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Article

Can Environmental Regulation Enhance Green Total Factor Productivity? – Evidence from 107 Cities in the Yangtze River Economic Belt

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Abstract: Promoting green development has become an important way to optimize the ecological and economic structure and promote sustainable development. The Yangtze River Economic Belt is an important economic corridor in China, and it remains to be examined whether the implementation of environmental regulations has enhanced the green total factor productivity (GTFP) of cities. This paper calculates the green total factor productivity of 107 cities within the Yangtze River Economic Belt by using the super-efficient SBM model and the GML index with Chinese city panel data from 2007-2019 and measures the intensity of environmental regulations through textual analysis. The bidirectional fixed-effects model constructed in this paper suggests an inverted U-shaped relationship between environmental regulation and GTFP, which is confirmed by a series of robustness tests. Green technology innovation and advanced industrial structure play a mechanism role in this. In regions with lower levels of green technology and industrial structure, the inverted U-shaped relationship between environmental regulation and green total factor productivity is more significant. In addition, the phenomenon of GTFP rising and then falling because of environmental regulation is more obvious in cities in the middle and upper reaches of the Yangtze River and outside the urban agglomerations. Therefore, when formulating environmental regulation policies, it is necessary to balance the relationship between economic development and environmental protection and harmonize the environment and economic development of the entire Yangtze River Basin.

Keywords: Environmental regulation; Green total factor productivity; Yangtze River Economic Belt

1. Introduction

China has now transitioned from a stage of rapid development to a phase of high-quality growth, shifting from extensive to intensive growth models. In this process, promoting the green development of the economy is conducive to optimizing and upgrading the economic structure, thereby fostering the sustainable development of China's economy. Harmonizing economic growth with ecological and environmental conservation is an inevitable choice for driving the high-quality development of China's economy. The government's role in environmental governance is extremely important. Due to the externality of environmental pollution, which leads to market failure, addressing environmental issues necessitates proactive government action. Environmental regulation has become a crucial measure to support green and sustainable development.

Neoclassical economic growth theory argues that improving production efficiency leads to sustainable economic development. Existing research shows that the improvement of total factor productivity (TFP) is the accumulation and improvement of productivity factors and is an effective way to optimize economic development (Ploeg et al., 2000). Neoclassical economic growth theory emphasizes that total factor productivity is the source of sustained economic growth, and the continuous improvement of total factor productivity is the sustained driving force of national and regional economic growth. As China's economy shifts from rapid expansion to high-quality development, it is imperative to improve total factor productivity (Xu et al., 2023). Traditional TFP calculations ignore resource and environmental factors, which are important components of the green transition. Therefore, based on TFP, green TFP comprehensively considers the impact of

economic activities on energy and the environment, and includes undesirable output in terms of output variables, which can comprehensively reflect the efficiency of a region in terms of energy utilization, environmental protection, and economic development, that is, the relationship between local economic development and environmental protection.

In the context of green development and transformation, it remains to be explored whether environmental regulation can promote the improvement of green TFP, especially for the cities in the Yangtze River Economic Belt, which connects the western, central, and eastern regions of China. The Yangtze River Economic Belt occupies an important position in the economic development pattern of our country. In 2022, the GDP of the Yangtze River Economic Belt region will reach 55.976.6 billion yuan, accounting for about 46 percent of China's GDP. The Yangtze River Economic Belt has unique ecological resources, including forest resources, water resources, wetland resources, biological resources, and so on, which also occupies an important position in the construction of ecological civilization in our country. Promoting environmental protection and economic development in the Yangtze River Economic Belt has far-reaching significance for the overall sustainable development of our country. Therefore, in the context of promoting the high-quality development of the Yangtze River Economic Belt, it is of certain practical significance to explore whether the implementation of environmental regulation policies by local governments affects the local green TFP(GTFP).

This paper uses the text analysis method to measure the intensity of environmental regulation and uses the super efficiency SBM model and GML index to estimate the GTFP of 107 cities in the Yangtze River Economic Belt. The results aim to shed light on the intrinsic relationship between these two factors and provide valuable insights for the formulation of relevant policies.

The three main innovative aspects of this paper are as follows: (1) The framework of the level of environmental regulation is constructed in an innovative way. Most of the literature only focuses on a single environmental regulation policy, which cannot fully reflect the government's environmental governance policy and the strength of policy implementation. Therefore, this paper draws on the practice of existing literature (Chen S. & Chen, 2018; Zhang J. & Chen, 2021), conducted text analysis on the government work report, and obtained the level of local environmental regulation. Based on the existing research, this paper constructs the index system of environmental protection words, selects environmental protection words again, and more comprehensively reflects the environmental regulation strength of local governments in the current year. (2) As for the relationship between environmental regulation and green TFP, the academia has not reached a conclusion on the relationship between environmental regulation and green TFP. This paper constructs and measures the green TFP in the Yangtze River Economic Belt, and empirically analyzes the impact of environmental regulation on green TFP from the perspective of green technology innovation and the optimization of industrial structure, to provide reference for the quantitative research on the development quality of the Yangtze River Economic Belt. (3) It attempts to explore the impact and mechanisms of environmental regulation on green TFP in the Yangtze River Economic Belt. There are few studies on the impact of environmental regulation on green TFP in the Yangtze River Economic Belt, and most of them start from the perspective of manufacturing and industrial enterprises (Yin et al., 2022; Yin & Wu, 2021), rarely in-depth discussion on the impact on the green TFP at the city level. It also has important reference value for green transformation and sustainable development of other developing countries and regions.

2. Materials and Methods

2.1. Literature Review

This section provides a literature review of environmental regulation, green total factor productivity, and the Yangtze River economic belt, respectively.

2.1.1. Research on Environmental Regulation

Although there is no unified official definition of the connotation of environmental regulation, the academic understanding of it is broadly converging. Regulation is the government through the

development of standards and other means to solve the economic subject in the process of the behavior of negative externalities and other market failures (Crafts, 2006; Y. Zhao et al., 2009). Environmental regulation has an important impact on the environment and economy.

In terms of environmental effects, the impact is mainly reflected in the direct emission reduction effect and spatial spillover effect. Environmental regulation represented by the government's energy-saving procurement policy can improve the energy structure in the initial stage of production, innovate production technology in the production process, improve pollution treatment capacity at the production the terminal, and then significantly inhibit carbon dioxide emissions (Bu & Zhao, 2022; Han et al., 2021), while energy-saving target constraints can drive enterprises to achieve pollution reduction by reducing production and improving the efficiency of source use (Han et al., 2020).

In addition, environmental regulations between regions may interact with each other, resulting in spatial spillover effects. The pollution haven hypothesis suggests that environmental regulations tend to make firms move to areas with weak regulations (Johnson et al., 1981). When the intensity of environmental regulation in a certain area increases, pollution will transfer to adjacent areas (K. Shen et al., 2017; Y. Shen & Ren, 2021). The transfer of pollution between regions may also be related to environmental regulation objectives, local government competition, and the strategic interaction of environmental regulation between regions (K. Shen & Zhou, 2020; Wu et al., 2021).

In terms of economic effect, environmental regulation has an impact on many economic activities, including resource allocation and productivity, technological innovation, industrial structure, and so on. Environmental regulation will lead to energy misallocation (Xiao et al., 2023) and resource misallocation (R. Chen & Zhou, 2022), which will further affect economic development. Some scholars believe that environmental regulation can affect productivity through resource reallocation (Han et al., 2017; Wang Y. et al., 2019).

In terms of technological innovation, the existing studies of scholars have verified the existence of the "Porter hypothesis" and believed that appropriate environmental regulation can promote technological innovation (Hu et al., 2020; Long & Wan, 2017; X. Zhao & Sun, 2016). Some studies have argued that while environmental regulation has achieved "incremental" green technological innovation, it has not achieved "quality enhancement" (Tao et al., 2021).

In terms of industrial structure, the inclusion of environmental performance as an exogenous impact in the official assessment and the environmental target constraints of local governments can promote the transformation and upgrading of local industries (Yu et al., 2020). Whether in resource-based or non-resource-based cities, environmental regulation can be used as a forcing mechanism to promote the rationalization and optimization of industrial structure, and to promote the development of urban industrial transformation (Li H. & Zou, 2018). Different factor input structures and possible thresholds can lead to differences in the effects of environmental regulation (Tong et al., 2016; Zhong et al., 2015).

2.1.2. Research on Green Total Factor Productivity

At present, China is undergoing a transformation from rapid economic growth to high-quality development. Total factor productivity is a comprehensive indicator that can measure the efficiency and quality of resource allocation within the economic framework and is a key indicator to evaluate the level of economic expansion (Geng et al., 2021). In macroeconomic research, the economic growth accounting framework provides the basis for the theory of total factor productivity. Traditionally, labor and capital have been considered the main drivers of economic growth. However, this view does not fully explain the observed increase in output during production activities (Rovigatti & Mollisi, 2018). A key factor that is often overlooked in the economic growth accounting framework is total factor productivity, also known as "surplus value". The concept of TFP was first proposed by economist Tinbergen, who incorporated time variables into the C-D production function to analyze changes in efficiency (Williams, 1945). TFP not only reflects technological progress, but also represents the operational efficiency of production. Solow, the American economist who first proposed the concept of total factor productivity, pointed out that 87.5% of the US economic growth came from the improvement of total factor productivity, and total factor productivity was an

important force promoting sustainable economic growth (Hartley et al., 2013). Subsequently, George Stigler independently explored the concept of TFP and conducted a study of TFP in the US manufacturing sector (Stigler, 1967).

Hiam Davis gave a comprehensive definition of total factor productivity (TFP) in his book *Productivity Accounting*, pointing out that TFP refers specifically to the production efficiency of all input factors, including labor, capital, land, etc. (Davis, H.S, 1954). Edward F. Denison further developed the concept of Solow residual and defined total factor productivity as the residual efficiency after considering the output growth rate and various input factors (Denison, E.F., 1962). The Denison model is constructed based on the concept of "residuals".

However, the traditional total factor productivity only considers the input variables of capital and labor in the calculation and does not include energy consumption. The Output only includes "Good Output," but does not include "Bad Output" such as environmental pollution, which cannot fully reflect the economic development and environmental status of a region. Based on this, some scholars put forward the concept of green total factor productivity, that is, energy consumption and environmental pollution factors are included in the accounting framework of total factor productivity, to better evaluate the economic and environmental level of a region.

In terms of measuring green total factor productivity (GTFP), Pittman incorporated bad output into the accounting system when using Data Envelopment Analysis (DEA) to calculate total factor productivity (Pittman, 1983). This green TFP, which includes undesirable outputs, has gradually become widely used. However, the traditional DEA model also has certain limitations.

Tone proposed the Slacks-based measurement (SBM) model to overcome the problem of ignoring slack variables in the traditional DEA model, and on this basis proposed the super efficiency SBM model (Tone, 2002) and the SBM model including unexpected output (Tone, 2003). The SBM model has been widely used in measuring green TFP. Many scholars measure green TFP based on SBM-DEA model combined with productivity index (Malmquist-Luenberger, ML). Ke li and Bo qiang Lin used ML index to measure the green economic growth efficiency of the manufacturing industry (K. Li & Lin, 2017); Lin and Meng used SBM-DEA model and ML index to evaluate the green TFP of China's six urban agglomerations (Lin & Meng, 2021). Li and Chen used the method of combining SBM model and ML index to measure the green TFP of China's Pearl River Delta urban agglomeration (Y. Li & Chen, 2021). When constructing a Global DEA model, that is, there is only one production frontier for all data, some scholars proposed the GML (Global-Malmquist-Luenberger) productivity index (Oh, 2010; Pastor & Lovell, 2005) established the GML index of the global production possibility set, which has also been widely used.

As for the influencing factors of green TFP, scholars have also carried out research on human capital, digitalization, foreign direct investment, trade openness, financial development, and other aspects (Du et al., 2023; Liu & Peng, 2023; Qi & Xu, 2018; Zhang F., 2017). Green TFP has become an important indicator to measure the level of urban green transformation and regional green development.

2.1.3. Research on the Yangtze River Economic Belt

The Yangtze River Economic Belt plays an extremely important role and significance in China's economic development and is a typical region of China taking the road of ecological priority and green development.

In terms of policy research on promoting the coordinated development of the economy and environment in the Yangtze River Economic Belt, Lu discussed the significance of the strategy of "jointly focusing on greater protection and not engaging in greater development." Development suggestions on industrial transfer and layout, infrastructure construction, and opening to the outside world are put forward (Lu, 2018). As China enters a stage of high-quality development, the Yangtze River Economic Belt faces new drivers, new challenges and new paths for coordinated development under the new development pattern (Wang H. et al., 2023).

As for the research on the economic development of the Yangtze River Economic Belt, Yang et al paid attention to the green innovation efficiency of the Yangtze River Economic Belt (Yang et al.,

2018). Existing studies have paid attention to the two-way interaction and spatial effect between environmental quality and economic growth in the Yangtze River Economic Belt (Liu et al., 2022), while carbon emission inequality and population carrying capacity of water resources are also important factors affecting the environment and economic development of the Yangtze River Economic Belt (Li H. et al., 2017; S. Zhang et al., 2021; Y. Zhang et al., 2021).

2.2. Theoretical Analysis and Research Hypothesis

The existing research on the impact of environmental regulation on green TFP is mainly divided into linear relationships and nonlinear relationships, and some scholars believe that the impact of environmental regulation on green TFP is promoting (Liu et al., 2020) or inhibition (Yin & Wu, 2021). Some scholars believe that the impact of environmental regulation on green TFP is very complex and not a simple linear relationship. Some scholars put forward the view that there is a "U" or "inverted U" relationship between the two (Gong et al., 2020; Li L. & Tao, 2012; Zhang F. & Song, 2019).

Environmental regulation, on the one hand, increases the cost of environmental protection and compresses the profit margin of enterprises. On the other hand, it will also encourage enterprises to carry out technological innovation and improve economic efficiency to maintain market competitiveness. Environmental regulation will lead to resource misallocation, thus reducing economic efficiency. However, because resources flow to enterprises with low energy consumption, low pollution, and high efficiency, it will also improve the overall economic efficiency and environmental level. In the medium and long term, environmental regulation will also affect the industrial structure of a region. Therefore, the impact of environmental regulation on green TFP is not a simple linear relationship. Therefore, this paper puts forward hypothesis 1.

H1: The impact of environmental regulation on green TFP is nonlinear.

The "cost following hypothesis" and "Porter hypothesis" believe that environmental regulation will inhibit and promote technological innovation respectively. When the level of environmental regulation is low, the profit margin of enterprises is small and the motivation for technological innovation is insufficient. On the one hand, the government will support and encourage enterprises' technological innovation behaviors, such as guiding enterprises to carry out technological innovation through tax incentives, financial subsidies and other measures. On the other hand, innovation itself is one of the core competitiveness of enterprises. Technological innovation has a crucial impact on green TFP. Based on this, this paper puts forward hypothesis 2.

H2: Environmental regulation affects green TFP through GTI.

Appropriate environmental regulation policies can affect the level of industrial structure by transferring industries from sectors with high energy consumption, high pollution and low efficiency to sectors with low energy consumption, low pollution and high efficiency, and promoting the development of emerging environmental protection industries and green industries. This kind of industrial restructuring has a positive effect on green TFP. However, if the level of environmental regulation is not appropriate, the range and speed of industrial adjustment may not be able to keep up with the market for a while, or exceed the bearing capacity of the market, which is not conducive to the level of green TFP. For a region, if there are no conditions for cultivating a new industry, it suddenly abandons its traditional competitive industry, which may lead to the recession of the local industry and even the economy, thus affecting the overall green TFP. Based on this, this paper puts forward hypothesis 3.

H3: Environmental regulation affects green TFP through the optimization of industrial structure.

2.3. Selection of Variables

2.3.1. Explained Variable

Explained variable: green total factor productivity (GTFP). This paper uses the SBM model including undesired output and GML index to measure green TFP. In this paper, we construct a super-efficient SBM model with undesired outputs and combine it with the Global-Marquist-Lemberg (GML) productivity index proposed by Pastor and Lovell to measure green total factor productivity (Pastor & Lovell, 2005). The calculation process is as follows.

Assuming that there are n decision-making units (DMUs), each city is treated as a production decision-making unit (DMU), and each DMU uses p factor inputs in period t . Define the matrix $X=[x_1, \dots, x_n] \in R^{p \times n} > 0$, which produces good outputs, i.e., desired outputs, $Y^g=[y^g_1, \dots, y^g_n] \in R^{se \times n} > 0$, and emits bad outputs, i.e., undesired outputs, $Y^b=[y^b_1, \dots, y^b_n] \in R^{su \times n} > 0$, and emits bad outputs, i.e., undesired outputs. If (x_0, y^g_0, y^b_0) is valid, then there exists no other combination (x, y^g, y^b) within the set of production possibilities that satisfies the following conditions: $x_0 \geq x$, $y^g_0 \leq y^g$, $y^b_0 \geq y^b$ and at least one of the conditions is a strict inequality sign. Accordingly, the solved SBM model is shown below:

$$E_c^G(x^t, y^{gt}, y^{bt}) = \min \frac{1 - \frac{1}{p} \sum_{i=1}^p \frac{s_i^x}{x_{i0}^t}}{1 + \frac{1}{s_e + s_u} (\sum_{k=1}^{s_e} \frac{s_k^g}{y_{k0}^{gt}} + \sum_{r=1}^{s_u} \frac{s_r^b}{y_{r0}^{bt}})} \quad (1)$$

$$s. t. x_{i0}^t = \sum_{j=1}^n \lambda_j x_j^t + s_i^x \quad (2)$$

$$y_{k0}^{gt} = \sum_{j=1}^n \lambda_j y_j^{gt} - s_k^{yg} \quad (3) \quad (3)$$

$$y_{i0}^{bt} = \sum_{j=1}^n \lambda_j y_j^{bt} + s_r^{yb} \quad (4) \quad (4)$$

$$s_i^x \geq 0, s_k^{yg} \geq 0, s_r^{yb} \geq 0, \lambda_j \geq 0, \forall i, j, k, r \quad (5) \quad (5)$$

Based on the results of the SBM model solution, the Green Total Factor Productivity (GTFP) index is calculated with reference to the Global-Malmquist-Luenberger (GML) index with undesired outputs derived by Pastor and Lovell (Pastor & Lovell, 2005), and the GTFP index is given by the formula:

$$GTFP(x^t, y^{gt}, y^{bt}; x^{t+1}, y^{gt+1}, y^{bt+1}) = \frac{E_c^G(x^{t+1}, y^{gt+1}, y^{bt+1})}{E_c^G(x^t, y^{gt}, y^{bt})} \quad (6)$$

In terms of indicator selection, this paper refers to the practice of existing literature and selects input-output variables, as shown in Table 1.

Table 1. Green total factor productivity input-output indicators.

Variant	Indicator type	Indicator selection
Input Variables	Labor Inputs	Number of employees at the end of the year (10,000)
	Capital Inputs	Fixed capital stock (billion yuan)
	Energy inputs	Energy consumption of standard coal (tons)
Expected outputs	GDP	Real GDP (billions of dollars)
Unexpected outputs	Wastewater emissions	Industrial wastewater emissions (tons)
	Sulfur dioxide emissions	Industrial sulfur dioxide emissions (tons)

Fume and dust emissions	Industrial fume and dust emissions (tons)
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2.3.2. Core Explanatory Variable

Explanatory variables: environmental regulation (ER). In this paper, we analyze the provincial government work report to get the frequency of environmental protection words in each province through text analysis method and multiply it with the proportion of industrial added value to GDP as the intensity of environmental regulation of local government. To facilitate the observation of data characteristics and empirical analysis, this paper multiplies the data obtained from the original calculation by 100 and converts them into percentages. The value of environmental regulation (ER) ranges between (0,1), the larger the value, the stronger the environmental regulation.

2.3.3. Mediating Variables

According to the mechanism analysis and research hypotheses, this paper analyzes the green technology innovation (GTI) and industrial structure advancement (IS) from two perspectives respectively.

Mechanism Analysis of Green Technology Innovation

According to the theoretical analysis and research hypothesis, environmental regulation affects green total factor productivity through the mechanism of green technological innovation. To test the mechanism of green technological innovation, the whole sample is divided into two groups of high and low according to the level of green technological innovation, and regressed separately. The green technological innovation level (GTI) of a region is measured by the number of green invention patent applications in the city in the year, and the data is obtained from the China Research Data Service Platform (CNRDS).

Mechanism Analysis of Advanced Industrial Structure

According to the theoretical analysis and research hypothesis, environmental regulation affects green total factor productivity through the mechanism of industrial structure adjustment. To test the mechanism of industrial structure advancedization, the whole sample is divided into two groups of high and low according to the level of industrial structure advancedization, and regressed separately. The ratio of the value added of tertiary industry to the value added of secondary industry is used to calculate the industrial structure advancement (IS), and the direction of industrial structure change is from the primary industry to the secondary industry and then to the tertiary industry, so the larger the value of the industrial structure advancement (IS) is, the more advanced the industrial structure is.

2.3.4. Control Variables

Referring to the existing studies, the level of financial development (FIN), the level of human capital (HC), the degree of fiscal intervention (GOV), the level of openness to the outside world (OPEN), and the level of infrastructure (ROAD), which have an impact on the city's green total factor productivity, are selected as control variables.

2.4. Model

Using Stata 17.0 to draw the fitting curve of environmental regulation and green total factor productivity, as shown in Figure 1, there is a nonlinear relationship between environmental regulation and green total factor productivity. Therefore, this paper refers to the existing literature and adds the square term of the explanatory variable environmental regulation in the equation to establish a nonlinear relationship model to empirically analyze the impact of environmental

regulation intensity on green total factor productivity. This paper constructs a two-way fixed effects model as follows:

$$GTFP_{it} = \alpha_0 + \beta_1 ER_{it} + \beta_2 ER_{it}^2 + \gamma \mathbf{controls}_{it} + \mu_i + \theta_t + \varepsilon_{it} \quad (7)$$

$GTFP_{it}$ represents the green total factor productivity of city i in year t ; ER_{it} represents the environmental regulation intensity of city i in year t ; ER_{it}^2 represents the square of the environmental regulation intensity of city i in year t ; and $\mathbf{controls}_{it}$ represents the set of control variables. μ_i and θ_t are the individual and time fixed effects, and ε_{it} is the error term. β_1 and β_2 reflect the effects of environmental regulation on green total factor productivity. β_1 and β_2 reflect the effect of environmental regulation on green total factor productivity, and the effect of government environmental regulation on green total factor productivity is analyzed according to the magnitude, direction and significance of β_1 and β_2 .

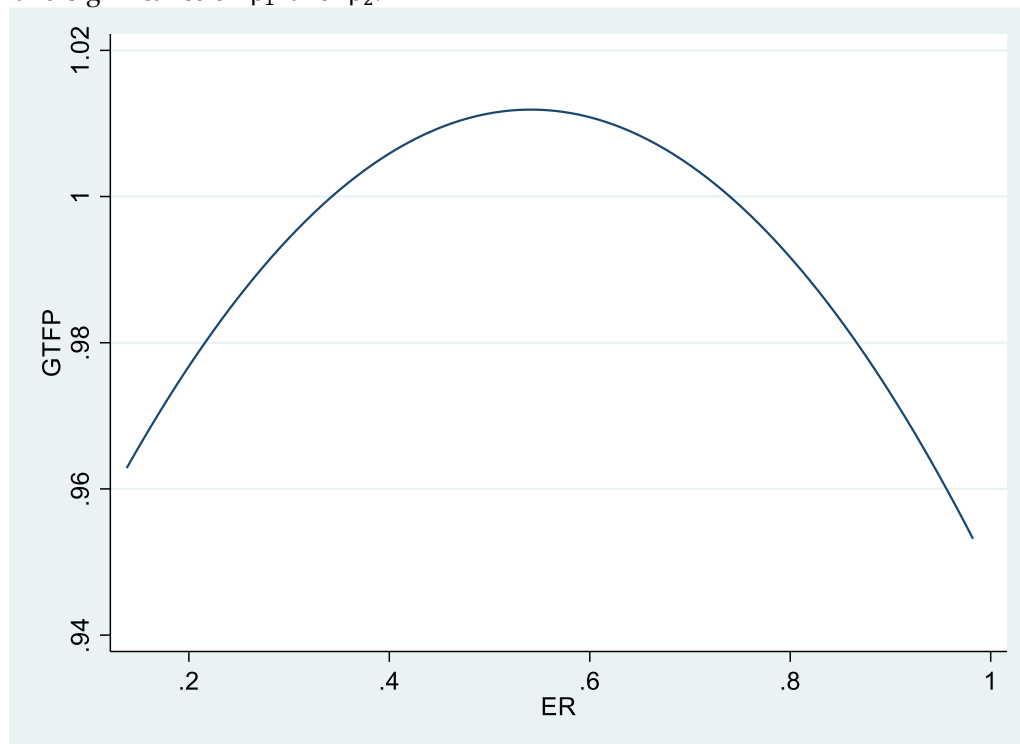


Figure 1. Fitted plot of environmental regulation and green total factor productivity.

2.5. Data Sources

This study focuses on cities along the Yangtze River Economic Belt, and the original samples were processed as follows: municipalities or autonomous prefectures with serious data gaps and areas where data consistency was affected by administrative division adjustments were excluded, and a final sample of 107 cities was retained. In addition, considering the completeness and comparability of the data, the time span of the study was determined to be from 2007 to 2019, avoiding the impact of the new crown epidemic in 2020 on the completeness of the data. For missing data, linear interpolation was used to fill in the blanks, and all price variables were deflated using 2006 as the base period, and finally adjusted to balanced panel data. The data sources mainly include China Urban Statistical Yearbook, China Energy Statistical Yearbook, China Urban Construction Statistical Yearbook, as well as statistical yearbooks and bulletins of relevant provinces and cities. To eliminate the interference of extreme values or outliers, the data were reduced by 1%. Table 2 shows the results of descriptive statistics.

Table 2. Descriptive statistics.

Variable	N	Mean	SD	Min	Max
GTFP	1391	1.001	0.132	0.574	1.558

ER	1391	0.463	0.172	0.138	0.982
FIN	1391	2.226	0.913	0.956	5.647
HC	1391	0.018	0.023	0.000	0.116
GOV	1391	0.184	0.08	0.076	0.491
OPEN	1391	0.17	0.241	0.003	1.312
ROAD	1391	16.875	6.746	4.04	38.2

3. Results

3.1. Benchmark Regression Results

The paper begins with regressions on the baseline model, the results of which are shown in Table 3. Columns (1) and (2) report the results without and with control variables, respectively, both using city-level clustering standard errors and controlling for individuals and time. As can be seen in Table 3, the regression coefficients of the regressions without and with control variables are positive for environmental regulation (ER) and negative for the environmental regulation squared term (ER2), and pass the 5% and 1% significance level tests, respectively. The results show that there is a non-linear relationship between environmental regulation (ER) and green total factor productivity (GTFP), and according to the regression coefficients of environmental regulation (ER) and its square term (ER2), the relationship is an inverted "U" shape.

Table 3. Baseline regression analysis results.

VARIABLES	(1)	(2)
	GTFP	GTFP
ER	0.291** (2.23)	0.301** (2.18)
ER2	-0.269*** (-2.66)	-0.282*** (-2.69)
FIN		-0.032* (-1.90)
HC		0.007 (0.01)
GOV		0.017 (0.12)
OPEN		0.015 (0.26)
ROAD		0.000 (0.01)
Constant	0.926*** (28.06)	0.976*** (23.40)
Observations	1,391	1,391
R-squared	0.080	0.083
Number of cities	107	107
City FE	YES	YES
Year FE	YES	YES

Note: Valid t-statistics in parentheses, ***p<0.01, **p<0.05, *p<0.1.

Adequate environmental regulation is conducive to the improvement of green total factor productivity levels. Environmental regulation encourages and supports the development of environmentally friendly industries and enterprises and inhibits the development of highly polluting and energy-consuming industries and enterprises. From the micro level, under the moderate environmental regulation policy, enterprises, as the main body of production activities, to improve market competitiveness, will carry out technological innovation, such as improving the production

process, applying cleaner production technology, producing environmentally friendly green products, etc., to improve the efficiency of resource utilization and reduce the emission of pollution, which will in turn promote the overall level of the environment and the improvement of economic efficiency. From the meso level, environmental regulation will guide the flow of production factors to industries that pay more attention to environmental protection, have higher efficiency and production capacity, and at the same time incentivize the transformation and upgrading of high-pollution, high-energy-consumption, and low-efficiency industries, thus enhancing green total factor productivity. Therefore, under an appropriate level of environmental regulation, the implementation of environmental regulation policy can realize a win-win situation for both economic and environmental benefits.

When the level of environmental regulation is within the appropriate range, strengthening environmental regulation is conducive to the enhancement of green total factor productivity; however, when the level of environmental regulation is too high, it will, on the contrary, have a negative impact on green total factor productivity. If environmental regulation is too strong, the profit margins of enterprises will be continuously compressed, which will seriously dampen the incentive of enterprises to produce, and enterprises will not have enough incentive to carry out technological innovation. Excessive environmental regulation will also affect the efficiency of resource allocation, thereby reducing economic efficiency. In summary, when the intensity of environmental regulation is within the appropriate range, the environmental and economic benefits brought by the implementation of environmental regulation policies are optimal. The benchmark regression results confirm the inverted U-shaped relationship between environmental regulation and green total factor productivity, verifying H1.

3.2. Mechanism Analysis

According to the mechanism analysis and research hypotheses, this paper analyzes green technology innovation (GTI) and industrial structure advancement (IS) from two perspectives respectively.

3.2.1. Mechanism Analysis of Green Technology Innovation

According to the theoretical analysis and research hypothesis, environmental regulation affects green total factor productivity through the mechanism of green technological innovation. To test the mechanism of green technological innovation, the whole sample is divided into two groups according to the level of green technological innovation into high and low regression. The regression results are shown in Table 4. The regression results of the group with the lower level of green technological innovation are shown in column (1) of Table 4, the regression coefficients of ER are significantly positive, and the regression coefficients of ER2 are significantly negative. According to the utest test, on the left side of the inflection point, the environmental regulation promotes the enhancement of the green total factor productivity and is significant at the 5% significance level; while on the right side of the inflection point, the environmental regulation inhibits the enhancement of the green total factor productivity and is significant at the 1% significance level, which is in line with the inverted "U" curve. The regression results of the group with the higher level of green technological innovation are shown in column (2) of Table 4, with positive regression coefficients of ER and negative regression coefficients of ER2, but neither of them is significant, nor does the utest test fail. The results show that the inverted U-shaped relationship of environmental regulation on green total factor productivity is significant in the group with lower levels of green technological innovation, but not in the group with higher levels of green technological innovation.

Table 4. Results of mechanism test for green technology level.

VARIABLES	(1)	(2)
	GTI_low	GTI_high
ER	0.286*	0.239

	(1.88)	(0.66)
ER2	-0.298***	-0.207
	(-2.66)	(-0.67)
FIN	0.004	-0.027
	(0.22)	(-0.85)
HC	-3.261*	0.825
	(-1.74)	(1.23)
GOV	-0.313**	0.326
	(-2.37)	(0.79)
OPEN	0.070	-0.149**
	(1.05)	(-2.31)
ROAD	-0.003	0.001
	(-1.60)	(0.47)
Constant	1.003***	1.049***
	(21.07)	(9.33)
Observations	697	694
R-squared	0.224	0.087
City FE	YES	YES
Year FE	YES	YES

Note: Valid t-statistics in parentheses, ***p<0.01, **p<0.05, *p<0.1.

For regions with higher levels of green technological innovation, the overall local technological level and innovation capacity are stronger, and innovation activities are less affected by environmental regulations. When the level of environmental regulation is higher, regions with higher levels of green technological innovation can rely on stronger technological strength to cope with higher standards of environmental requirements, and innovation activities are not affected, so they are still able to achieve stable growth in green total factor productivity. In other words, for regions with higher levels of green technological innovation, the increasing intensity of environmental regulations will not lead to a decline in green total factor productivity.

For regions with lower levels of green technological innovation, the implementation of environmental regulatory policies has a stronger impact on technological innovation. A moderate level of environmental regulation can incentivize enterprises to innovate and thus enhance green total factor productivity. However, when the level of environmental regulation is too high, enterprises face increased costs of technological innovation and difficulties in technological upgrading, which inhibits their innovative activities and is not conducive to enhancing green total factor productivity. Comparing the two sets of regression results, when the level of green technological innovation is low, the conclusion that environmental regulation has a non-linear effect on green total factor productivity is more significant, verifying the mechanism of green technological innovation in this non-linear effect H2.

3.2.2. Analysis of the Mechanism of Industrial Structure Advancement

According to the theoretical analysis and research hypothesis, environmental regulation affects green total factor productivity through the mechanism of industrial structure adjustment. To test the mechanism of industrial structure advancement, the full sample is divided into two groups of high and low according to the level of industrial structure advancement and regressed separately. The ratio of the value added of the tertiary industry to the value-added of the secondary industry is used to calculate the industrial structure advancement (IS), and the direction of industrial structure change is from the primary industry to the secondary industry and then to the tertiary industry, so the larger the value of the industrial structure advancement (IS) is, the more advanced the industrial structure is proved to be.

The regression results are shown in Table 5. Column (1) shows the regression results of the group with a lower industrial structure, the regression coefficient of ER is significantly positive, the

regression coefficient of ER2 is significantly negative, and the regression results are significant at the 5% significance level in Utest test, which is consistent with the inverted "U" curve. The inflection point of the curve is 0.6026, the slope of the left side of the inflection point is 0.2150, and the slope of the right side of the inflection point is -0.1758. Compared with the whole sample, the inflection point of the inverted "U"-shaped curve is shifted backward, and the curve is more gentle in the group of the industrial structure of the lower level. Column (2) shows the regression results of the group with a higher level of industrial structure advancement, the regression coefficient of ER is positive but not significant, and the regression coefficient of ER2 is negative at a 10% significance level, which does not pass the utest test. That is, the inverted "U" shaped relationship between environmental regulation and green total factor productivity does not exist in the group with higher levels of intra-industry structure. There is no "U" shaped relationship.

Table 5. Results of the Mechanism Test for Advanced Industrial Structure.

VARIABLES	(1)	(2)
	IS_low	IS_high
ER	0.279*	0.407
	(1.76)	(1.28)
ER2	-0.231**	-0.489*
	(-2.03)	(-1.69)
FIN	-0.016	-0.037
	(-0.51)	(-1.41)
HC	-0.630	-0.391
	(-0.80)	(-0.52)
GOV	-0.158	-0.105
	(-1.01)	(-0.33)
OPEN	0.187***	-0.031
	(2.76)	(-0.35)
ROAD	-0.002	0.001
	(-1.66)	(0.23)
Constant	0.961***	1.017***
	(15.27)	(14.54)
Observations	696	695
R-squared	0.191	0.115
City FE	YES	YES
Year FE	YES	YES

Note: Valid t-statistics in parentheses, ***p<0.01, **p<0.05, *p<0.1.

For the lower level of industrial structure, the implementation of environmental regulation policies has a stronger impact on industrial structure. Appropriate environmental regulation can force the transformation and upgrading of industrial structures. On the one hand, high energy-consuming, high-polluting, and low-efficiency enterprises are forced to close or shut down due to the pressure of pollution control, and low energy-consuming, low-polluting, and high-efficiency enterprises have more competitive advantages, which is conducive to the transformation and upgrading of the traditional industries. On the other hand, environmental regulation leads to the emergence of green, environmentally friendly, and efficient new industries, which further reduce energy consumption and pollution emissions, improve economic efficiency, and promote green total factor productivity. However, when the intensity of environmental regulation is too high, in the face of higher standards of environmental protection requirements, relying on lower industrial structure and technology level, enterprises can hardly bear the high environmental protection costs, which is unfavorable to the enhancement of green total factor productivity.

Regions with a higher industrial structure tend to have stronger overall strength and more advanced industrial systems and technologies, and the impact of environmental regulations on green

total factor productivity is weaker. In the face of stronger environmental regulations, regions with more developed industrial structures are better able to cope with them and flexibly adjust their economic activities according to the tightness or looseness of the policies. Therefore, even in the face of higher environmental requirements, the region's green TFP growth will not be affected. Comparing the two sets of regression results, when the level of industrial structure is lower, environmental regulations are more likely to have a non-linear impact on green total factor productivity, i.e., the mechanism of advanced industrial structure in hypothesis h3 is verified.

3.3. Robustness Tests

3.3.1. System GMM Model

The model may also suffer from a two-way causality problem, in which local governments also consider the level of economic development and environmental level of the region when formulating environmental regulation policies, i.e., the green total factor productivity may, in turn, affect the intensity of environmental regulation, and thus the model may suffer from endogeneity. In this paper, a dynamic panel regression model is used to mitigate the endogeneity by introducing the first-order lagged term of the explanatory variable GTFP into the equation, which is estimated using a system GMM. The dynamic panel model is constructed as follows:

$$GTFP_{it} = \alpha_0 + \beta_1 GTFP_{i,t-1} + \beta_2 ER_{it} + \beta_3 ER2_{it} + \gamma controls_{it} + \mu_i + \theta_t + \varepsilon_{it} \quad (8)$$

The results estimated using system GMM are shown in Table 6, and the regression coefficients of L. GTFP, ER, and ER2 are significant at 5%, 1%, and 1% significance levels, respectively. According to the utest test, there is an inverted "U" shaped relationship between the effect of environmental regulation (ER) on green total factor productivity (GTFP) with an inflection point of 0.5627. According to the correlation test estimated by the systematic GMM model, the p-values of AR (1) and AR (2) are 0.000 and 0.307, respectively, which means that they satisfy first-order differential autocorrelation of the disturbance term and no second-order differential autocorrelation; the p-value of Hansen's test is 0.226, i.e., the instrumental variables are valid. The endogeneity problem of the model is further mitigated by systematic GMM regression, which verifies the robustness of the results.

Table 6. System GMM regression results.

VARIABLES	GTFP
L.GTFP	-0.109** (-2.17)
ER	0.951*** (2.83)
ER2	-0.845*** (-3.16)
FIN	-0.000 (-0.04)
HC	0.323* (1.71)
GOV	0.068 (0.63)
OPEN	0.039 (1.36)
ROAD	-0.001 (-1.30)
Constant	0.882*** (6.12)
Observations	1,284
Number of city	107

City FE	YES
Year FE	YES

Note: Valid t-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

3.3.2. Utest Test

Although the regression coefficients of the explanatory variables ER and ER2 in the baseline regression results satisfy the conditions for an inverted "U"-shaped relationship, it does not necessarily mean that such a relationship exists. For example, when the inflection point does not fall within the interval of the variable, the point does not have economic significance. Based on this, the utest test is conducted on the model to test whether it satisfies the "U" type relationship. The regression results are shown in Table 7, and the test results include the intervals, slopes, t-values, and P-values of the left and right sides of the inflection points and the overall extreme points, t-values, and P-values, with columns (1) and (2) being the results of the test of the left and right sides of the inflection points without control variables, and columns (3) and (4) being the results of the test of the left and right sides of the inflection points with the inclusion of the control variables. As can be seen from Table 6-4, the utest test is significant at the 1% and 5% level of significance when control variables are added and when no control variables are added, respectively; the extreme points are within the range of values of environmental regulation (ER); and the positive and negative slopes of the left and right sides of the inflection points are also in line with the hypothesis. It shows that environmental regulation (ER) and green total factor productivity (GTFP) have an inverted "U" shape relationship, which confirms the robustness of the results.

Table 7. Utest test results.

VARIABLES	(1)	(2)	(3)	(4)
	Left side	Right side	Left side	Right side
Interval	0.1380	0.9823	0.1380	0.9823
Slope	0.2167	-0.2373	0.2232	-0.2529
t-value	2.08	-2.8302	2.0216	-3.0180
$P > t $	0.0199	0.0027	0.0229	0.0016
Extreme point		0.5410		0.5339
t-value		2.08		2.02
$P > t $		0.0199		0.0229

3.3.3. Elimination of Outliers

The samples selected in this paper are 107 cities along the Yangtze River Economic Belt, including the two municipalities of Shanghai and Chongqing. Due to the administrative level and city scale being different from other cities, to test the robustness of the empirical results, the samples of Chongqing and Shanghai are excluded, and the sample size is reduced for regression analysis. The regression results are shown in Table 8. The regression coefficient of environmental regulation (ER) is significantly positive, and the regression coefficient of the square term of environmental regulation (ER2) is significantly negative. According to the utest test, the inflection point of the curve is 0.5166 when no control variables are added, and the inflection point of the curve is 0.5100 when control variables are added, and both pass the test of the significance level of 5%, i.e., the conclusion that the inverted "U"-shaped relationship between environmental regulation (ER) and green total factor productivity (GTFP) is robust.

Table 8. Regression results excluding municipalities.

VARIABLES	(1)	(2)
	GTFP	GTFP
ER	0.228*	0.240*
	(1.85)	(1.84)

ER2	-0.221** (-2.33)	-0.235** (-2.38)
FIN		-0.033* (-1.97)
HC		0.021 (0.04)
GOV		0.023 (0.15)
OPEN		0.024 (0.40)
ROAD		-0.000 (-0.00)
Constant	0.949*** (26.33)	1.010*** (22.02)
Observations	1,365	1,365
R-squared	0.082	0.085
Number of city	105	105
City FE	YES	YES
Year FE	YES	YES

Notes: Robust t-statistics in parentheses, ***p<0.01, **p<0.05, *p<0.1.

3.4. Heterogeneity Analysis

Due to the heterogeneity of the development of different regions, this paper divides the sample into the middle and upper reaches of the Yangtze River and the lower reaches for heterogeneity analysis; and also divides the sample into cities located in urban agglomerations and cities not within urban agglomerations for heterogeneity analysis.

3.4.1. Heterogeneity Analysis between the Upper and Lower Reaches of the Yangtze River

The Yangtze River Economic Belt has a vast basin, and there are obvious ecological and environmental differences, economic foundation differences, and development gaps between the upper, middle, and lower reaches of the Yangtze River. The economic volume of the lower reaches of the Yangtze River accounts for more than half of the total economic volume of the entire Yangtze River Economic Belt, so this paper divides the Yangtze River Economic Belt into the middle and upper reaches and the lower reaches and investigates the regional heterogeneity of environmental regulations on green total factor productivity.

The regression results are shown in Table 9, in which column (1) is the regression result for the middle and upper reaches of the Yangtze River, the regression coefficient of ER is positive but not significant, and the regression coefficient of ER2 is significantly negative. The utest test shows that the original hypothesis is rejected at the 10% significance level, i.e., there is an inverted U-shaped relationship between environmental regulations and green TFP in the middle and upper reaches of the Yangtze River. Column (2) shows the regression results for the lower reaches of the Yangtze River, and the regression coefficients of ER and ER2 are not significant, that is, the inverse "U" relationship does not exist in the lower reaches of the Yangtze River.

Table 9. Results of heterogeneity analysis between the lower, middle and upper reaches of the Yangtze River.

VARIABLES	(1) Up&Mid	(2) Down
ER	0.298 (1.60)	0.385 (1.43)
ER2	-0.318**	-0.277

	(-2.33)	(-1.16)
FIN	-0.035	-0.029
	(-1.34)	(-1.15)
HC	-0.494	-1.254
	(-0.77)	(-1.08)
GOV	-0.094	0.209
	(-0.56)	(0.79)
OPEN	-0.033	-0.039
	(-0.32)	(-0.68)
ROAD	0.000	0.001
	(0.01)	(0.30)
Constant	1.000***	0.969***
	(15.80)	(14.36)
Observations	858	533
R-squared	0.099	0.091
Number of city	66	41
City FE	YES	YES
Year FE	YES	YES

Notes: Robust t-statistics in parentheses, ***p<0.01, **p<0.05, *p<0.1.

The lower reaches of the Yangtze River have relatively stronger economic strength and environmental management ability, and the implementation of environmental regulation policies does not have a significant impact on the inverted "U" of its green total factor productivity. The lower reaches of the Yangtze River have more mature industrial systems and more advanced technology levels, and the comprehensive strength of enterprises is stronger, which makes them more capable of coping with the challenges posed by environmental regulations. In addition, the lower reaches of the Yangtze River have developed faster and realized the importance of environmental protection earlier than the middle and upper reaches of the Yangtze River. The laws and regulations on environmental protection are more complete, and the implementation of environmental policies is more effective, so they can continue to promote the growth of green total factor productivity. Therefore, when the level of environmental regulation is high, the negative impacts of environmental regulation can be offset through a variety of ways, such as technological progress, efficiency improvement, and policy improvement.

Compared with the lower reaches of the Yangtze River, the middle and upper reaches of the Yangtze River have relatively weaker economic strength and weaker environmental governance capacity. Many cities in the middle and upper reaches of the Yangtze River are dominated by resource-intensive industries or heavy industries, which are facing greater environmental pressure, and their economic development is easily affected by environmental regulation policies. When the level of environmental regulation is high, relying on less mature industrial systems and inferior technology levels, the middle and upper reaches of the Yangtze River are faced with the dual challenges of economic development and environmental protection and are subject to more constraints in improving green total factor productivity.

3.4.2. Heterogeneity Analysis Within and Outside Urban Agglomeration

The cities along the Yangtze River Economic Belt are divided into two groups: the cities located in the urban agglomeration and the cities outside the urban agglomeration, and the heterogeneity of environmental regulation on green total factor productivity is studied. The regression results are shown in Table 10. Columns (1) and (2) report the regression results of cities outside the urban agglomeration and cities inside the urban agglomeration respectively. The results show that for the group outside the urban agglomeration, the regression coefficient of environmental regulation (ER) is significantly positive, and the regression coefficient of the square term of environmental regulation (ER²) is significantly negative. Utest test results show that it is significant at the level of 5%

significance, so the relationship between environmental regulation and green total factor productivity satisfies an inverted "U" shape. For the group located in the urban agglomeration, the environmental regulation (ER) and its square term (ER2) are not significant, that is, they do not conform to the inverted "U" relationship.

Table 10. Results of heterogeneity analysis within and outside urban agglomeration.

VARIABLES	(1) Out_agg	(2) In_agg
ER	0.394** (2.06)	0.176 (0.89)
ER2	-0.371** (-2.64)	-0.164 (-1.10)
FIN	-0.023 (-1.18)	-0.020 (-0.69)
HC	0.213 (0.33)	0.139 (0.12)
GOV	-0.191 (-0.88)	0.026 (0.16)
OPEN	0.258** (2.48)	-0.085 (-1.58)
ROAD	-0.001 (-0.36)	0.000 (0.33)
Constant	0.947*** (17.88)	1.019*** (12.67)
Observations	637	754
R-squared	0.138	0.067
Number of city	49	58
City FE	YES	YES
Year FE	YES	YES

Notes: Robust t-statistics in parentheses, ***p<0.01, **p<0.05, *p<0.1.

Urban agglomeration is the product of the mature stage of urban development. As the highest spatial organization form of urban development, urban agglomeration has gathered many people and industries, which has remarkable economies of scale and industrial cluster advantages. Cities located in urban agglomerations can share infrastructure and reduce production costs. Cities within urban agglomerations can realize industrial complementarity and coordinated development. Big cities can transfer eliminated industries to small and medium-sized cities, and small and medium-sized cities can enjoy the advantages of capital, technology, and other factors in big cities, and undertake the industries transferred by big cities. At the same time, cities in urban agglomerations can strengthen economic, cultural, and technological exchanges, that are conducive to the flow of capital, technology, knowledge, and other elements, promote the optimal allocation of resources, and stimulate innovation vitality.

Compared with the cities outside the urban agglomeration, the cities inside the urban agglomeration are more conducive to the improvement of green total factor productivity. In the face of environmental regulations, cities located in urban agglomerations can weaken the adverse effects to some extent. When faced with a higher level of environmental regulation, cities within urban agglomerations can rely on economies of scale and the advantages of industrial clusters to reduce environmental protection costs, promote technological innovation and industrial upgrading, and then always maintain the growth of green total factor productivity. For the cities located outside the urban agglomeration, there is no economic advantage of the urban agglomeration. When the level of environmental regulation is high, the binding force and environmental pressure are stronger, which

strengthens the inverted "U" relationship between environmental regulation and green total factor productivity.

4. Discussion

The results confirm the inverted "U"-shaped relationship between environmental regulation and green total factor productivity, and explain the existence mechanism of the inverted "U"-shaped relationship from the two paths of green technological innovation and industrial structure upgrading, which verifies the research hypotheses. Since the model may be endogenous, this paper adopts the GMM method to mitigate the endogeneity problem and conducts robustness tests on the model using Utest and removing outliers. A series of tests confirm the robustness of the results.

The result is a little different from and makes up for experience. The policy implication of this is that the "degree" of environmental regulation should be well grasped. When the level of environmental regulation is kept within an appropriate range, it will have a positive effect on the overall economic and environmental benefits of society. But the policy implementation is "too much", only correctly grasping the "degree" to maximize the benefits. For the formulation of environmental regulatory policies, it is important to do a good job of balancing ecological and economic benefits on the premise that the loss of economic benefits can be controlled.

In formulating and implementing environmental regulatory policies, the government will inevitably consider the local resources, environment, and economic conditions. The Yangtze River Economic Belt covers 11 provinces and cities in China, spanning three major economic zones in the western, central, and eastern regions of China. In the next study, it's necessary to consider regional heterogeneity, for example, based on the level of development, resource endowment, and level of urbanization, etc., to further analyze whether and why the inverted U-shape between environmental regulation and green total factor productivity exists in each region.

5. Conclusion

5.1. Research Conclusion

Based on the previous literature research, theoretical analysis, indicator measurement and empirical analysis process, this paper takes 107 cities along the Yangtze River Economic Belt as the research object, explores the impact of environmental regulation on green total factor productivity, and draws the following conclusions:

First, the effect of environmental regulation on green total factor productivity is inverted U-shaped. Before environmental regulation reaches a specific level, green total factor productivity increases as the level of environmental regulation increases; however, after reaching the inflection point, environmental regulation has a dampening effect on green total factor productivity, i.e., green total factor productivity decreases as the intensity of environmental regulation increases. The robustness of the results is confirmed in the subsequent robustness test.

Secondly, this paper adopts the group regression method to carry out the mechanism test. According to the regression results, in the group with lower level of green technological innovation and lower level of industrial structure, the regression coefficients of the environmental regulation and its squared term are in line with the expectation and significant, which conforms to the inverted "U" shape; while in the group with higher level of green technological innovation and higher level of industrial structure, the regression coefficients of environmental regulation and its square term are not significant. The results show that environmental regulation affects green total factor productivity through two mechanisms: green technological innovation and industrial structure advancement.

Third, this paper further discusses the heterogeneity of environmental regulations affecting green total factor productivity. In the sample of cities in the middle and upper reaches of the Yangtze River, environmental regulations show an inverted U-shaped effect on green TFP, while in the sample of cities in the lower reaches, this effect is not significant. The results show that the higher level of overall development in the lower reaches of the Yangtze River weakens the impact of environmental regulations on green TFP. In the sample of cities that are not within city clusters,

environmental regulations show an inverted U-shaped effect on green TFP, while in the sample of cities that are in city clusters, this effect is not significant. The results suggest that the advantages of city clusters, such as industrial agglomeration and economies of scale, can weaken the impact of environmental regulations on green total factor productivity.

5.2. Policy Recommendations

First, it is necessary for the government to adopt appropriate regulatory means to promote the coordinated development of the economy and the environment. Environmental pollution is a typical external behavior that leads to market failure and needs to be solved by the government. However, the level of environmental regulation should be appropriate. The government, in the formulation of environmental regulatory policies, needs to balance the relationship between economic development and environmental protection, not for the sake of economic development and wanton destruction of the ecological environment, not because of the protection of the ecological environment and give up economic development. Moderate environmental regulation can bring economic and environmental benefits to a win-win situation.

Second, emphasize the role of technological innovation. Technological innovation in the coordinated development of the economy and the environment is a very important position. China's economy is currently in the labor, resource-driven to technology, knowledge-driven transformation, in which innovation is to promote economic transformation of the important driving force. Technological innovation is not only conducive to improving production efficiency and product quality, but also improves the environment by increasing resource utilization efficiency and using clean energy. The government should strengthen its support for technological innovation.

Third, when formulating environmental regulatory policies, the special characteristics of different regions within the Yangtze River Economic Belt must be considered, and differentiated management strategies should be implemented. The provinces of Yunnan, Guizhou, and Sichuan in the upper reaches of the Yangtze River, despite their relative lag in economic development, bear important ecological functions, such as water conservation and ecological protection, which are crucial to the sustainable development of the entire economic belt. Therefore, environmental regulations should be strengthened in these regions, while an ecological compensation mechanism should be established to ensure that ecological benefits are prioritized. For the more economically developed and densely populated downstream regions such as Jiangsu, Zhejiang and Shanghai, which are in a critical period of economic transformation, more attention should be paid to environmental protection and the promotion of green development, to realize the harmonization of economic development and environmental protection.

Fourth, the development of the Yangtze River Economic Belt requires overall planning and strengthening inter-regional cooperation and coordination. It is recommended to establish inter-provincial, inter-municipal and inter-basin cooperation mechanisms, promote regional cooperation in ecological restoration and environmental protection, improve the factor market, promote the free flow of factors such as labor, capital, and technology, promote the orderly transfer of industries, and drive the less-developed regions by the developed regions to jointly promote the overall prosperity of the Yangtze River Economic Belt. Through such a regionally coordinated development strategy, the relationship between economic growth and environmental protection can be effectively balanced to promote the green and sustainable development of the Yangtze River Economic Belt.

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