor productivity). *Arid Land Resour. Environ.* **2014**, *28*, 14–19.
29. Tang, D.; Tang, J.; Ma, T. Environmental regulation efficiency and TFP in China—Econometric explanation based on SBM—Undesirable and DEA—Malmquist. *J. Arid Land Resour. Environ.* **2016**, *30*, 7–12.
30. Wang, H. Comparison and selection of environmental regulation policy in China: Based on Bayesian model averaging approach. *China Popul. Resour. Environ.* **2016**, *26*, 132–138.
31. Zhang, J.X.; Liu, Y.M.; Chang, Y.; Zhang, L.X. Industrial eco-efficiency in China: A provincial quantification using three-stage data envelopment analysis. *J. Clean. Prod.* **2017**, *143*, 238–249. [\[CrossRef\]](#)
32. Fontana, S.; D'Amico, E.; Coluccia, D.; Solimene, S. Does environmental performance affect companies' environmental disclosure? *Meas. Bus. Excel.* **2015**, *19*, 42–57. [\[CrossRef\]](#)
33. Wang, N. The role of the construction industry in China's sustainable urban development. *Habitat Int.* **2014**, *44*, 442–450. [\[CrossRef\]](#)
34. Gouldson, A.; Carpenter, A.; Afionis, S. An international comparison of the outcomes of environmental regulation. *Environ. Res. Lett.* **2014**, *9*, 074019. [\[CrossRef\]](#)

35. Wang, X.; Zhang, C.; Zhang, Z. Pollution haven or porter? The impact of environmental regulation on location choices of pollution-intensive firms in China. *Environ. Manag.* **2019**, *248*, 109248. [CrossRef]
36. Chen, X.; Qian, W. Effect of marine environmental regulation on the industrial structure adjustment of manufacturing industry: An empirical analysis of China's eleven coastal provinces. *Mar. Policy* **2020**, *113*, 103797. [CrossRef]
37. Shehabi, M. Diversification effects of energy subsidy reform in oil exporters: Illustrations from Kuwait. *Energy Policy* **2020**, *138*, 110966. [CrossRef]
38. Wu, H.; Hao, Y.; Ren, S. How do environmental regulation and environmental decentralization affect green total factor energy efficiency: Evidence from China. *Energy Econ.* **2020**, *91*, 104880. [CrossRef]
39. Wu, H.; Li, Y.; Hao, Y.; Ren, S.; Zhang, P. Environmental decentralization, local government competition, and regional green development: Evidence from China. *Sci. Total Environ.* **2020**, *708*, 135085. [CrossRef] [PubMed]
40. Chatterjee, S.; Karmakar, A.K. Asymmetric Information, Non-cooperative Games and Impatient Agents: Modelling the Failure of Environmental Awareness Campaigns. In *Analytical Issues in Trade, Development and Finance*; India Studies in Business and Economics Book Series; Springer: Berlin/Heidelberg, Germany, 2014; pp. 241–249.
41. Garcia-Valiñas, M.A. What level of decentralization is better in an environmental context? An application to water policies. *Environ. Resour. Econ.* **2007**, *38*, 213–229. [CrossRef]
42. Burgess, R.; Hansen, M.; Olken, B.A.; Potapov, P.; Sieber, S. The political economy of deforestation in the tropics. *STICERD—Econ. Organ. Public Policy Discuss. Pap. Ser.* **2012**, *127*, 1707–1754. [CrossRef]
43. Sigman, H. Decentralization and environmental quality: An international analysis of water pollution levels and variation. *Land Econ.* **2014**, *90*, 114–130. [CrossRef]
44. Chang, H.F.; Sigman, H.; Traub, L.G. Endogenous decentralization in federal environmental policies. *Int. Rev. Law Econ.* **2014**, *37*, 39–50. [CrossRef]
45. Goel, R.K.; Mazhar, U.; Nelson, M.A.; Ram, R. Different forms of decentralization and their impact on government performance: Micro-level evidence from 113 countries. *Econ. Model.* **2017**, *62*, 171–183. [CrossRef]
46. Alborno, F.; Cole, M.A.; Elliott, R.J.; Ercolani, M.G. In search of environmental spillovers. *World Econ.* **2009**, *32*, 136–163. [CrossRef]
47. Charnes, A.; Cooper, W.W.; Rhodes, E. Measuring the efficiency of decision making units. *Eur. J. Oper. Res.* **1978**, *2*, 429–444. [CrossRef]
48. Tone, K. A Slacks-Based measure of efficiency in data envelopment analysis. *Eur. J. Oper. Res.* **2001**, *130*, 498–509. [CrossRef]
49. National Bureau of Statistics. China Statistics Yearbook on Construction (2009–2020). Available online: <https://www.zgtjnj.org/navisearch-2-0-0-1-china-0.html> (accessed on 1 June 2022).
50. National Bureau of Statistics. China Energy Statistical Yearbook (2009–2020). Available online: <https://www.zgtjnj.org/navisearch-2-0-0-1-china-0.html> (accessed on 1 June 2022).
51. GB/T 2589-2008; General Principles for Calculation of the Comprehensive Energy Consumption. National Standard of the People's Republic of China: Beijing, China, 2008. Available online: <https://max.book118.com/html/2019/0418/5023341233002030.shtm> (accessed on 1 June 2022).
52. IPCC. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme; IGES: Hayama, Japan, 2006. Available online: <https://www.ipcc.ch/report/2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/> (accessed on 1 June 2022).
53. China Association of Building Energy Efficiency. China Building Energy Consumption Research Report. 2018. Available online: <https://www.cabee.org/site/content/23568.html> (accessed on 1 June 2022).
54. Zheng, D.; Shi, M. Multiple environmental policies and pollution haven hypothesis: Evidence from China's polluting industries. *J. Clean. Prod.* **2017**, *141*, 295–304. [CrossRef]
55. Li, R.; Ramanathan, R. Exploring the relationships between different types of environmental regulations and environmental performance: Evidence from China. *J. Clean. Prod.* **2018**, *196*, 1329–1340. [CrossRef]
56. Shen, N.; Liao, H.; Deng, R.; Wang, Q. Different types of environmental regulations and the heterogeneous influence on the environmental total factor productivity: Empirical analysis of China's industry. *J. Clean. Prod.* **2019**, *211*, 171–184. [CrossRef]
57. National Bureau of Statistics. China Environmental Yearbook (2009–2020). Available online: <https://www.zgtjnj.org/navisearch-2-0-0-1-china-0.html> (accessed on 1 June 2022).
58. National Bureau of Statistics. China Statistical Yearbook (2009–2020). Available online: <https://www.stats.gov.cn/sj/ndsj/> (accessed on 1 June 2022).
59. Zhang, J.; Ouyang, Y.; Ballesteros-P, P.; Li, H.; Philbin, S.P.; Li, Z.; Skitmore, M. Understanding the impact of environmental regulations on green technology innovation efficiency in the construction industry. *Sustain. Cities Soc.* **2021**, *65*, 102647. [CrossRef]
60. Yuan, S.; Wu, Z. Financial openness and Chinese regional growth imbalance: New insight from spatial spillovers. *N. Am. J. Econ. Financ.* **2021**, *57*, 101435. [CrossRef]
61. Guo, R.; Yuan, Y. Different types of environmental regulations and heterogeneous influence on energy efficiency in the industrial sector: Evidence from Chinese provincial data. *Energy Policy* **2020**, *145*, 111747. [CrossRef]

62. Ran, Q.; Zhang, J.; Hao, Y. Does environmental decentralization exacerbate China's carbon emissions? Evidence based on dynamic threshold effect analysis. *Sci. Total Environ.* **2020**, *721*, 137656. [[CrossRef](#)] [[PubMed](#)]
63. Wang, L.; Song, X.; Song, X. Research on the measurement and spatial-temporal difference analysis of energy efficiency in China's construction industry based on a game cross-efficiency model. *J. Clean. Prod.* **2021**, *278*, 123918. [[CrossRef](#)]

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