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How Environmental Regulations Affect Green Total Factor Productivity—Evidence from Chinese Cities

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Abstract: Environmental pollution and resource waste in Chinese cities have become important obstacles to sustainable economic development, and it is urgent to change the mode of economic development and improve the quality of economic development. In response to this challenge, this study proposes environmental regulation as a solution and empirically tests the impact of environmental regulation on green total factor productivity. The empirical results show that environmental regulation can significantly improve urban green total factor productivity, the public environmental concern and green finance strengthen the positive effect of environmental regulation on urban green total factor productivity. The mechanism test shows that environmental regulation can improve urban green total factor productivity through green technological innovation and industrial structure upgrading. Heterogeneity analysis reveals that, compared to the resource-based cities, the positive effect of environmental regulation on urban green total factor productivity is more significant in the non-resource-based cities with relatively developed traditional finance and high levels of industrial modernisation. Compared to the central and western as well as the northeast regions of China, the positive effect of environmental regulation on urban green total factor productivity is more significant in the eastern region due to capital accumulation and technological constraints. The results of the study remain reliable after a series of endogeneity and robustness tests. These studies provide an important research basis for providing more targeted environmental regulation programmes and better improving green total factor productivity.

Keywords: environmental regulation; green total factor productivity; green technological innovation; public environmental concern; green finance; industrial structure upgrading

Citation: Ye, Z.; Liu, Y.; Rong, Y. How Environmental Regulations Affect Green Total Factor Productivity—Evidence from Chinese Cities. *Sustainability* **2024**, *16*, 3010. https://doi.org/10.3390/su16073010

Academic Editor: Cristina Raluca Gh. Popescu

Received: 8 February 2024
Revised: 31 March 2024
Accepted: 3 April 2024
Published: 4 April 2024

1. Introduction

Currently, the worsening environmental pollution challenges are drawing global attention to this urgent issue. According to the Global Environmental Performance Index Report 2022, China ranks 160th out of 180 countries and regions evaluated in environmental performance. The main reason leading to the above results is the excessive reliance on massive inputs of energy, capital, and labour in economic growth, while neglecting environmental resources and protection [1,2]. In order to reduce environmental pollution and resource inefficiency, the Chinese government has implemented a variety of environmental regulation policies, including raising emission standards, increasing penalties for pollution, promoting emissions trading, and imposing restrictions on heavily polluting industries [3–6]. The government aims to exert pressure on enterprises through environmental regulations, influencing their environmental decisions and actions [7,8], thereby driving economic transformation across the entire society. This process can also be understood as an enhancement of green total factor productivity.

Based on previous literature, environmental regulations have been identified as a significant driver for promoting sustainable economic development. However, the economic consequences of environmental regulations vary among the world's major economies. In developed countries, government environmental regulations often compel enterprises to upgrade outdated production processes, phase out obsolete industrial equipment, strengthen pollution control measures, aid enterprises in green innovation, and thereby enhance urban green total factor productivity [9–11]. Conversely, these conclusions have not been confirmed in emerging economies and developing countries. Some studies suggest that due to differences in resource endowments and pressures from economic development, environmental regulations in developing countries may lead to a phenomenon known as "greenwashing" by enterprises [12,13]. This entails enterprises avoiding the costs associated with green transformation by disclosing false information regarding their green initiatives. This behaviour does not effectively enhance green total factor productivity and may even result in negative consequences. Therefore, exploring the economic consequences of environmental regulations at the urban level in China may provide valuable insights for other countries globally.

In research focusing on the impact of environmental regulation on green total factor productivity, some studies suggest that green total factor productivity integrates resource consumption and pollution emissions into the production function, in addition to traditional inputs like labour, capital, and technology [14,15]. Compared to total factor productivity, green total factor productivity places a greater emphasis on the sustainability of the economy. However, studies have found that the economic consequences of environmental regulation on green total factor productivity are not clear-cut and may exhibit positive, negative, or nonlinear relationships. Some studies suggest that environmental regulation drives the development of digital infrastructure [16], the clustering of productive service industries [17], green technology innovation [18], and resource allocation [19], fostering green total factor productivity. Conversely, other studies suggest that environmental regulation could reduce enterprises' export capabilities [20], increase financial costs [21], and diminish enterprises' competitiveness [22], consequently exerting negative effects on green total factor productivity. Taking into account the differences in institutional environments and market development levels, the impact of environmental regulation on green total factor productivity may also exhibit a "U-shaped" or "inverted U-shaped" relationship due to variations in governmental enforcement capacity and market forces [23,24]. These discussions need to be contextualised within the framework of China's governmental system. Furthermore, existing research has lacked discussion on the relationship between environmental regulation and green total factor productivity at the urban level, as well as analysis on how to enhance the positive effects of environmental regulation and reduce the negative impacts of environmental regulation. In terms of green total factor productivity measurement, the previous literature primarily utilises radial CCR models or non-radial SBM models to estimate the input–output relationships of enterprises, with less consideration from a hybrid radial perspective. This could potentially lead to estimation biases and consequently result in errors in research conclusions. This paper conducts a more in-depth study of these issues.

This study aims to investigate the impact of environmental regulation on green total factor productivity using a panel dataset of 289 Chinese cities. Firstly, the Windows–Malmquist–Luenberger model based on a hybrid distance function (EBM) is used to re-evaluate green total factor productivity. The research reveals that environmental regulation can significantly enhance urban green total factor productivity. Public environmental concern and green finance strengthen the positive impact of environmental regulation on urban green total factor productivity. Secondly, mechanism tests indicate that environmental regulation can increase urban green total factor productivity through green technological innovation and industrial structure upgrading. Thirdly, heterogeneity analysis reveals that the enhancement effect of environmental regulation on green total factor productivity is more significant in the eastern regions and the non-resource-based cities with relatively developed traditional finance and high levels of industrial modernisation.

Our study makes several contributions to the literature. Firstly, this paper innovates the calculation method of green total factor productivity. Distinguished from previous studies that utilised either the radial CCR model or the non-radial SBM model, this study employs a hybrid radial EBM model to green total factor productivity. This new approach simultaneously considers both the homogenous proportionality (e.g., energy input and environmental pollution) and non-homogenous proportionality (e.g., labour input and environmental pollution) relationships between input and output, incorporating the advantages of both the CCR and SBM models. The calculated indicators are more closely aligned with actual circumstances, making the research conclusions more reliable. Secondly, this study enriches the existing literature exploring the relationship between environmental regulation and green total factor productivity. Few studies have directly examined this relationship at the urban level. Previous studies have mainly relied on data from listed enterprises or leading manufacturing enterprises. This study utilises urban-level data, which can better reflect the overall green development situation in cities, encompassing both large enterprises and small- and medium-sized enterprises, which is beneficial for proposing differentiated environmental regulation strategies tailored to cities with different levels of economic development and resource endowments. Thirdly, while the existing literature has discussed the mechanisms of environmental regulation's impact on green total factor productivity, there has been limited exploration of how to strengthen the positive effects of environmental regulation. This study takes a perspective from China's policy and decision-making system, considering how environmental regulation impacts green total factor productivity. It also examines the role of green finance in enhancing the market attractiveness of environmental regulation, as well as the impact of public environmental concerns on increasing the pressure for the implementation of environmental regulation. The study provides targeted policy recommendations on how to enhance and improve the effectiveness of environmental regulation policies.

2. Theoretical Analysis and Research Hypothesis

2.1. Environmental Regulation and Green Total Factor Productivity

Under the framework of the China Political Promotion Championship, the political promotion of local government officials is highly correlated with the economic growth, tax revenue growth and employment growth of the region. This requires local governments to be more cautious when implementing environmental regulations. They prefer to gradually increase emerging industries and restrict the development of backward industries, rather than directly letting backward industries exit the market, and encourage enterprises to achieve regulatory purposes through green transformation. At the same time, enterprises are also seeking government subsidies, financing loans and market access under the pretext of economic pressure caused by the implementation of environmental regulations [25]. Then, with the cooperation of the government and enterprises, urban green technology innovation and industrial structure upgrading will be promoted, thereby improving the urban green total factor productivity. Specifically:

First, environmental regulation promotes urban green technology innovation. From the perspective of innovation resources and capabilities, stronger environmental regulations will force companies to invest more resources in green process improvement and equipment transformation to prevent being ordered to exit the market by the government. Although the environmental regulations costs may squeeze out a part of R&D capital, enterprises will still mitigate potential environmental risks by improving product quality and environmental performance [26–28]. From the perspective of an innovation environment, strong local government environmental regulation can enhance the agglomeration of productive services in the region and increase the scale of green infrastructure construction. The geographic agglomeration of enterprises in the jurisdiction forms an economic agglomeration, which is beneficial for addressing common green technology issues among enterprises, leveraging green economic spillover effects, and ultimately enhancing urban green total factor productivity [29,30]. From the perspective of social acceptance of innovation, the local government's environmental regulation can enhance the willingness of consumers to buy green products [31,32]. In fact, young people in China are more willing to associate environmental protection and green concepts with recyclability, health, and safety. This makes consumers more willing to purchase green products such as biodegradable plastic bags, diatomaceous earth products, and recycled paper cups, even at prices higher than the normal selling price. This provides an important market for enterprises' green innovation for businesses, helping them enhance green competitiveness, improve innovative production processes, reduce unit energy consumption, and resource waste, and ultimately enhance urban green total factor productivity.

Second, environmental regulation can help promote industrial structure upgrading. The industrial structure upgrading includes reducing backward production capacity and increasing advanced production capacity. From the perspective of reducing backward production capacity, environmental regulation policies such as environmental taxes and pollution control regulations increase the relative prices of pollution factors and external constraints on the production process and limit the continued entry of low-end enterprises by shaping environmental barrier effects [4,33], and the resulting cost increase effect and production constraint effect force existing enterprises to transform their production structures and promote the transfer of production factors such as labour and capital to clean industries such as the service industry [29], effectively reducing the proportion of heavy industrial enterprises and resource-based enterprises in the city, promoting the rational allocation and dynamic balance of factor resources among the social and economic structures, and ultimately promoting the improvement of urban green total factor productivity [34,35]. From the perspective of increasing advanced production capacity, environmental regulations can help optimise the allocation of data factors and accelerate the accumulation of human capital in green industries, which can help increase the number of low-pollution, low-emission, and low-energy-consumption productive service industries and strategic emerging industries in the city [36,37], and also help scientific research institutes and environmental protection institutes to obtain more policy support, which can help enterprises in their regions to achieve as much as possible the minimisation of resource inputs in the production process and maximise the outputs [38,39], and promote the upgrading of the industrial structure, and ultimately contribute to the enhancement of the city's green total factor productivity. Accordingly, the following hypotheses are proposed:

Hypothesis 1. *Environmental regulation can effectively enhance urban green total factor productivity.*

2.2. The Moderating Effect of Public Environmental Concern

In the context of China's political system, public appeals for environmental protection, energy conservation, and emission reduction can be translated into the state's policy agenda in a variety of ways and urge adjustments in the political system [40,41]. For example, amidst the public's calls for air quality and haze in China, the central government issued the "Circular of the State Council on the Issuance of the Three-Year Action Plan for Winning the Battle of Defending the Blue Sky", which linked the political promotion of local officials to environmental protection. Following this, local governments are very concerned about the public opinion on environmental protection in their regions, and when the public searches and posts about environmental protection topics on social media, the local governments in their regions will place more emphasis on the importance of environmental regulation in the government's work reports. It has been found that when people are more concerned about environmental issues in their cities, they will be more active in filing judicial lawsuits against high-polluting enterprises in their areas, complaining to higher administrative authorities or negatively criticising the government on local government websites [42,43], which will put greater public opinion pressure on the local government, thus prompting the local government to reduce high-polluting, high-energy-consuming, and high-emission industries [44,45], and pay more attention to the concept of environmental protection, thus increasing the local green total factor productivity. Accordingly, the following hypotheses are proposed:

Hypothesis 2. *Public environmental concern enhances the positive effect of environmental regulation on urban green total factor productivity.*

2.3. The Moderating Effect of Green Finance

In the context of China's political system, financial institutions often have to take into account the government's philosophy of governance when seeking to make as much profit as possible [46]. In the context of environmental regulation by the government, banks tend to have a green finance philosophy and subsequently apply discriminatory credit policies to different types of enterprises. For example, green enterprises are given lower interest rates, larger credit limits and longer repayment terms, while non-green enterprises are punished with high financing costs and restrictions on the expansion of non-green enterprises [47,48]. In this way, it encourages more enterprises to invest in green industries or carry out technological transformation and upgrading of enterprises. At the same time, the more sound the city's green financial system is, the more it helps to send a signal to the outside world that the government and financial institutions support the development of green industries, so that enterprises pay more attention to the environmental risks they face during the production and operation process, improve their corporate social responsibility, and promote the green transformation of the city where they are located.

In addition, given that local governments rely heavily on financial institutions for their financial expenditures, the more complete the green financial system of a city is, the richer the economic resources available to the government, which leads to stronger financial support for enterprises when the government carries out environmental regulation, and better supply chain support conditions in the market [49,50], thus enabling factors of production, such as capital, labour and technology, to concentrate in the field of environmental protection more quickly and improve the green transformation of the host city and environmental protection, and increase the green total factor productivity of the city. Accordingly, the following hypotheses are proposed:

Hypothesis 3. *Green finance enhances the positive effect of environmental regulation on urban green total factor productivity.*

Through the above analysis, in order to more intuitively reflect the research ideas of this paper and the relationship between variables, the theoretical model was constructed, as shown in Figure 1.

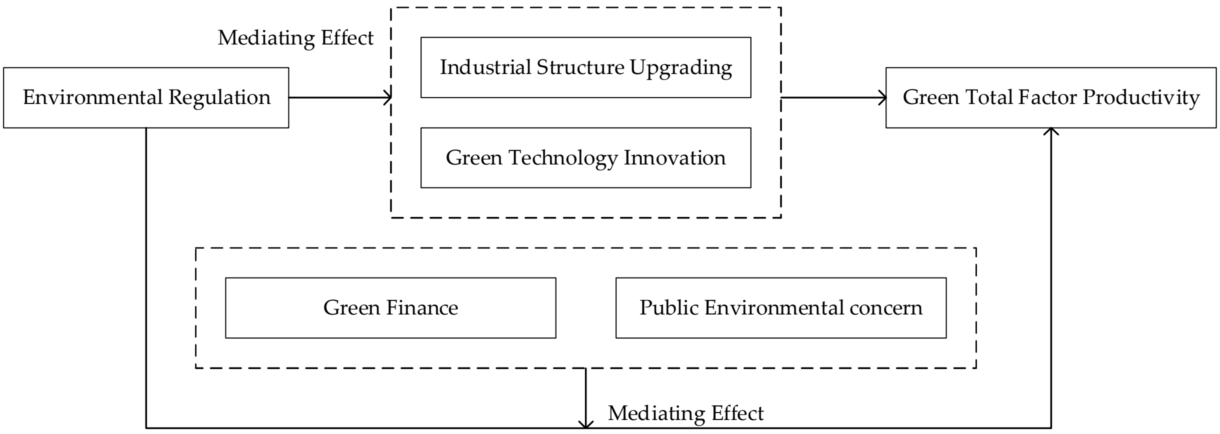

Figure 1. The theoretical model.

3. Research Design

3.1. Sample Selection and Data Sources

In this paper, panel data at the prefecture-level urban level in China from 2003 to 2021 are selected as sample data. Due to the large amount of missing data related to some prefecture-level cities, in order to ensure the robustness of the empirical regression results, this paper excludes the prefecture-level urban with missing values and finally takes 289 prefecture-level cities in China as the research sample. The indicators are obtained from the China Urban Statistical Yearbook, China Energy Statistical Yearbook, China Environmental Statistical Yearbook, and provincial and municipal statistical yearbooks. Missing data for individual cities are recursively processed using the mean interpolation method and the average annual growth rate of the last five years.

3.2. Variables Selection and Measurement

3.2.1. Explained Variables

Green Total Factor Productivity (GTFP): Adopts Tone and Tsutsui's [51] hybrid distance function compatible with radial and non-radial characteristics, i.e., the EBM model. Compared with the traditional CCR model with fixed scale compensation and the SBM model based on slack variables, the EBM model can effectively avoid the problem that the results of the CCR model are higher than the actual efficiency level due to the failure to consider the slack variables, as well as the problem that the results of the SBM model are lower than the actual efficiency level due to the neglect of the linear relationship between the input factors. The input-orientated EBM model, which takes into account undesired outputs, is as follows:

$$
\begin{gathered}
y^* = \min \frac{\theta - \varepsilon_x \left(1/\sum_{i=1}^{m} w_i^-\right) \sum_{i=1}^{m} w_i^- s_i^- / x_{ik}}{\varphi + \varepsilon_y \left(1/\sum_{r=1}^{q} w_r^g\right) \sum_{r=1}^{q} w_r^g s_r^g / y_{rk} + \varepsilon_z \left(1/\sum_{t=1}^{p} w_t^b\right) \sum_{t=1}^{p} w_t^b s_t^b / y_{tk}} \\
\text{s.t. } X\lambda + s_i^- = \theta_{xk} \\
Y^g \lambda - s_r^g = \varphi y_k \\
Z^b \lambda + s_t^b = \varphi z_k \\
\lambda, s_i^-, s_r^g, s_t^b, \geq 0
\end{gathered}
\tag{1}
$$

where y^* is the optimal value of efficiency; θ is the radial efficiency value; w_i^-, w_r^g and w_t^b represent the weights of inputs, desired outputs and non-desired outputs, respectively, and $\sum w = 1$; ε_x is the parameter containing the radial efficiency value and the non-radial relaxation, when $\varepsilon_x = 0$, the EBM will be simplified to the input-orientated CCR model, and when $\theta = \varepsilon_x = 1$, the model will be transformed to the SBM model.

On this basis, the Malmquist–Luenberger index model is used to measure the change in green total factor productivity considering undesired output, and the change in green total factor productivity (GTFP index) from period t to t + 1 is measured by the following formula:

$$
GTFP_t^{t+1} = \left[\frac{D_0^t\left(x^t, y^t, b^t, g^t\right)}{1 + D_0^t\left(x^{t+1}, y^{t+1}, b^{t+1}, g^{t+1}\right)} \times \frac{D_0^{t+1}\left(x^t, y^t, b^t, g^t\right)}{1 + D_0^{t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}, g^{t+1}\right)} \right]^{\frac{1}{2}} \tag{2}
$$

where $D_0^t\left(x^t, y^t, b^t, g^t\right)$ is a distance function for period t, representing the distance between the decision unit and the efficient production frontier. If $GTFP_t^{t+1} > 1$ indicates that urban green total factor productivity is improved from period t to period t + 1, and vice versa, it is reduced.

This study referenced the existing literature to determine the input and output indicators related to green total factor productivity. At the input level, labour, energy, and capital were selected as input factors. The labour input indicator is determined by the number of employees in the secondary industry of urban; the energy input indicator is calculated by multiplying the industrial value-added of urban by the energy consumption intensity corresponding to the industrial value-added of the province; and the capital input indicator is calculated by multiplying the fixed asset investment of urban by the ratio of industrial investment to total social investment of province. At the output level, industrial value-added is selected as the expected output. The composite index of industrial smoke, industrial SO_2, and industrial wastewater emissions is used as the unexpected output.

3.2.2. Explanatory Variables

Environmental Regulations (ER): Environmental regulation can solve the problem of negative externalities of environmental pollution by means of commanding or incentivising regulation, so as to achieve the purpose of effective management of the ecological environment. The sewage charge per unit of GDP reflects the intensity of environmental regulation to a certain extent, and the higher the amount of sewage charge in the reservoir means the higher the intensity of environmental regulation. In this paper, the ratio of the amount of sewage charges to GDP is used to express the environmental regulation (ER). The missing values of sewage charges at the prefectural and municipal levels are relatively large and based on the study of Song et al. [52], since sewage charges are mainly collected for industrial wastewater, the weights of industrial wastewater discharges of the cities in the provinces are multiplied by the provincial level sewage charge data to obtain the municipal level sewage charge data. It should be noted that because China implemented the environmental protection fee to tax in 2018, the data after 2018 is the environmental protection tax revenue.

3.2.3. Mediating Variables

Industrial Structure Upgrading (IND): Industrial structure upgrading reflects the level of transformation and upgrading of industrial structure, which refers to the process of shifting the centre of gravity of industrial structure from primary industry to secondary and tertiary industries one by one. Drawing on existing studies, IND uses the industrial structure upgrading index to measure [53].

Green Technology Innovation (INNO): Management innovations and technological innovations that aim to protect the environment are collectively referred to as green technological innovations. Drawing on existing research, IND measures the number of green patents filed in a given year by [54].

3.2.4. Moderating Variables

Public Environmental Concerns (HAZE): Public environmental concerns can strengthen the local government's attention to environmental governance issues, which makes the local government more willing to improve the environmental pollution situation in the city through environmental regulation and other means. Drawing on Wu et al. [55], the public environmental concern is measured by the Baidu "haze" search index.

Green Finance (FIN): Green finance refers to the institutional arrangement that promotes the greening transformation of the economy through green credit, green bonds, green development funds, green insurance and other financial instruments and related policies. Drawing on the research of Liu and He [56], the entropy method is used to measure the green finance index based on the seven indicators of green credit, green investment, green insurance, green bond, green support, green fund and green equity.

3.2.5. Control Variables

In order to control the impact of indicators other than environmental regulation on green total factor productivity, drawing on existing studies [57,58], this paper selects the level of social consumption (CSR), the level of openness (FDI), the financial capacity (FR), the emphasis on education (TECH) and the ability to invest in fixed assets (INF) as control variables. In addition, in order to avoid the interference of regional characteristics and macroeconomic characteristics on the regression results, this paper controls both regional individual and time fixed effects.

The variables are defined as shown in Table 1.

Table 1. Variable definition table.

Variable Type	Variable Name	Variable Codes	Variable Description
Explained Variable	Green Total Factor Productivity	GTFP	Measured by the Windows–Malmquist–Luenberger model based on the hybrid distance function (EBM).
Explanatory Variable	Environmental Regulation	ER	Measured by the ratio of the amount of sewage charges deposited to GDP. The weights are weighted by the proportion of the city's industrial wastewater emissions to the industrial wastewater emissions of the province in which it is located, and multiplied by the provincial sewage fee data to derive the following.
Mediating Variables	Industrial Structure Upgrading	IND	Drawing on the study of Gan et al. [53], the index of advanced industrial structure was selected to measure.
	Green Technology Innovation	INNO	The number of green utility patents filed in the region in the current year was selected as a proxy variable for green technological innovation.
Moderating Variables	Public Environmental Concern	HAZE	Referring to Wu et al. [55], the public environmental concern was measured by Baidu's "haze" search index.
	Green Finance	FIN	Drawing on the study of Liu and He [56], the green finance index is chosen to measure the green technology innovation.
Control Variables	Social Consumption Level	CSR	Total retail sales of consumer goods (in trillion yuan).
	Openness Level	FDI	Actual utilisation of foreign direct investment in the year (in trillion yuan).
	Financial Capacity	FR	Revenue within the general budget of local finance (unit: trillion yuan).
	Education Emphasis	TECH	Expenditure on education (unit: trillion yuan).
	Fixed Asset Investment Capacity	INF	Fixed asset investment (unit: trillion yuan)

3.3. Model Construction

In order to test the above hypothesis, the following model is constructed in this paper.

$$\mathrm{GTFP_{i,t}} = \alpha_0 + \alpha_1\mathrm{ER_{i,t}} + \alpha_2\mathrm{CSR_{i,t}} + \alpha_3\mathrm{FDI_{i,t}} + \alpha_4\mathrm{FR_{i,t}} + \alpha_5\mathrm{TECH_{i,t}} + \alpha_6\mathrm{INF_{i,t}} + \delta_\mathrm{i} + \partial_\mathrm{t} + \varepsilon_\mathrm{i,t} \quad (3)$$

In the formula, i denotes city; t denotes year; $\mathrm{ER_{i,t}}$ denotes environmental regulations and $\mathrm{GTFP_{i,t}}$ denotes green total factor productivity; $\alpha_n(n = 1, 2, \ldots, 9)$ is the parameter to be estimated, and δ_i, ∂_t and $\varepsilon_\mathrm{i,t}$ denote the individual fixed effects (urban fixed effect), time fixed effects and random perturbation terms, respectively, and the rest of the variables are defined as shown in Table 1.

According to research Hypothesis 1, environmental regulations can improve green total factor productivity through industrial structure upgrading and green technology innovation, in order to test whether the above research hypothesis is valid, the two-step intermediation method is used to test the indirect mechanism that may exist in it, the specific formula is as follows:

$$\mathrm{MI_{i,t}} = \beta_0 + \beta_1\mathrm{ER_{i,t}} + \beta_2\mathrm{CSR_{i,t}} + \beta_3\mathrm{FDI_{i,t}} + \beta_4\mathrm{FR_{i,t}} + \beta_5\mathrm{TECH_{i,t}} + \beta_6\mathrm{INF_{i,t}} + \sigma_\mathrm{i} + \varphi_\mathrm{t} + \varepsilon_\mathrm{i,t} \quad (4)$$

In the formula, $\mathrm{MI_{i,t}}$ represents the mediating mechanism variable, and industrial structure upgrading (IND) and green technology innovation (INNO) are selected as proxy variables for testing, respectively. Where σ_i, φ_t, $\varepsilon_\mathrm{i,t}$, and $\varepsilon_\mathrm{i,t}$ denote the individual fixed effects, time fixed effects, and random perturbation terms, respectively, and the other control variables are kept in the same way as in Equation (3).

According to Hypothesis 2 and Hypothesis 3 research hypotheses, environmental regulation can significantly increase urban green total factor productivity, and the higher the level of green finance development and public environmental concern, the more it helps to increase the induced effect. In order to test whether the above research hypotheses are valid, the cross-multiplier term is introduced to test, the specific formula is as follows:

$$GTFP_{i,t} = \gamma_0 + \gamma_1 ER_{i,t} + \gamma_2 ER_{i,t} * NI_{i,t} + \gamma_3 NI_{i,t} + \gamma_4 CSR_{i,t} + \gamma_5 FDI_{i,t} + \gamma_6 FR_{i,t} + \gamma_7 TECH_{i,t} + \gamma_8 INF_{i,t} + \upsilon_i + \phi_t + \varepsilon_{i,t} \quad (5)$$

In the formula, $NI_{i,t}$ represents the moderating variables, and green finance (FIN) and public environmental concerns (HAZE) are selected as proxy variables for the test, respectively. Where υ_i, φ_t, $\varepsilon_{i,t}$ represent individual fixed effects, time fixed effects and random perturbation terms, respectively, and other control variables are consistent with Equation (3).

4. Empirical Analysis and Results

4.1. Data Description

Table 2 reports the results of the descriptive statistics. The results show that: (1) The mean value of green total factor productivity (GTFP) is 1.010, the minimum value is 0.488, and the maximum value is 1.655, which indicates that there are obvious differences in the distribution of green total factor productivity among cities, and it is of great significance to study the green total factor productivity; (2) The mean value of environmental regulation (ER) is 0.005, the minimum value is 0.001, and the maximum value is 1.212, which indicates that the level of environmental regulation in Chinese cities is still low and unevenly distributed; (3) The mean values of industrial structure upgrading (IND) and green technological innovation (INNO) are 0.982 and 0.051, which indicates that the green technological innovation ability of Chinese cities is still insufficient compared with the advantages in industrial accumulation. (4) The mean values of green finance (FIN) and public environmental concerns (HAZE) are 0.630 and 0.453, respectively, indicating that environmental regulation has a better institutional environment and is better recognised and supported by society. The inclusion of public environmental concerns and green finance in the analysis of moderating effects is of comparative importance. In addition, the distribution ranges of the values of the other control variables (CSR, FDI, FR, TECH, INF) in the table are roughly close to the findings of Liu et al. [59] and Shangguan et al. [60], which can prevent the problem of heteroskedasticity arising from the statistical regression due to the excessive differences.

Table 2. Descriptive statistics.

Variables	Observations	Average	Standard Deviation	Minimum	Maximum
GTFP	4826	1.010	0.470	0.488	1.655
ER	4826	0.005	0.008	0.001	1.212
CSR	4826	0.075	0.125	0.001	1.593
FDI	4826	0.005	0.013	0.001	0.348
FR	4826	0.017	0.044	0.001	0.717
TECH	4826	0.005	0.008	0.001	0.114
INF	4826	0.132	0.173	0.001	2.477
IND	4826	0.982	0.493	0.089	5.350
INNO	4826	0.051	0.181	0.000	3.467
FIN	4826	0.630	0.483	0.000	1.000
HAZE	4826	0.453	0.498	0.000	1.000

4.2. Analysis of Regression Results

Based on the results of the Hausman test, the regression was conducted using a fixed-effects model, controlling for individual city effects and yearly effects. The regression results are shown in Table 3. The regression coefficient of ER in column (1) is significantly positive at the 1% level, indicating that environmental regulation can effectively improve urban green total factor productivity and H1 is supported. In other words, environmental regulation can create a favourable environment and market for green technological innovation, reduce the cost of green innovation and industrial structure upgrading of enterprises, and thus increase urban green total factor productivity. The regression coefficient of ER * HAZE in column (2) is significantly positive at the 5% level, indicating that public environmental concern strengthens the promotion effect of environmental regulation on green total factor productivity, and H2 is supported, that is to say, public environmental concern contributes to the implementation of the government's green policy, and also contributes to the provision of markets for the green products produced by the enterprises, which then increases the green total factor productivity more substantially. The regression coefficient of ER * FIN in column (3) is significantly positive at the 1% level, indicating that green finance strengthens the promotion effect of environmental regulation on green total factor productivity, and H3 is supported. Green finance helps to provide more financial support for government finances and also helps to urge enterprises to transform through discriminatory credit policies, which provides grounded resource support for the improvement of urban green total factor productivity.

Table 3. Regression results of baseline regression.

Variables	(1)	(2)	(3)
	Baseline Regression	**Moderating Effect**	**Moderating Effect**
ER	0.230 ***	−0.424	−0.239
	(2.70)	(−1.53)	(−1.53)
HAZE		−0.003	
		(−1.20)	
ER * HAZE		0.521 **	
		(2.31)	
FIN			−0.005 **
			(−2.33)
ER * FIN			1.131 ***
			(3.83)
CSR	−0.030	−0.045 *	−0.035 *
	(−1.53)	(−1.69)	(−1.69)
FDI	−0.109 *	−0.027	−0.133 **
	(−1.96)	(−0.50)	(−2.35)
FR	0.094 *	0.082	0.079
	(1.68)	(1.06)	(1.47)
TECH	−0.279	0.183	−0.123
	(−0.82)	(0.44)	(−0.37)
INF	0.029 ***	0.032 **	0.037 ***
	(3.29)	(2.48)	(4.25)
_cons	1.011 ***	1.010 ***	1.013 ***
	(5.68)	(3.87)	(5.16)
Id	YES	YES	YES
Year	YES	YES	YES
N	4826	4826	4826
R^2	0.135	0.152	0.172

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.3. Mechanism Testing

The above theoretical analyses show that environmental regulation can improve green total factor productivity through green technological innovation and industrial structure upgrading. In order to test the validity of the above analyses, this paper uses industrial structure upgrading (IND) and green technological innovation (INNO) as the mediating variables, respectively, and verifies the above mediating effects through a two-step method.

Table 4 reports the results of the descriptive statistics. The results show that the regression coefficient of ER in column (1) is significantly positive at the 1% level, which indicates that environmental regulation will effectively promote the upgrading of industrial structure, and through the withdrawal of high pollution, high emission and high energy consumption enterprises from the market, the green enterprises can obtain more capital, technology and labour support to achieve the transformation of the old and new kinetic energy, which in turn will promote the improvement of the city's green total factor productivity. The coefficient of ER in column (2) is significantly positive at the 5% level, indicating that environmental regulation can encourage enterprises to improve their outdated production processes, reduce energy consumption and resource waste per unit, and then increase the green total factor productivity of the city. Considering the reliability of the conclusion, this paper still refers to the three-stage mediation test method, using the Sobel mediation test, in order to better make the combination of statistical significance and economic significance, empirical research found that the results of the Sobel Z value were 3.011, 2.031, and its significance level was significant at the 1%, 5% level, respectively, indicating that part of the mediation effect was established.

Table 4. Regression results of the mechanism testing.

Variables	**(1)**	**(2)**
	IND	**INNO**
ER	3.516 ***	1.492 **
	(3.12)	(1.99)
CSR	−0.198	0.740 ***
	(−0.92)	(4.43)
FDI	−0.239	−0.698
	(−0.34)	(−1.33)
FR	−1.836 **	2.465 *
	(−2.27)	(1.90)
TECH	14.347 ***	4.540
	(2.93)	(0.97)
INF	0.054	−0.142
	(0.56)	(−1.43)
_cons	0.959 ***	−0.024 ***
	(5.13)	(−4.89)
Id	YES	YES
Year	YES	YES
N	4826	4826
R^2	0.367	0.772

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.4. Heterogeneity Analysis

China has a relatively large land area, which makes different regions choose different development modes based on their resource endowments, which in turn affects the policy effects of environmental regulation. There is also a huge development gap between non-resource cities and resource cities, and between the eastern, central and western regions and the northeastern region, making it necessary to analyse the spatial distribution of environmental regulations.

Firstly, this paper divides the 289 cities in the sample into resource-based cities and non-resource-based cities, and subdivides them into growth, maturity, decline, and regeneration cities according to the stage of development of the resource-based cities, and conducts regressions separately. The regression results are shown in Table 5. The regression coefficients of ER are significantly positive in column (1), but not significant in columns (2), (3), and (4), which indicates that there are significant challenges to the advancement of environmental regulation. When resource-based cities are in the growth phase, the cities have very high-quality mineral resources, low extraction costs, and low sewage costs in the extraction process, and are able to adapt to the pressure of environmental regulation policies. When resource cities are in the maturity, decline, and regeneration phases, they face large historical burdens and lack capital and mature technology, which prevents environmental regulation from achieving the desired results. At the same time, the coefficient of ER in column (5) is significantly positive, indicating that non-resource cities have lighter environmental burdens and weaker resource constraints and that environmental regulations can promote green total factor productivity.

Table 5. Heterogeneity tests for urban categories.

Variables	(1)	(2)	(3)	(4)	(5)
	Growth	**Maturity**	**Decline**	**Regeneration**	**Non-Resource**
ER	0.792 ***	0.114	0.888	−0.474	0.233 **
	(3.25)	(1.16)	(1.06)	(−0.47)	(1.99)
CSR	−0.100	−0.172 *	−0.329	−0.158	−0.022
	(−0.24)	(−1.83)	(−1.04)	(−0.87)	(−1.11)
FDI	0.020	−1.139	−4.060	−1.780 *	−0.081
	(0.01)	(−1.11)	(−1.25)	(−1.82)	(−1.51)
FR	−0.035	0.420	−1.783	−0.383	0.038
	(−0.10)	(0.93)	(−0.98)	(−0.46)	(0.71)
TECH	−0.349	−2.236	0.191	−0.656	0.043
	(−0.26)	(−1.37)	(0.07)	(−0.17)	(0.12)
INF	0.057	0.124 ***	0.244 **	0.173 **	0.019 **
	(0.78)	(2.99)	(2.50)	(2.24)	(2.24)
_cons	1.013 ***	1.017 ***	1.008 ***	1.026 ***	1.009 ***
	(9.27)	(4.88)	(13.60)	(10.64)	(4.27)
Id	YES	YES	YES	YES	YES
Year	YES	YES	YES	YES	YES
N	201	998	383	243	3001
R^2	0.121	0.135	0.135	0.125	0.185

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Secondly, given the economic gap between China's coastal regions and internal regions, there may be a gap between the policy implementation capacity, technology accumulation capacity, and the public's environmental concerns faced by environmental regulation. In this paper, according to the division of China's regional sectors, the eastern region, the midwestern region, and the northeastern region are selected for regression. The regression results are shown in Table 6. The coefficients of ER are significantly positive in column (1), while columns (2) and (3) are not significant. This suggests that due to lower environmental pressure, higher levels of capital accumulation, and easier access to international green consumption concepts and green technologies, the eastern coastal region is more able to use environmental regulations to achieve green total factor productivity. In contrast, the midwestern and northeastern regions, with their weaker technological accumulation capacity and greater pressure on economic growth, may be constrained by local fiscal and employment pressures in the process of implementing environmental regulations, making it impossible for the policy to achieve the expected results.

Table 6. Heterogeneity tests for regional distributions.

Variables	(1)	(2)	(3)
	Eastern	**Midwestern**	**Northeastern**
ER	0.230 ***	0.230	0.363
	(2.70)	(1.70)	(0.99)
CSR	0.001	−0.030	−0.008
	(0.03)	(−1.53)	(−0.12)
FDI	−0.053	−0.109 *	−0.118
	(−0.38)	(−1.96)	(−0.94)
FR	0.021	0.094 *	0.212
	(0.41)	(1.68)	(0.56)
TECH	−0.151	−0.279	−3.350
	(−0.41)	(−0.82)	(−1.30)

Table 6. *Cont.*

Variables	(1)	(2)	(3)
	Eastern	**Midwestern**	**Northeastern**
INF	0.032 **	0.029 ***	0.038
	(2.38)	(3.29)	(1.45)
_cons	1.008 ***	1.011 ***	1.013 ***
	(3.87)	(5.68)	(8.35)
Id	YES	YES	YES
Year	YES	YES	YES
N	1548	2699	579
R^2	0.134	0.135	0.132

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5. Robustness and Endogeneity Tests

In order to ensure the reliability of the findings, to make the results robust and to maximise control for endogeneity in the study, six tests were used to ensure the robustness of the findings: variable substitution, extended observation window, instrumental variable test (IV), Heckman's test, propensity score matching (PSM), and placebo test (PT).

5.1. Robustness Test I: Replacing Explanatory and Explained Variables

To further test the reliability of our conclusions, we conduct a robustness test by replacing variables from two perspectives. From the perspective of the explanatory variables, we draw on previous studies using green total factor productivity measured by SBM and GML models as the replacement variables. From the perspective of the explanatory variables, we draw on previous studies to select the frequency of environmental regulation words (ER1) and the number of environmental enforcement penalties (ER2) in the government work report as the proxy variables for environmental regulation. The regression results are shown in Table 7, the findings are consistent with the baseline regression results.

Table 7. Robustness test I: main explanatory variables and explained variables replacement.

Variables	(1)	(2)	(3)	(4)
	SBMDDF	**GMLDDF**	**ER1**	**ER2**
ER	0.120 *	0.130 ***		
	(1.69)	(2.63)		
ER1			0.001 ***	
			(7.95)	
ER2				1.272 ***
				(3.20)
CSR	0.061 ***	−0.017 *	0.001	0.012
	(4.51)	(−1.71)	(0.05)	(0.45)
FDI	−0.147 ***	−0.039 *	−0.050	−0.068
	(−2.68)	(−1.67)	(−0.35)	(−0.51)
FR	0.036	0.021	0.009	0.007
	(0.46)	(0.85)	(0.18)	(0.15)
TECH	−0.412	0.007	−0.099	−0.139
	(−0.68)	(0.03)	(−0.27)	(−0.37)
INF	−0.004	0.007	0.029 **	0.030 **
	(−0.46)	(1.43)	(2.16)	(2.10)
_cons	0.996 ***	0.897 ***	1.009 ***	1.005 ***
	(8.58)	(5.58)	(3.41)	(2.27)
Id	YES	YES	YES	YES
Year	YES	YES	YES	YES
N	4826	4826	4826	4826
R^2	0.153	0.158	0.138	0.125

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5.2. Robustness Test II: Extended Observation Window

In order to avoid that the impact of environmental regulations on green total factor productivity is only an episodic phenomenon of the current year, this paper extends the observation window of the sample, lags environmental regulations by 1–3 periods and then re-regresses the sample. The regression results are shown in Table 8, the results show that, after the observation window is extended, environmental regulations are still able to promote green total factor productivity, but this influence will be attenuated with the extension of the time window, which suggests that there is still a policy pandering situation in the market and that the market force of spontaneous green transformation is not strong enough.

Table 8. Robustness test II: extending the observation window.

Variables	(1)	(2)	(3)
	L1.ER	**L2.ER**	**L3.ER**
L1.ER	0.170 **		
	(1.99)		
L2.ER		0.139 *	
		(1.68)	
L3.ER			0.038
			(0.30)
CSR	−0.030	−0.037 *	−0.034
	(−1.55)	(−1.91)	(−1.62)
FDI	−0.105 *	−0.092 *	−0.094 *
	(−1.90)	(−1.72)	(−1.69)
FR	0.093 *	0.065	0.074
	(1.66)	(1.22)	(1.31)
TECH	−0.273	−0.041	−0.125
	(−0.79)	(−0.12)	(−0.35)
INF	0.028 ***	0.025 ***	0.027 ***
	(3.11)	(2.84)	(2.79)
_cons	1.010 ***	1.010 ***	1.011 ***
	(4.99)	(5.03)	(4.56)
Id	YES	YES	YES
Year	YES	YES	YES
N	4572	4318	4064
R^2	0.135	0.125	0.125

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5.3. Endogeneity Test: IV + Heckman + PSM + PT

Considering the possible endogeneity problem and reverse causality problem in this paper, the following tests are carried out: (1) Instrumental variable test (IV): this paper chooses the air mobility coefficient as an instrumental variable. On the one hand, the airflow rate is geographically motivated and is not affected by local government environmental regulations and other control variables. On the other hand, the faster air movement speed helps to reduce local pollution and environmental regulation pressure. In addition, a weak homogeneity test was conducted on the instrumental variables, and the regression F-statistic was greater than 10, rejecting the original hypothesis of weak instrumental variables. (2) Heckman test: in order to avoid the influence of potential sample selection on the conclusions of this paper, the Heckman test is conducted. In the first stage, the average environmental regulation intensity within the same urban agglomeration is added on the basis of the control variables of the main regression model and the inverse Mills ratio (lambda) is obtained. In the second stage, the inverse Mills ratio is added as a control variable to the model regression. (3) Propensity score matching test (PSM): this paper takes the cities with lower than average environmental regulation as the experimental group, and the cities with higher than average environmental regulation as the control group, and adds urban per capita energy consumption, market potential and social insurance contribution rate as covariates for 1:1 neighbourhood matching on the basis of the original control variables. Individuals in the intervention state of the average intervention effect (ATT) is significant after covariate matching the experimental group and the control group standardised error is basically less than 10%, that is, the mean value is not significantly different from the number of covariates, the matching of the balance is acceptable, and then the matching samples are regressed again. (4) Placebo test (PT): in order to address the impact of the omission of certain key control variables on the conclusions of this paper. In this paper, a placebo test is used, where the environmental regulation variables are randomly exchanged across prefecture-level cities and regressed again on the disrupted and re-matched samples. Table 9 reports the regression results of the above tests, which show that the main conclusions remain valid.

Table 9. Endogeneity test I: IV + PSM + Heckman + Placebo Test.

Variables	(1)	(2)	(3)	(4)
	IV	**HECKMAN**	**PSM**	**PT**
ER	0.200 **	0.435 **		
	(2.43)	(1.99)		
LAMBDA		−0.379 **		
		(−2.52)		
Treated			0.022 ***	
			(2.55)	
lie				0.025
				(0.42)
CSR	−0.021 *	0.105	−0.029	−0.040 *
	(−1.90)	(0.54)	(−1.49)	(−1.82)
FDI	−0.063	1.566 **	−0.103 *	−0.122 **
	(−1.09)	(2.12)	(−1.86)	(−2.21)
FR	0.082 **	−0.826	0.093	0.124 *
	(2.27)	(−0.99)	(1.61)	(1.94)
TECH	−0.280	−12.738 *	−0.301	−0.315
	(−1.39)	(−1.77)	(−0.84)	(−0.77)
INF	0.011 **	0.467 **	0.026 ***	0.023 **
	(2.24)	(2.06)	(2.86)	(2.25)
_cons	1.010 ***	1.023 ***	1.011 ***	1.012 ***
	(14.58)	(9.75)	(5.55)	(4.91)
Id	YES	YES	YES	YES
Year	YES	YES	YES	YES
N	4824	4777	2791	4826
R^2	0.123	0.112	0.123	0.113

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

6. Conclusions and Discussion

6.1. Conclusions

Rapid industrialisation and urbanisation in China have led to significant energy consumption by urban industries. The issue of environmental pollution is becoming increasingly prominent. This has prompted the government to implement environmental regulation policies to facilitate the transformation of the economic model, which can also be viewed as a process of enhancing green total factor productivity.

This study aims to investigate the impact of environmental regulation on green total factor productivity using a panel dataset of 289 Chinese cities. The research finds that environmental regulation can significantly enhance urban green total factor productivity. Public environmental concern and green finance strengthen the positive impact of environmental regulation on urban green total factor productivity. Mechanism tests indicate that environmental regulation can increase urban green total factor productivity through green technological innovation and industrial structure upgrading. Taking into account the differences in resource endowment, this study subdivides cities by category and economic sector. Heterogeneity analysis reveals that, compared to the resource-based cities, the positive effect of environmental regulation on urban green total factor productivity is more significant in the non-resource-based cities with relatively developed traditional finance and high levels of industrial modernisation. Compared to the central and western as well as the northeast regions of China, the positive effect of environmental regulation on urban green total factor productivity is more significant in the eastern region due to capital accumulation and technological constraints. The above conclusions of the study remain valid after changing variable measurement, extending the observation window, instrumental variable tests (IV), Heckman tests, propensity score matching (PSM), and placebo tests (PT).

6.2. Recommendations

Based on the research findings, the following policy insights are provided for the Chinese government departments. Firstly, the government needs to continue to adhere to environmental regulatory policies, construct green infrastructure and research platforms, guide technology exchange among enterprises, enhance the overall green innovation level of cities, and continuously promote the upgrading of industrial structures. Secondly, guide the public to pay more attention to urban environmental pollution and energy conservation issues, and involve the public in the entire process of formulating and supervising daily environmental protection policies. At the same time, expand and strengthen the green financial security system, and continuously increase special green financial securities, funds, and credits. Form a better coordinate with existing environmental regulatory policies. Thirdly, taking into consideration the development history, capital accumulation, technological reserves, and economic growth pressures of different regions, provide more policy support to resource-based cities in maturity, decline, and regeneration stages. Encourage the eastern region to summarise their environmental regulatory experiences and support the development of the central and western as well as the northeastern regions through green technology and capital assistance. Enhance the environmental regulatory capabilities of underdeveloped areas to promote the improvement of green total factor productivity.

6.3. Theoretical Contributions

This study contributes to filling the gap in research on the relationship between environmental regulations and green total factor productivity, thereby making an incremental contribution to the existing knowledge system. Specifically: Firstly, this paper innovates the calculation method of green total factor productivity. Distinguished from previous studies that utilised either the radial CCR model or the non-radial SBM model, this study employs a hybrid radial EBM model to green total factor productivity. In the actual production process, enterprises exhibit both radial and non-radial relationships between inputs and outputs. For example, enterprises input both energy and labour in their production operations. Energy input is linearly related to environmental pollution, while labour input shows a non-linear relationship with environmental pollution. Failure to consider both relationships can lead to bias in estimating green total factor productivity. Therefore, this study opts to utilise a hybrid radial EBM model that considers both linear and non-linear relationships, filling a significant gap in this area of research. Secondly, this study innovates the research data on environmental regulation. Previous studies on the economic consequences of environmental regulation mainly relied on data from Chinese-listed companies or leading manufacturing enterprises. Most of these enterprises are located in coastal cities and economically developed regions in China, which cannot represent the situation in China's inland regions enterprises and small and medium-sized enterprises. In contrast, this study uses data at the urban level, which better reflects the comprehensive situation of urban green development, including large enterprises and small- and medium-sized enterprises. It also considers the wide economic development level differences and resource endowment disparities between Chinese cities, making the research conclusions more practical. Thirdly, this paper expands the scenario factors of the "environmental regulation and urban green total factor productivity" relationship from a theoretical perspective, as existing research lacks analysis on how to enhance the positive effects of environmental regulations and reduce the negative impacts of environmental regulations. This study has identified the role of green finance in enhancing the attractiveness of environmental regulation markets, as well as the impact of public environmental concerns on increasing the pressure for the implementation of environmental regulations, providing new theoretical perspectives for future researchers.

6.4. Limitations and Future Research

Although this paper provides important findings, it still has some limitations. Firstly, the focus of this study on China limits the generalisability of the study results to different economic, social, and regulatory environments, necessitating consideration of more countries, especially developing and developed countries. Secondly, the data of this study may not cover all dimensions of environmental regulation affecting green total factor productivity, and potential key factors may be overlooked. Finally, mediating and moderating factors may need to be supplemented to better reflect the actual situation.

Author Contributions: Conceptualisation, Z.Y. and Y.R.; methodology, Y.L.; software, Z.Y. and Y.L.; validation, Z.Y. and Y.L.; formal analysis, Z.Y.; investigation, Z.Y. and Y.R.; resources, Z.Y., Y.L. and Y.R.; data curation, Z.Y.; writing—original draft preparation, Z.Y. and Y.R.; writing—review and editing, Z.Y., Y.L. and Y.R.; visualisation, Z.Y. and Y.R.; supervision, Z.Y. and Y.R.; project administration, Z.Y. and Y.R.; funding acquisition, Z.Y. All authors have read and agreed to the published version of the manuscript.

Funding: The authors gratefully acknowledge the support for this research provided by the National Planning Office of Philosophy and Social Science (NPOPSS) of China, grant number 21BGL110.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are available from authors upon reasonable request.

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

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