Pol. J. Environ. Stud. Vol. XX, No. X (XXXX), 1-18

DOI: *10.15244/pjoes/188044* ONLINE PUBLICATION DATE:

Original Research

Heterogeneous Environmental Regulation, Foreign Direct Investment and Green Total Factor Productivity: An Empirical Study Based on Provincial Panel Data of China

Jie Xue[1], Liyi Shi[1], Shan Xu[1]*, Zhenyan Li[1]

[1] School of Economics, Hangzhou Dianzi University, Hangzhou 310018, China

Received: 01 February 2024
Accepted: 27 April 2024

Abstract

Foreign Direct Investment (FDI) is a double-edged sword, promoting the economic growth of host countries while also bringing severe environmental issues. The implementation of different types of environmental regulations and the inflow of FDI both impact the growth of green total factor productivity (GTFP) in host countries. How to cope with the relationship between these three factors is vital for developing countries. This paper utilizes panel data from 30 provinces in China for the period of 2005-2020 to analyze the effects of command-and-control, market-incentive-based, and public voluntary environmental regulations on GTFP at the national level and the coastal and inland levels. Furthermore, a stepwise regression approach is employed to explore the moderating effect of FDI on the relationship between environmental regulation and GTFP. The findings provide insights into the coordinated development of the environment, FDI, and the economy. The results indicate that: Firstly, at the national level, the three types of environmental regulations have different effects on GTFP in China. Command-and-control regulation inhibits GTFP growth, market-incentive-based regulation promotes GTFP growth, and public voluntary environmental regulation shows no significant impact on GTFP. Additionally, FDI has a significant moderating effect on both command-and-control and market-incentive-based regulations with GTFP, strengthening the negative relationship between command-and-control regulation and GTFP and weakening the positive relationship between market-incentive-based regulation and GTFP. Secondly, at the coastal and inland levels, command-and-control regulation inhibits the growth of GTFP in inland areas, while market-incentive-based regulation promotes the growth of GTFP in coastal and inland regions. Public voluntary regulation has no significant impact on GTFP in coastal areas but has a negative effect on GTFP in inland areas. Besides, there is heterogeneity in the moderating effect of FDI between the three types of environmental regulations and GTFP.

Keywords: heterogeneous environmental regulation, FDI, green total factor productivity, moderating effect

* e-mail: suzzan8469@163.com

Introduction

With the trend of economic globalization, the increasing pressure on resources and the environment poses challenges to economic development. The promotion of the concept of green development has attracted the attention of the world towards the development of a green economy. Since the implementation of economic reforms and the opening up of policy in the 1980s, China has experienced rapid expansion in its overall economic size and achieved sustained and stable growth. Significant progress has been made in the energy industry, but it has also resulted in certain negative impacts on the ecological environment. Environmental pollution issues have frequently emerged, including acid rain, desertification, greenhouse gas emissions, and ozone layer depletion. Addressing pollution prevention and control, the "Twenty Major Issues" report of China emphasizes the need to deepen environmental pollution prevention and continue the efforts to safeguard blue skies, clean water, and pristine land. Easing the contradiction between environmental protection and economic development and implementing a green economy development strategy is necessary for the long-term development of China's economy. GTFP is seen as the key to realizing the development of a green economy. Improving GTFP is crucial to the development of China's green economy. Meanwhile, the implementation of environmental regulation is aimed at promoting the development of China's green economy by employing various types of regulatory instruments.

With the deepening of China's reforms and opening up, FDI has continued to flow in. From the beginning of the 21st century to the present, more than two decades later, China's actual utilization of foreign capital has increased by about three times, with absorbing foreign capital accounting for the first in developing countries. In 2020, the global FDI inflow ranked the top three countries or regions, in order of the United States, China, and Hong Kong. According to research, FDI inflow is one of the main driving forces for economic growth [1], but it has also contributed to the increasing prominence of environmental problems in China, and the impact of FDI on the ecological environment of host countries has gradually become the focus of academic attention. Two opposing views have been proposed, namely the "pollution paradise" and "pollution halo" hypotheses. The former argues that developed countries have relatively stricter environmental regulations than developing countries, which makes the cost of polluting industries in developed countries higher, in which case polluting industries in developed countries will move to developing countries with lower environmental standards. The latter argues that FDI flows to developing countries promote their technological progress, which in turn improves the environment in developing countries. In addition, the practice of FDI in promoting economic development has also revealed some problems. First, there is the problem of "bottom-up competition". Some local governments, driven by "GDP worship" and vested interests, in order to attract the inflow of FDI at the expense of the ecological environment, restrict the implementation of environmental standards to increase the GDP of the region. Second, there is the problem of regional disharmony between FDI and green economic development. Due to the geographical location and the implementation of the national strategy for unbalanced development, there is a big gap between FDI and green economic development in different regions of China, which is mainly reflected in the coastal and inland areas. Coastal regions usually have a higher level of FDI and green economic development than inland regions due to their convenient transport and communication conditions and favorable policies.

Environmental regulation, as a constraining force aimed at environmental protection, influences the location choice of foreign investment. Environmental regulation is considered to have a filtering effect on FDI, with some negative effects, but also some positive effects. While environmental regulation has an impact on FDI, it also has an impact on green economic development. Therefore, what are the impacts of different types of environmental regulation on the green economy, and what role does FDI play in these impacts? How can appropriate environmental regulation be formulated so that the inflow of FDI can promote the development of the green economy? These are issues worthy of in-depth exploration. Therefore, this paper focuses on the relationship between heterogeneous environmental regulation, FDI, and GTFP and makes a comparative analysis of different regions. It is hoped that the research in this paper will have a certain reference value for relevant government departments to make reasonable use of the policy tool of environmental regulation, so as to promote the development of the global green economy and realize the concept of green development.

The contribution of this paper has two main aspects. On one hand, with regard to the innovative research perspective, this paper originates from the perspective of heterogeneous environmental regulation, incorporating regional heterogeneity into the research framework to explore the relationship among environmental regulation, FDI, and GTFP. It endeavors to offer fresh research insights and enrich relevant theoretical frameworks. On the other hand, concerning the innovative research path, this paper treats FDI as a moderating variable to examine its regulatory effect on heterogeneous environmental regulation and GTFP. Through empirical testing, it further analyzes the mechanism of influence among the three variables. This approach provides a new methodological pathway for explaining the complex relationship among environmental regulation, FDI, and GTFP.

The remainder of this paper is structured as follows: Section 2 provides a comprehensive review of existing studies on the relationship between environmental regulation, FDI, and GTFP. Section 3 describes the GTFP measurement methodology and the analysis of the results. Section 4 illustrates the theoretical assumptions, model, sample, and data selection. Section 5 presents the empirical tests and analysis of the results. Section 6 concludes the research and gives policy recommendations.

Literature Review

To date, scholars have primarily explored the relationship between environmental regulation, FDI, and GTFP in terms of environmental regulation and GTFP, FDI, and GTFP, as well as the interactions among these three factors.

Environmental Regulation and GTFP

With the increasing prominence of environmental issues, neglecting pollution emissions when measuring productivity may lead to an overestimation of GTFP, thereby introducing uncertain economic consequences to policy formulation [2]. Environmental regulation can have uncertain effects on GTFP through the "compliance cost" and "innovation compensation" mechanisms [3]. Consequently, research on the relationship between environmental regulation and total factor productivity (TFP) is primarily divided into three main perspectives.

The first perspective is the negative effect of "compliance cost," which argues that environmental regulation will suppress GTFP. Allen argued that in developing countries, inconsistent environmental regulation policies and other constraints make the implementation of environmental regulation ineffective and inhibit the rise of GTFP [4]. Tang et al. used the DID and DDD models to empirically find that command-and-control environmental regulation has a negative impact on the green innovation efficiency of Chinese industrial enterprises [5]. Lin and Xu found that the implementation of carbon taxes has a negative effect on GTFP [6]. Li et al. demonstrated that implementing policies like "Two Control Zones" can inhibit the improvement of GTFP in Chinese cities [7]. Zhang and Qiao conducted research and found that command-and-control and incentive-based environmental regulation have obstructive effects on GTFP in the manufacturing industry [8].

The second perspective is the positive effect of "innovation compensation," which suggests that environmental regulation can promote GTFP. Porter and Linde argued that while environmental regulations inevitably increase costs, they can stimulate technological innovation activities in companies and improve their performance in the long run, a viewpoint known as the "Porter hypothesis." [9]. Domazlicky and Weber found that environmental regulation did not reduce the growth rate of GTFP by measuring the GTFP of six major chemical industries in the United States [10]. Spang et al. found that command-and-control environmental regulation has a significant positive effect on environmental protection and improving energy efficiency [11]. Guo et al. discovered a significant positive impact of environmental regulation on technological innovation, which in turn has a promoting effect on GTFP, validating and supporting the Porter hypothesis [12]. Ghosal et al. demonstrated that environmental regulation has a significant positive impact on GTFP in the paper industry [13]. Guan et al. found that technological progress is crucial for regional GTFP improvement [14]. Zhang discovered a positive correlation between GTFP and environmental regulation based on data from 491 manufacturing firms [15]. Yu and Yan found that environmental regulation can promote GTFP improvement in areas with light, moderate, and heavy pollution, but the promoting effect decreases sequentially [16].

The third perspective posits that the impact of environmental regulation on GTFP is either insignificant or exhibits a nonlinear relationship. Kemp and Pontoglio argued that market-incentive-based environmental regulation tools have limited incentives for technological innovation, thus having no significant impact on GTFP [17]. Sanchez-Vargas et al., through studying the relationship between environmental regulation and manufacturing sector GTFP in Mexico, discovered a nonlinear relationship between the two [18]. Wang and Shen found an inverted U-shaped relationship between environmental regulation and industrial GTFP [19]. Wu et al. found a U-shaped relationship between market-incentive-based and public voluntary environmental regulation and GTFP growth, but command-and-control environmental regulation had no significant impact on GTFP [20]. Zhang et al. found that moderate environmental regulation has a promoting effect on GTFP, but when they exceed a certain threshold, strict environmental regulation inhibits GTFP growth [21].

FDI and GTFP

To examine the specific situations regarding the contrasting hypotheses of "pollution haven" and "pollution halo," scholars have conducted extensive research, resulting in three main perspectives:

The first perspective supports the "pollution haven" hypothesis, positing that inward FDI exacerbates environmental pollution in host countries and inhibits GTFP growth. Al-Mulali and Tang employed a multidimensional framework to examine the effectiveness of the pollution haven hypothesis in Gulf Cooperation Council (GCC) countries [22]. Rafindadi et al. pointed out that developing countries reduced environmental protection requirements in order to develop their economies, thus attracting developed countries to transfer highly polluting industries to developing countries, exacerbating environmental pollution in the host countries, which is not conducive to the improvement of GTFP [23]. Wu et al. found that FDI constrained GTFP in the eastern region of China by studying the factors influencing environmental total factor productivity in manufacturing [24]. Sun et al. used an extended STIRPAT model to analyze the effect of FDI on industrial GTFP in the Yangtze River Delta urban agglomeration of China, showing a restraining effect [25].

The second perspective supports the "pollution halo" hypothesis, suggesting that inward FDI can generate positive technology spillovers in host countries, leading to reduced pollution emissions and promoting GTFP growth. Liobikienė and Butkus believed that FDI stimulates economic growth and environmental quality through technology transfer, disseminates green technologies, and reduces emissions [26]. Abdo et al. considered that TNCs can reduce ecological degradation in host countries by acquiring high production patterns and advanced technologies through FDI to replace old polluting technologies and enhance capacity for sustainable development [27]. Cui and Lin found that foreign investment contributed to GTFP growth, particularly in the eastern region of China [28]. Zhang et al., focusing on 108 cities in the Yangtze River Economic Belt of China, concluded that FDI had both direct and indirect positive effects on GTFP [29].

The third perspective suggests an uncertain relationship between inward FDI and host country GTFP. Fu et al. found that overall, FDI's impact on China's GTFP was not significant, but the effects varied depending on the source of FDI [30]. Ascani, through examining the relationship between FDI inflows in different regions of Italy and manufacturing technological innovation capability, discovered that only specific types of FDI were conducive to improving innovation capabilities, while other types of FDI may have negative consequences [31].

Environmental Regulation, FDI, and GTFP

Yang et al. found that the level of environmental regulation in the eastern region is positively correlated with the ease of FDI introduction, while the opposite is true in the central and western regions [32]. Qiu et al. found that FDI had a "pollution haven" effect on GTFP in the eastern and central regions of China and a "pollution halo" effect in the western region, and the strengthening of environmental regulation weakened the negative impact of FDI on GTFP [33]. Xie et al. discovered that the interaction between economic incentive-based environmental regulation and FDI promoted industrial green development, while the interaction effect between command-and-control environmental regulation and FDI was not significant [34]. Li and Wu found that FDI positively moderated the relationship between environmental regulation and GTFP in the Yangtze River Delta and Central China City Clusters but negatively moderated the relationship in the Chengdu-Chongqing City Cluster in China [35].

After reviewing the research literature on the relationship between environmental regulation, FDI, and GTFP, several findings emerge. Firstly, different types of environmental regulation tools have varying effects on GTFP. Additionally, the effects of different types of environmental regulations on GTFP exhibit regional heterogeneity, which has received limited attention in the existing literature. Secondly, there is scarce research considering the moderating effect of FDI on the relationship between heterogeneous environmental regulation and GTFP, with a lack of consideration for regional heterogeneity. Therefore, this paper will consider the deficiencies of existing research. The contributions of this paper are summarized as follows: Firstly, this paper takes the perspective of heterogeneous environmental regulation and incorporates regional heterogeneity into the research framework to investigate the relationship between environmental regulation, FDI, and GTFP, attempting to provide new research experiences and enrich relevant theoretical studies. Secondly, in this paper, FDI is used as a moderating variable to test the moderating effect of FDI between heterogeneous environmental regulation and GTFP and to further analyze the influence mechanism among the three.

Measurement and Analysis of GTFP

Method Selection

The measurement methods for TFP in the existing literature can be classified into two categories: parametric methods and non-parametric methods. Parametric methods require the assumption of a specific production function and estimate the parameters based on observed input-output data. The two commonly used parametric methods are the Solow Residual and Stochastic Frontier Analysis (SFA). On the other hand, non-parametric methods do not require the assumption of a specific production function. Instead, they utilize mathematical programming techniques to measure TFP based on the input-output relationship. The most widely used non-parametric method is Data Envelopment Analysis (DEA). Considering the presence of non-zero slack, which indicates either input overuse or output underperformance, the directional distance function model often tends to overestimate the efficiency of decision-making units (DMUs). To address this issue, Tone [36] and Fukuyama & Weber [37] extended the model to incorporate slack-based measures (SBM). Feng and Zhang concluded that the SBM model is more in line with the real meaning of GTFP by comparing and analyzing the results of the SBM model and the underlying directional distance function model for measuring GTFP [38]. In summary, the combination of the Slacks-Based Measure (SBM) model and the Malmquist index is an effective method for measuring GTFP. In this paper, this approach is utilized to calculate GTFP.

Firstly, we consider the production possibilities set for unexpected outputs. In this paper, each province in China is treated as a decision-making unit (DMU) to construct the production frontier. It is assumed that each DMU utilizes N inputs $x=(x_1,\cdots,x_N)\in R_N^+$ to produce M desirable outputs $y=(y_1\cdots y_M)\in R_M^+$, with I undesirable outputs $b=(b_1,\cdots b_I)\in R_I^+$. λ_k^t represents the weight assigned to each cross-sectional observation. We can apply the data envelopment analysis (DEA) for modeling:

$$P^t(x^t)=\left\{(y^t,b^t):\sum_{k=1}^{k}\lambda_k^t y_{km}^t\geq y_{km}^t,\forall m;\sum_{k=1}^{k}\lambda_k^t b_{ki}^t =b_{ki}^t,\forall i;\sum_{k=1}^{k}\lambda_k^t x_{kn}^t\leq x_{ki}^t,\forall n;\ \sum_{k=1}^{k}\lambda_k^t=1,\lambda_k^t\geq 0,\forall k\right\} \tag{1}$$

Next, we construct the SBM model, considering unexpected outputs. Following the approach proposed by Tone [36], Fukuyama and Weber [37], which considers the relaxation problem, we set up the SBM model considering unexpected outputs as follows:

$$\begin{cases} \vec{S}_V^{t}(x^{t,k'}, y^{t,k'}, b^{t,k'}, g^x, g^y, g^b) = \\ \max[\frac{1}{N}\sum_{n=1}^{N}\frac{s_n^x}{g_n^x} + \frac{1}{M+I}(\sum_{m=1}^{M}\frac{s_m^y}{g_m^y} + \sum_{i=1}^{I}\frac{s_i^b}{g_i^b})]/2 \\ s.t.\sum_{k=1}^{K}\lambda_k^t x_{kn}^t + s_n^x = x_{k'n}^t, \forall n; \\ \sum_{k=1}^{K}\lambda_k^t y_{km}^t - s_m^y = y_{k'm}^t, \forall m; \\ \sum_{k=1}^{K}\lambda_k^t b_{ki}^t + s_i^b = b_{k'i}^t, \forall i; \\ \sum_{k=1}^{K}\lambda_k^t = 1, \lambda_k^t \ge 0, \forall k; \\ s_n^x \ge 0, \forall n; s_m^y \ge 0, \forall m; s_i^b \ge 0, \forall i \end{cases} \tag{2}$$

Where $\vec{S}_V^{t}$ represents the directional distance function under variable returns to scale. If we remove the constraint on $\sum_{k=1}^{k}\lambda_k^t = 1, \lambda_k^t \ge 0, \forall k$, then the directional distance function under constant returns to scale can be represented by $\vec{S}_C^{t}$. Here, $(x^{t,k'}, y^{t,k'}, b^{t,k'})$, (g^x, g^y, g^b), and (s_n^x, s_m^y, s_i^b) denote the input and output vectors, direction vector variables, and slack variables for province *k*, respectively.

Then, the SBM model incorporating unexpected outputs, according to the method proposed by Chung and Fare [39], is applied to calculate the Malmquist index. The GTFP from period t to t+1 is represented as:

$$GTFP = \left\{ \frac{1+\vec{S}_C^{t}(x^t, y^t, b^t; g^t)}{1+\vec{S}_C^{t}(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1})} \times \frac{1+\vec{S}_C^{t+1}(x^t, y^t, b^t; g^t)}{1+\vec{S}_C^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1})} \right\}^{\frac{1}{2}} \tag{3}$$

Additionally, GTFP can be further decomposed into two indices: Green Efficiency Change (GEC) and Green Technology Change (GTC). If GTFP, GEC, and GTC are all greater than 1, it indicates that the DMU has experienced growth in GTFP, improvements in technology change, and enhancements in technology efficiency from period t to t+1.

Variable Selection and Data Description

Selection of Input Indicators

In this paper, the input resources can be categorized into two main types: social resources and natural resources. Social resource inputs include capital input and labor input. The calculation of capital input is based on the "sustainable inventory method", as proposed by Zeng et al. [40]. The formula is as follows:

$$K_{it} = I_{it} + (1-\delta_{it})K_{it-1} \tag{4}$$

Where *i* and *t* represent the province and year, respectively. *K*, *I*, and *δ* denote the stock of fixed capital, annual social fixed capital investment, and depreciation rate, respectively. The data is deflated by the base year of 2004. Labor input is measured by the number of people employed in society. For natural resource inputs, the common approach used by most researchers is to measure them using total energy consumption.

Selection of Output Indicators

The output can be divided into desirable outputs and undesirable outputs. Taking prices into account, this paper adjusts each province's nominal GDP with 2004 as the base year. Regarding undesirable outputs, we use three industrial waste indicators to measure them, which include industrial wastewater discharge, industrial sulfur dioxide emissions, and industrial solid waste, according to most researchers.

Since GTFP is calculated based on relative efficiency, this paper requires data from 2004 to 2020 to estimate GTFP for each province in China from 2005 to 2020. The data sources include the statistical yearbooks of each province and the "China Environmental Statistical Yearbook."

Analysis of GTFP Results

We utilize input-output data from 2004 to 2020 and employ MAXDEA software to calculate GTFP for 30 provinces in China. The analysis will focus on the overall and regional trends of GTFP changes.

Trends in the National GTFP and Its Index Decomposition

Table 1. National GTFP and Its Index Decomposition from 2005 to 2020.

Year	GTFP	GEC	GTC
2005	0.8088	0.9768	0.8270
2006	0.9427	0.9796	0.9668
2007	0.9905	0.9914	0.9989
2008	1.0149	1.0119	1.0031
2009	0.9751	0.9622	1.0173
2010	0.9858	0.9772	1.0092
2011	0.9836	0.9586	1.0262
2012	0.9776	0.9677	1.0101
2013	1.0055	1.0304	0.9760
2014	0.9934	0.9507	1.0460
2015	1.0168	0.9773	1.0404
2016	1.0196	0.9929	1.0270
2017	1.0302	0.9839	1.0471
2018	1.0336	0.9871	1.0471
2019	1.0326	1.0012	1.0313
2020	1.0214	1.0456	0.9768

Table 1 presents the overall GTFP of China (30 provinces) from 2005 to 2020, along with the decomposition of the GEC and GTC indices. During this period, only eight years, namely 2008, 2013, and 2015-2020, had GTFP values greater than 1, indicating growth in GTFP. Conversely, the remaining eight years witnessed a decline in GTFP. Specifically, among the eight years with GTFP growth, only 2008 and 2019 had both GEC and GTC values greater than 1. This suggests that the growth in GTFP during these two years was driven by both improved technical efficiency and technological progress. In the other six years with GTFP growth, either GEC or GTC exceeded 1, indicating that the growth was attributed to either enhanced technical efficiency or technological progress. These findings highlight the varying factors influencing GTFP growth across different years, including changes in technical efficiency and advancements in technology.

Trends in GTFP at the national, coastal, and inland levels

In order to better compare the regional disparities and their differences with the national level, the measurements of GTFP for the national, coastal, and inland[1] regions are presented in Table 2. It can be observed that during the years 2008, 2013, and 2015 to 2019, both the coastal and inland regions exhibited GTFP values greater than 1, indicating nationwide growth in GTFP. However, in the years 2007 and 2014, only the coastal region experienced GTFP growth; thus, the national GTFP did not achieve growth in these two years.

Table 2. The measurements of GTFP for the national, coastal, and inland regions in China from 2005 to 2020.

Year	National GTFP	Coastal GTFP	Inland GTFP
2005	0.8088	0.8739	0.7711
2006	0.9427	0.9825	0.9197
2007	0.9905	1.0108	0.9787
2008	1.0149	1.0016	1.0226
2009	0.9751	0.9717	0.9770
2010	0.9858	0.9797	0.9894
2011	0.9836	0.9915	0.9790
2012	0.9776	0.9921	0.9692
2013	1.0055	1.0146	1.0002
2014	0.9934	1.0041	0.9871
2015	1.0168	1.0139	1.0186
2016	1.0196	1.0226	1.0179
2017	1.0302	1.0336	1.0282
2018	1.0336	1.0348	1.0330
2019	1.0326	1.0121	1.0444
2020	1.0214	0.9948	1.0369

[1]According to the way of division in the China Marine Statistical Yearbook (2015), the coastal region includes: Tianjin, Hebei, Liaoning, Shandong, Shanghai, Jiangsu, Zhejiang, Fujian, Guangdong, Hainan, Guangxi, totaling 11 provinces (municipalities); the inland region includes: Beijing, Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan, Inner Mongolia, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang and Tibet, totaling 20 provinces (municipalities).

Material and Methods

Theoretical Mechanism

(1) Effect of environmental regulation on GTFP

Environmental regulation has both a negative "compliance cost" effect and a positive "innovation compensation" effect on GTFP, and the magnitude of these direct effects determines the overall impact of environmental regulation on GTFP. Furthermore, different types of environmental regulations may have contrasting effects on GTFP. Some studies have found a negative relationship between command-and-control environmental regulation and GTFP (e.g., Zhang and Qiao, 2022 [8]). On the other hand, some scholars have concluded that market-incentive-based environmental regulation has a positive impact on GTFP (e.g., Hu, 2022 [41]). There has been relatively little exploration of the impact of public voluntary environmental regulation on GTFP compared to the first two types of regulations. Hu et al. discovered a positive relationship between public voluntary environmental regulation and GTFP [42]. Based on previous studies, this paper argues that command-and-control environmental regulation with coercive power may hinder the growth of GTFP, while more flexible market-incentive-based and public voluntary environmental regulation may promote the growth of GTFP. Thus, we propose hypothesis H1a, H1b, and H1c:

H1a: Command-and-control environmental regulation has a negative effect on GTFP.

H1b: Market-incentive-based environmental regulation has a positive effect on GTFP.

H1c: Public voluntary environmental regulation has a positive effect on GTFP.

(2) Mechanisms of the Effects of Environmental Regulation, FDI, and GTFP

On one hand, FDI can promote the growth of GTFP by mitigating the negative "compliance cost" effect and strengthening the positive "innovation compensation" effect of environmental regulation. On the other hand, FDI can inhibit the growth of GTFP by weakening the positive "innovation compensation" effect and enhancing the negative "compliance cost" effect of environmental regulation. Thus, we propose Hypothesis H2:

H2: FDI has a significant moderating effect on environmental regulation and GTFP.

Variable Selection

Explained Variables

In this paper, we select the GTFP values of 30 provinces from 2005 to 2020 in China, as measured in Section 3.

Core Explanatory Variables

Due to the various measurement approaches for different types of environmental regulations, this paper selects appropriate indicators based on previous research to measure them.

(1) Command-and-Control Environmental Regulation (CONER)

Command-and-control environmental regulation can be measured from three perspectives: environmental pollution control costs, government-enacted environmental protection laws and regulations, and the effectiveness of environmental regulation implementation. From the third perspective, most scholars use composite indicators to calculate comprehensive indices of pollutant emissions. In this paper, we refer to Ye [43] and others to calculate a composite index for various types of pollution emissions in the regions to represent the intensity of command-and-control environmental regulation. We select three indicators: industrial wastewater discharge, industrial sulfur dioxide emissions, and industrial particulate matter emissions, and calculate them using the entropy method. The steps are as follows:

The first step is to use the extreme value method to normalize and eliminate the dimensional influence of the three negative indicators. The formula is as follows:

$$Z_{\mathrm{ij}} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)} \tag{5}$$

In these equations, i denotes the province, j denotes the index, x_{ij} denotes the initial value of the jth indicator in the ith province, $\max(x_j)$ and $\min(x_j)$ denote the maximum and minimum values of the jth indicator, respectively.

The second step is to determine the weighting coefficients for each indicator. The formula is as follows:

$$W_j = \frac{x_{ij}}{\sum_{j=1}^{3} x_{ij}} \tag{6}$$

The third step is to calculate the intensity of command-and-control environmental regulation in each province. The formula is as follows:

$$CONER_{\mathrm{i}} = \frac{1}{3}\sum_{j=1}^{3} W_j Z_{ij} \tag{7}$$

(2) Market-Incentive-Based Environmental Regulation (MARER)

Drawing on the practice of most scholars, this paper selects the ratio of sewage tax and fee to local GDP in each province of China to measure market-incentive-based environmental regulation. The collection of sewage taxes and fees has wide coverage and spans multiple periods. It is a dominant tool in current market-incentive-based environmental regulation in China and is highly representative [34].

(3) Public Voluntary Environmental Regulation (PUBER)

Environmental proposals are an important form of public participation in environmental regulation and, to some extent, reflect the level of public willingness to engage in environmental governance in China. Therefore, this paper draws on the practice of Wu et al. [20] to select the number of environmental proposals in the regional two sessions to measure the public's voluntary environmental regulation.

Moderator Variable

With reference to the practice of most scholars, FDI is measured by the ratio of actual utilization of foreign investment to GDP in each province of China [30].

Control Variables

(1) Industrial structure. Industrial structure mainly reflects the proportion of different types of industries in a country's economic structure. The differences in industrial structure can have varying impacts on GTFP. Given that China is still in the development stage of industrialization, the ratio of the value added of the secondary industry to GDP is used to measure the industrial structure [30].

(2) GDP per capita. GDP per capita is the GDP of each province of China divided by the total population of the region at the end of the year. It is generally observed that regions with higher economic levels tend to have a stronger environmental awareness among the public, which in turn influences environmental protection [43].

(3) External trade dependence. In international trade, heterogeneous impacts arise from differences in the structure of imported and exported goods. If the majority of exported goods are resource-intensive, an expansion in domestic production scale can have adverse effects on the environment. However, if the exported goods are technology-intensive, it can help alleviate pollution in the environment. In this paper, the ratio of regional import and export trade volume to regional GDP is chosen to measure foreign trade dependence [20].

(4) Government intervention. Government intervention in economic entities is more direct and effective, while also influencing the role of market-incentive-based regulation. The extent of government intervention can directly impact environmental governance. This paper measures the degree of government intervention by using the ratio of general public budget expenditure to GDP [34].

(5) Population density. In regions with high population density, a larger number of people are affected by

pollution, which can impact the intensity of public voluntary environmental regulation in China. This, in turn, can influence GTFP.

(6) Innovation level. This paper measures the level of innovation in a region using the number of patent applications and grants. An increase in innovation level is beneficial for reducing emission costs. However, the impact of innovation on reducing pollution emissions is uncertain due to the unknown directions of innovation [30].

The selection and description of model variables are detailed in Table 3.

Model Construction

Based on the previous theoretical analysis, an econometric model was constructed. The GTFP obtained from the third chapter is considered the dependent variable, while FDI serves as the moderating variable. The core explanatory variable is environmental regulation (ER), which encompasses command-and-control environmental regulation (CONER), market-incentive-based environmental regulation (MARER), and public voluntary environmental regulation by the public (PUBER). Meanwhile, to address heteroscedasticity and multicollinearity issues, a logarithmic transformation was applied to the variables. Models are constructed as follows:

To begin with, the panel regression model is constructed in order to test hypotheses H1a, H1b, and H1c, as shown in model (8).

$$\ln GTFP_{it} = \alpha_0 + \alpha_1 \ln ER_{it} + \alpha_2 \ln X_{it} + u_{it} \quad (8)$$

where i denotes the province, t represents the time, α_0、α_1、α_2 is the coefficient to be estimated, X_{it} represents the control variables, including industrial structure (STR), GDP per capita (PGDP), external trade dependence (TRA), government intervention (GOV), population density (DEN), and u_{it} innovation level (INN), and is a randomized perturbation term. For the purpose of avoiding model confusion, the variable environmental regulation is numbered with a when it is a command-and-control environmental regulation, b when it is a market-incentive-based environmental regulation, and c when it is a public voluntary environmental regulation.

Subsequently, for testing hypothesis H2, we use hierarchical regression. The moderator variable FDI was incorporated on the basis of model (8), given as model (9). Next, the interaction term between FDI and environmental regulation was introduced in model (9), as shown in model (10) below.

$$\ln GTFP_{it} = \beta_0 + \beta_1 \ln ER_{it} + \beta_2 \ln FDI_{it} + \beta_3 \ln X_{it} + u_{it} \quad (9)$$

$$\begin{aligned} \ln GTFP_{it} &= \gamma_0 + \gamma_1 \ln ER_{it} + \gamma_2 \ln FDI_{it} \\ &+ \gamma_3 \ln FDI_{it} * \ln ER_{it} + \gamma_4 \ln X_{it} + u_{it} \end{aligned} \quad (10)$$

Where β_0、β_1、β_2、β_3 、 γ_0、γ_1、…… γ_4 is the coefficient to be estimated, the rest of the variables are consistent with model (8).

Data Sources

We used the relevant data from 2005 to 2020 as a sample, which were obtained from the "China Statistical Yearbook", "China Environmental Yearbook", "China Environmental Statistical Yearbook", Provincial Statistical Yearbooks, and the official website of the National Bureau of Statistics for the relevant years. The descriptive variable statistics are given in Table 4.

Results and Discussion

We used the Stata16 software to examine and perform regression analysis on nationwide sample data. Before the regression test, in order to avoid the phenomenon of "pseudo-regression" in the panel regression, we need to carry out the unit root test on the variables. We used the

Table 3. Description of indicator variables.

Type	Variables	Variable description
Explained variables	GTFP	Measurements from Section 3
Core explanatory variables	Command-and-control environmental regulation (CONER)	Composite index of environmental regulation using the entropy weight method
	Market-incentive-based Environmental Regulation (MARER)	sewage tax/GDP
	Public voluntary environmental regulation (PUBER)	The number of environmental proposals for the two sessions
Moderator variable	FDI	Actual utilization of foreign investment/GDP
Control variables	Industrial structure (STR)	Value Added in Secondary Industries/GDP
	GDP per capita (PGDP)	GDP/Population at year-end
	External trade dependence (TRA)	total value of imports and exports/GDP
	Government intervention (GOV)	General public budget expenditure/GDP
	Population density (DEN)	Total population at year-end/Province area
	Innovation level (INN)	Patent applications granted

Table 4. Descriptive statistics of variables.

Variable	Sample Size	Mean	Standard Deviation	Minimum	Maximum
GTFP	480	0.9895	0.0711	0.5332	1.2120
CONER	480	0.4668	0.1640	0.0490	0.7147
MARER	480	4.3170	4.2192	0.1589	47.6962
PUBER	480	511.7126	457.1389	16.0000	5845.0000
FDI	480	2.2202	1.7663	0.0103	8.1916
STR	480	44.9652	8.6729	15.8000	61.5000
PGDP	480	4.4424	2.8220	0.5052	16.4889
TRA	480	0.2989	0.3605	0.0076	1.7222
GOV	480	0.2257	0.0990	0.0798	0.6430
DEN	480	0.2756	0.1259	0.0189	0.6307
INN	480	4.1180	7.5231	0.0079	70.9725

LLC test, and the results are shown in Table 5. The results show that the variables are stationary series and there is no panel unit root. Subsequently, the panel regression model was subjected to an F-test and a Hausman test. All of them were finally determined to be fixed-effect models.

Table 5. Results of the LLC test for variables.

Variables	LLC test	Conclusions
lnGTFP	-3.5751*** (0.0002)	stable
lnCONER	-5.9430*** (0.0000)	stable
lnMARER	-5.9578*** (0.0000)	stable
lnPUBER	-9.2275*** (0.0000)	stable
lnFDI	-6.4478*** (0.0000)	stable
lnSTR	-4.1335*** (0.0000)	stable
lnPGDP	-2.4581*** (0.0070)	stable
lnTRA	-4.1296*** (0.0000)	stable
lnGOV	-4.0880*** (0.0000)	stable
lnINN	-5.0722*** (0.0000)	stable

Note: ***, **, and * denote coefficients significant at 1%, 5%, and 10% statistical levels, respectively. The p value is in brackets.

Analysis of Regression Results at the National Level

Analysis of the Effects of Environmental Regulation on GTFP

We test the panel regression model (8) for the effect of three types of environmental regulations on GTFP. The regression results are presented in Table 6.

Table 6. Regression results of environmental regulation and GTFP at the national level.

	(8a)	(8b)	(8c)
lnCONER	-0.3610***		
	(0.0776)		
lnMARER		0.0485***	
		(0.0137)	
lnPUBER			0.0027
			(0.0094)
lnSTR	-0.0082***	-0.4433***	-0.4152***
	(0.0013)	(0.0521)	(0.0524)
lnPGDP	0.0121**	0.0773**	0.0379
	(0.0049)	(0.0351)	(0.0338)
lnTRA	0.0260	0.0333*	0.0241
	(0.0615)	(0.0189)	(0.0190)
lnGOV	-0.5537***	-0.1870***	-0.1772***
	(0.1597)	(0.0480)	(0.0490)
lnDEN	-0.0511	-0.0036	-0.0023
	(0.0886)	(0.0160)	(0.0163)
lnINN	-0.0034**	-0.0270	-0.0280
	(0.0015)	(0.0194)	(0.0196)
_cons	1.4122***	0.9870***	0.9732***
	(0.0890)	(0.2086)	(0.2225)
N	480	480	480
R^2	0.1594	0.1747	0.1516
F-value	11.9995	13.3947	11.3084

Note: ***, **, and * denote coefficients significant at 1%, 5%, and 10% statistical levels, respectively. The estimated standard error is in brackets. The same as below.

From the results in the above table, the regression coefficient of command-and-control environmental regulation on GTFP is -0.3610, which is significant at the 1% level. It shows that command-and-control environmental regulation in China inhibits the growth of GTFP, indicating a greater "compliance cost" effect than an "innovation compensation" effect. Specifically, government-led command-and-control environmental regulation puts enterprises in a passive, receptive position, affecting their choice of production decisions and their initiative and enthusiasm for pollution control. Meeting emission standards involves high costs, squeezes productive inputs, and reduces efficiency, leading to a trade-off between firm performance and environmental protection. The level of environmental regulation that each specific company can bear differs. If environmental policies are uniformly applied without considering individual circumstances, it can have a counterproductive effect on GTFP growth. Thus, command-and-control environmental regulation has a negative impact on GTFP growth in China, validating hypothesis H1a.

The regression coefficient of market-incentive-based environmental regulation on GTFP is 0.0485, significant at the 1% level, indicating that this type of regulation significantly promotes GTFP growth in China. The "innovation compensation" effect outweighs the "compliance cost" effect. More specifically, the implementation of pollution taxes and fees, as one of the most typical market-incentive-based environmental regulation measures in China, has been tested over time. The system allows companies to proactively analyze costs and effects based on their own conditions, aiming to maximize profits when marginal revenue equals marginal cost. Through this approach, companies actively improve production methods, optimize management mechanisms, and innovate green and environmentally friendly technologies, thereby enhancing productivity, improving market competitiveness, offsetting the costs of previous environmental governance, and increasing profitability. Thus, market-incentive-based environmental regulation has a positive impact on GTFP growth in China, verifying hypothesis H1b.

The regression coefficient of public voluntary environmental regulation on GTFP is 0.0027, but it does not pass the significance test. The result shows that while public voluntary environmental regulation has a positive impact on GTFP growth in China, the effect is not significant. It means that the role played by the public voluntary environmental regulation tools in China is not obvious, failing to validate hypothesis H1c.

Analysis of the Moderating Effects of FDI

Due to the insignificant regression coefficients of the public voluntary type of environmental regulation in

Table 7. Regression results in the moderating effect of FDI at the national level.

	(9a)	(10a)	(9b)	(10b)
lnCONER	-0.3461***	-0.3914***		
	(0.0779)	(0.0789)		
lnMARER			0.0561***	0.0586***
			(0.0151)	(0.0151)
lnFDI	-0.0107*	-0.0118*	-0.0150**	-0.0129**
	(0.0062)	(0.0061)	(0.0062)	(0.0063)
lnFDI*lnCONER		-0.0716***		
		(0.0254)		
lnFDI*lnMARER				-0.0115*
				(0.0068)
lnSTR	-0.0079***	-0.0077***	-0.0084***	-0.0085***
	(0.0013)	(0.0013)	(0.0014)	(0.0013)
lnPGDP	0.0109**	0.0115**	0.0206***	0.0215***
	(0.0050)	(0.0049)	(0.0056)	(0.0056)
lnTRA	0.0365	0.0356	0.1569**	0.1776**
	(0.0616)	(0.0612)	(0.0680)	(0.0690)
lnGOV	-0.5745***	-0.5026***	-0.6259***	-0.5830***
	(0.1598)	(0.1606)	(0.1595)	(0.1612)
lnDEN	-0.0616	-0.0662	-0.0546	-0.0522
	(0.0886)	(0.0879)	(0.0892)	(0.0890)
lnINN	-0.0035**	-0.0038**	-0.0014	-0.0012
	(0.0015)	(0.0015)	(0.0015)	(0.0015)
_cons	1.4246***	1.4183***	1.1521***	1.1244***
	(0.0890)	(0.0884)	(0.0920)	(0.0933)
N	480	480	480	480
R^2	0.1650	0.1798	0.1542	0.1596
F-value	10.9201	10.7415	10.0741	9.3058

model (8c), we do not test the moderating effect of FDI on its relationship with GTFP. Next, this section will separately examine the moderating effects of FDI as a moderator variable on the relationship between command-and-control and market-incentive-based environmental regulation and GTFP using panel regression models (9) and (10). The regression results are presented in Table 7.

It can be seen from Table 7: The R-squared values for models (9a) and (10a) are 0.1650 and 0.1798, respectively, with the latter being higher than the former. This suggests that FDI has a moderating effect between command-and-control environmental regulation and GTFP. In model (10a), the regression coefficient of the interaction term between FDI and command-and-control environmental regulation is -0.0716, significant at the 1% level. This indicates that FDI has a significant moderating effect, and its coefficient, similar to the regression coefficient of command-and-control environmental regulation in model (8a), is negative. This implies that the negative impact of command-and-control environmental regulation on GTFP is strengthened with increasing FDI, showing a significant intensifying effect. The reason behind this is that the combination of FDI and command-and-control environmental regulation can lead to a "race to the bottom" competition. FDI attracted by lowering environmental protection standards tends to enter pollution-intensive industries, which, through negative structural effects, affect China's environment, thereby inhibiting GTFP growth.

The R-squared values for models (9b) and (10b) are 0.1542 and 0.1596, respectively, with the latter being higher than the former. This suggests that FDI has a moderating effect between market-incentive-based environmental regulation and GTFP. In model (10b), the regression coefficient of the interaction term between FDI and market-incentive-based environmental regulation is -0.0115, significant at the 10% level. This indicates that FDI has a significant moderating effect, and its coefficient is opposite in sign to the regression coefficient of market-incentive-based environmental regulation in model (8b). It shows that the positive impact of market-incentive-based environmental regulation on GTFP weakens with increasing FDI, demonstrating a weakening effect. The main reason for this is that although market-incentive-based environmental regulation stimulates innovation for domestic companies, its effectiveness for FDI inflows is limited. Inflows often bring advanced technologies, creating a significant gap with domestic firms, requiring time for absorption, and hindering technological innovation. Alternatively, inflows may bring lower-level technologies

Table 8. Regression results of environmental regulation and GTFP in coastal and inland areas.

	Coast			Inland		
	(8ac)	(8bc)	(8cc)	(8ai)	(8bi)	(8ci)
lnCONER	-0.1924			-0.3418***		
	(0.1832)			(0.0459)		
lnMARER		0.0544*			0.0367***	
		(0.0315)			(0.0095)	
lnPUBER			0.0001			-0.0153**
			(0.0001)			(0.0063)
lnSTR	-0.0207***	-0.0181***	-0.0207***	-0.0035***	-0.0039***	-0.0033***
	(0.0040)	(0.0028)	(0.0040)	(0.0007)	(0.0008)	(0.0008)
lnPGDP	0.0139	0.0175*	0.0170	-0.0029	0.0023	-0.0033
	(0.0125)	(0.0099)	(0.0126)	(0.0039)	(0.0046)	(0.0043)
lnTRA	0.3053**	0.2907***	0.3488**	-0.1437***	-0.0066	-0.1304***
	(0.1464)	(0.0997)	(0.1445)	(0.0397)	(0.0547)	(0.0432)
lnGOV	-0.5742	-1.8649***	-0.6743	-0.4441***	-0.5160***	-0.5807***
	(0.5634)	(0.4057)	(0.5685)	(0.0840)	(0.0891)	(0.0889)
lnDEN	-0.1619	0.3822	-0.1240	-0.0005	-0.0114	0.0045
	(0.3659)	(0.2515)	(0.3632)	(0.0431)	(0.0461)	(0.0468)
lnINN	-0.0042*	-0.0017	-0.0042*	0.0103***	0.0128***	0.0122***
	(0.0024)	(0.0017)	(0.0024)	(0.0028)	(0.0030)	(0.0031)
_cons	1.8787***	0.5815***	1.7233***	1.1463***	0.9262***	1.0891***
	(0.2910)	(0.2198)	(0.2792)	(0.0470)	(0.0499)	(0.0588)
N	176	176	176	304	304	304
R^2	0.2136	0.3008	0.2138	0.4214	0.3409	0.3199
F-value	6.1313	9.7119	6.1391	28.9290	20.5427	18.6842

that have little impact on domestic firms' technological progress or even increase energy consumption. FDI, through negative technological effects, affects China's GTFP growth. Therefore, hypothesis H2 is confirmed.

Regarding the control variables, the coefficient of industrial structure (STR) is significantly negative, reflecting that deeper industrialization suppresses the growth of GTFP. The coefficient of per capita GDP (PGDP) is significantly positive, revealing that higher per capita GDP contributes to boosting the growth of GTFP. The coefficient of trade dependence (TRA) is positive and passes the significance test in some models, indicating that an increase in the ratio of trade volume to GDP benefits GTFP growth to some extent. The coefficient of government intervention (GOV) is significantly negative, indicating that increased government intervention will dampen the growth of GTFP; density per capita (DEN) has a negative coefficient without passing the significance test; and the coefficient of innovation level (INN) is negative and passes the significance test in some of the models. It shows that the increase in the number of patents granted by enterprises has an inhibiting effect on GTFP growth to a certain extent. This suggests that there may be a phenomenon of "quantity over quality" in companies' patent applications, which occupies resources and hampers GTFP growth.

Analysis of Regional Empirical Results

To better distinguish the models, based on the original model numbering, coastal areas are added as c to the number, and inland areas are added as i to the number.

Effect of Environmental Regulation on GTFP in Coastal and Inland Areas

The panel regression model (8) of the effect of three types of environmental regulations on GTFP in coastal and inland areas is shown in Table 8.

According to Table 8., firstly, the regression coefficient of command-and-control environmental regulation on GTFP did not pass the significance test in coastal areas, while it was significantly negative in inland areas. This means that command-and-control environmental regulation has no significant effect on the growth of GTFP in the coastal region but has a significant inhibiting effect on GTFP growth in inland areas. Hypothesis H1a is supported in inland areas but not in coastal areas. The reason behind this difference could be that coastal areas have more established pollution control systems due to their earlier development, resulting in less impact from command-and-control environmental regulation on economic activities. Secondly, both coastal and inland areas show significantly positive regression coefficients for market-incentive-based environmental regulation, indicating a positive effect on GTFP growth. Hypothesis H1b is supported in both areas. Thirdly, the regression coefficient of public voluntary environmental regulation did not pass the significance test in coastal areas, while it was significantly negative in inland areas. This implies that public, voluntary environmental regulation hinders GTFP growth in inland areas. The reason for this could be that some inland enterprises face severe pollution issues, and strengthening public voluntary environmental regulation increases environmental governance pressure and costs, thereby suppressing GTFP growth. Therefore, hypothesis H1c is not supported in both coastal and inland areas.

Moderating Effects of Coastal and Inland FDI

Due to the insignificant regression coefficients of command-and-control and public voluntary environmental regulation in models (8ac) and (8cc), respectively, only the moderating effect of FDI on market-incentive-based environmental regulation and GTFP is examined in coastal areas. The panel regression models (9) and (10) are used to test the moderating effect of FDI in coastal areas, and their regression results are shown in Table 9.

Table 9. Regression results in the moderating effect of FDI in coastal areas.

	(9bc)	**(10bc)**
lnMARER	0.0566*	0.0652*
	(0.0324)	(0.0347)
lnFDI	0.0064	0.0028
	(0.0267)	(0.0273)
lnFDI*lnMARER		-0.0181
		(0.0263)
lnSTR	-0.0176***	-0.0171***
	(0.0029)	(0.0030)
lnPGDP	0.0238*	0.0248*
	(0.0126)	(0.0127)
lnTRA	0.3372***	0.3629***
	(0.1025)	(0.1092)
LnGOV	-1.4352**	-1.4169**
	(0.5928)	(0.5944)
lnDEN	0.4576*	0.5278*
	(0.2699)	(0.2889)
lnINN	-0.0303	-0.0300
	(0.0352)	(0.0352)
_cons	0.4187*	0.3517
	(0.2459)	(0.2649)
N	176	176
R^2	0.3005	0.3026
F-value	8.4303	7.5212

From Table 9., it can be observed that the regression coefficient of the interaction term between FDI and market-incentive-based environmental regulation in coastal areas did not pass the significance test. This indicates that FDI has no significant moderating effect, meaning that FDI does not have a significant impact on the relationship between market-incentive-based environmental regulation and GTFP in coastal areas. Hypothesis H2 is not supported in coastal areas.

The panel regression models (9) and (10) are used to test the moderating effect of FDI in inland areas, and their regression results are shown in Table 10.

The regression results from Table 10. reveal the following: Firstly, the R^2 values for models (9ai) and (10ai) are 0.4789 and 0.4847, respectively, with the latter being higher than the former.

This suggests that FDI in inland areas has a moderating effect between command-and-control environmental regulation and GTFP. In model (10ai), the coefficient of the interaction term is significantly negative, indicating a significant moderating effect of FDI. The coefficient shares the same sign as the command-and-control environmental regulation coefficient in model (8ai), suggesting that the negative impact of command-and-control environmental regulation on GTFP is strengthened with increased FDI, indicating an enhancing effect. These findings are consistent with the empirical results at the

Table 10. Regression results for the moderating effect of FDI in inland areas.

	(9ai)	**(10ai)**	**(9bi)**	**(10bi)**	**(9ci)**	**(10ci)**
lnCONER	-0.2876***	-0.3179***				
	(0.0447)	(0.0478)				
lnMARER			0.0177*	0.0162*		
			(0.0093)	(0.0094)		
lnPUBER					-0.0000	-0.0000
					(0.0000)	(0.0000)
lnFDI	-0.0206***	-0.0233***	-0.0167**	-0.0171**	-0.0264***	-0.0260***
	(0.0055)	(0.0057)	(0.0067)	(0.0067)	(0.0064)	(0.0066)
lnFDI*lnCONER		-0.0411*				
		(0.0233)				
lnFDI*lnMARER				0.0068		
				(0.0063)		
lnFDI*lnPUBER						0.0000
						(0.0000)
lnSTR	-0.0026***	-0.0023***	-0.0027***	-0.0026***	-0.0027***	-0.0028***
	(0.0007)	(0.0007)	(0.0008)	(0.0008)	(0.0007)	(0.0008)
lnPGDP	-0.0511***	-0.0536***	-0.0036	-0.0022	-0.0015	-0.0017
	(0.0118)	(0.0118)	(0.0090)	(0.0091)	(0.0457)	(0.0458)
lnTRA	-0.0785**	-0.0675*	0.0067	0.0090	-0.1408***	-0.1409***
	(0.0391)	(0.0395)	(0.0121)	(0.0122)	(0.0423)	(0.0424)
lnGOV	-0.2367**	-0.1969**	-0.0515***	-0.0546***	-0.0099**	-0.0098**
	(0.0969)	(0.0991)	(0.0159)	(0.0161)	(0.0044)	(0.0044)
lnDEN	-0.0057	-0.0064	-0.2887***	-0.2932***	-0.6019***	-0.6090***
	(0.0082)	(0.0082)	(0.1057)	(0.1058)	(0.0872)	(0.0919)
lnINN	0.0181***	0.0190***	0.0208***	0.0213***	0.0174***	0.0173***
	(0.0025)	(0.0026)	(0.0027)	(0.0027)	(0.0032)	(0.0033)
_cons	1.0701***	1.0662***	0.8945***	0.9033***	1.0454***	1.0477***
	(0.0509)	(0.0508)	(0.0567)	(0.0573)	(0.0466)	(0.0476)
N	304	304	304	304	304	304
R^2	0.4789	0.4847	0.3760	0.3787	0.3514	0.3516
F-value	31.8189	28.8433	20.8669	18.6939	18.7623	16.6278

national level. Secondly, from models (9bi) and (10bi), it can be observed that the regression coefficient of the interaction term between FDI and market-incentive-based environmental regulation is not significant. This indicates that FDI does not have a significant moderating effect on the relationship between market-incentive-based environmental regulation and GTFP. Thirdly, based on models (9ci) and (10ci), it is evident that the regression coefficient of the interaction term between FDI and public voluntary environmental regulation is not significant. This suggests that FDI does not have a significant moderating effect on the relationship between public voluntary environmental regulation and GTFP. In conclusion, hypothesis H2 holds true in the inland region.

Robustness Test

To test the robustness of the panel regression results, the core explanatory variables, i.e., command-and-control, market-incentive-based, and public voluntary environmental regulation, are lagged by one period, and the variables l.lnCONER, l.lnMARER, and l.lnPUBER are generated to test the robustness of their models.

Regression Robustness Tests at the National Level

The regression results with a lag of one period for the core explanatory variables at the national level are shown in Tables 11. and 12. The results of the variables are more similar to the previous findings, and their significance remains unchanged. This indicates that the panel regression results in this study are robust.

Regional regression robustness tests

Considering the space issue, the results of the robustness test of the control variables are not put into the table. The regression results with a lag of one period for the core explanatory variables at the regional level are shown in Tables 13., 14., and 15. The results for the variables are more similar to the previous findings, with no change in significance, indicating that the results are robust.

Table 11. Robustness test results of lagged one-period regressions of environmental regulation and GTFP at the national level.

	(8a)	**(8b)**	**(8c)**
l.lnCONER	-0.3513***		
	(0.0766)		
l.lnMARER		0.0512***	
		(0.0136)	
l.lnPUBER			-0.0109
			(0.0087)
lnSTR	-0.0081***	-0.4434***	-0.4089***
	(0.0013)	(0.0522)	(0.0520)
lnPGDP	0.0110**	0.0666**	0.0569**
	(0.0048)	(0.0259)	(0.0262)
lnTRA	-0.0007	0.0387**	0.0283
	(0.0596)	(0.0183)	(0.0184)
lnGOV	-0.5173***	0.0745**	0.0326
	(0.1608)	(0.0340)	(0.0326)
lnDEN	0.0363	-0.1642***	-0.1549***
	(0.1085)	(0.0465)	(0.0472)
lnINN	-0.0033**	-0.0267	-0.0255
	(0.0014)	(0.0186)	(0.0188)
_cons	1.3792***	1.1222***	1.1554***
	(0.1009)	(0.2043)	(0.2175)
N	450	450	450
R^2	0.1754	0.1783	0.1531
F-value	12.5456	12.8043	10.6694

Table 12. Robustness test results for one-period lagged FDI moderation effects at the national level.

	(9a)	**(10a)**	**(9b)**	**(10b)**
l.lnCONER	-0.3283***	-0.3832***		
	(0.0763)	(0.0765)		
l.lnMARER			0.0624***	0.0633***
			(0.0145)	(0.0145)
lnFDI	-0.0182***	-0.0198***	-0.0150**	-0.0129**
	(0.0060)	(0.0059)	(0.0062)	(0.0063)
lnFDI*l.lnCONER		-0.0944***		
		(0.0250)		
lnFDI*l.lnMARER				-0.0158**
				(0.0064)
lnSTR	-0.0075***	-0.0073***	-0.0084***	-0.0085***
	(0.0013)	(0.0013)	(0.0013)	(0.0013)
lnPGDP	0.0089*	0.0099**	0.0192***	0.0198***
	(0.0048)	(0.0047)	(0.0053)	(0.0053)
lnTRA	0.0138	0.0192	0.1426**	0.1722***
	(0.0592)	(0.0583)	(0.0642)	(0.0649)
lnGOV	-0.5492***	-0.4732***	-0.5655***	-0.5090***
	(0.1596)	(0.1583)	(0.1590)	(0.1597)
lnDEN	-0.0021	0.0396	0.0331	0.0584
	(0.1082)	(0.1071)	(0.1080)	(0.1078)
lnINN	-0.0034**	-0.0038***	-0.0014	-0.0011
	(0.0014)	(0.0014)	(0.0014)	(0.0014)
_cons	1.4076***	1.3869***	1.1286***	1.0896***
	(0.1004)	(0.0990)	(0.0990)	(0.0997)
N	450	450	450	450
R^2	0.1932	0.2203	0.1930	0.2047
F-value	12.3362	12.9025	12.3139	11.7556

Table 13. Robustness test results of lagged one-period regressions of environmental regulation and GTFP in coastal and inland areas.

	Coast			**Inland**		
	(8ac)	**(8bc)**	**(8cc)**	**(8ai)**	**(8bi)**	**(8ci)**
l.lnCONER	-0.0073			-0.3564***		
	(0.1862)			(0.0465)		
l.lnMARER		0.0795***			0.0228**	
		(0.0283)			(0.0096)	
l.lnPUBER			0.0000			-0.0268***
			(0.0001)			(0.0059)
N	165	165	165	285	285	285
R^2	0.2616	0.3593	0.2637	0.4526	0.3428	0.3775
F-value	7.4410	11.7757	7.5201	30.5924	19.2969	22.4387

Table 14. Robustness test results for the lagged one-period moderating effect of FDI in coastal areas.

	(9bc)	(10bc)
l.lnMARER	0.0892***	0.0947***
	(0.0294)	(0.0305)
lnFDI	-0.0190	-0.0221
	(0.0232)	(0.0237)
lnFDI* l.lnMARER		-0.0162
		(0.0235)
N	165	165
R^2	0.3633	0.3654
F-value	10.4146	9.2774

Table 15. Robustness test results for the one-period lagged moderating effect of FDI in inland areas.

	(9ai)	(10ai)	(9bi)	(10bi)	(9ci)	(10ci)
l.lnCONER	-0.2947***	-0.2554***				
	(0.0475)	(0.0477)				
l.lnMARER			0.0191**	0.0168*		
			(0.0091)	(0.0092)		
l.lnPUBER					-0.0000	-0.0000
					(0.0000)	(0.0000)
lnFDI	-0.0156**	-0.0235***	-0.0121*	-0.0130*	-0.0252***	-0.0240***
	(0.0061)	(0.0061)	(0.0068)	(0.0068)	(0.0069)	(0.0069)
lnFDI*l. lnCONER		-0.0668***				
		(0.0243)				
lnFDI*l. lnMARER				0.0083		
				(0.0063)		
lnFDI*l. lnPUBER						0.0051
						(0.0041)
N	285	285	285	285	285	285
R^2	0.4877	0.4556	0.3708	0.3751	0.3678	0.3715
F-value	30.7018	23.8983	19.0096	17.1433	18.7595	16.8803

Conclusions and Enlightenment

Conclusions

Based on the above empirical validation, the main conclusions are drawn as follows: (1) The three types of environmental regulations exert varying effects on GTFP in China. Command-and-control environmental regulation hampers China's GTFP growth, while market-incentive-based environmental regulation promotes it. Public voluntary environmental regulation has no significant impact on GTFP. In particular, command-and-control environmental regulation negatively impacts GTFP growth in inland regions, while its effect on coastal regions is insignificant; market-incentive-based environmental regulation has a positive influence on GTFP growth in both coastal and inland areas; and public, voluntary environmental regulation has no significant impact on GTFP growth in coastal regions but negatively affects it in inland regions. (2) FDI has a significant moderating effect on the impact of command-and-control environmental regulation on GTFP, enhancing their relationship. FDI also exhibits a significant moderating effect on the relationship between market-incentive-based environmental regulation and GTFP, but it weakens this relationship. In contrast, there is no significant impact of public voluntary environmental regulation on GTFP growth, and therefore, no examination is conducted on the moderating effect of FDI in this relationship. In coastal regions, FDI does not exhibit a significant moderating effect on the relationship between market-incentive-based environmental regulation and GTFP. The other two types of environmental regulations have no significant impact on GTFP, and thus, no examination is conducted on the moderating effect of FDI in these relationships. In inland regions, FDI has a significant moderating effect on the relationship between command-and-control environmental regulation and GTFP, enhancing their relationship. However, FDI does not show a significant moderating effect on the relationship between market-incentive-based, public voluntary environmental regulation and GTFP.

Recommendations

(1) Selection of appropriate environmental regulation tools

Market-incentive-based environmental regulation promotes GTFP growth in China as a whole, which mainly promotes technological innovation, reduces emissions, and lowers environmental costs through the "innovation compensation" effect. Therefore, it is necessary to reinforce the use of market-incentive-based environmental regulatory tools, including sewage taxes, tradable sewage licenses, and so on. Stimulate enterprises to take the initiative in technological innovation and take the initiative to combat pollution. First of all, protect the trading of environmental protection products in terms of laws, regulations, and policies, and build a fair and efficient exchange platform for technological innovation. Besides, market access and licenses should be used to guide market power into the fields of environmental monitoring and environmental impact assessment. Reduce the government's rent-seeking space and utilize the role of the market mechanism. Finally, optimize the sewage trading system, allocate the initial right to sewage in a scientific manner, clarify the qualifications of the main body of sewage trading, and simplify the trading process to reduce the cost of trading.

(2) Enhancing the quality and level of imported foreign capital

In the acquisition of foreign investment, the quality and standard of foreign investment need to be emphasized. For regions with a lower level of economic development and a feebler capacity for sewage control, they ought to selectively introduce foreign investment in light of the region's own resources and technological characteristics, avoiding the blind introduction of foreign investment and promoting their economic development while reducing pollution emissions. For regions with a higher level of economic development and a stronger capacity for sewage management, their level of openness to the outside world should be raised, and high-technology and clean foreign-funded enterprises should be introduced in a flexible mode.

(3) Adaptation of environmental regulatory policies to local conditions

As for coastal areas, the use of command-and-control environmental regulatory tools can be limited and the use of market-incentive-based environmental regulatory tools can be increased, so that enterprises can give full play to their autonomy and selectivity to achieve the goals of economic development and reduction of pollutant emissions. As for inland areas, apart from enlarging the use of market-incentive-based environmental regulation to incentivize industrial transformation and upgrading of enterprises, command-and-control, and public voluntary environmental regulation should also be reformed. With regard to command-and-control environmental regulation, the relevant departments are required to speed up the formulation of laws and regulations that are compatible with the economic, social, and environmental situation at the present stage, as well as the revision of the original pollutant discharge standards and environmental quality standards. Regarding public voluntary environmental regulation, strengthen the system of environmental information disclosure and expand the scope of environmental information disclosure by the government and enterprises, enabling the public to obtain relevant information in a timely manner.

This paper has measured and analyzed the GTFP and explored the relationship between environmental regulation, FDI, and GTFP, providing certain references for achieving a win-win situation of emission reduction and efficiency gains. However, there are still shortcomings. Firstly, in terms of theoretical research, this paper only discussed a macro perspective without examining it from a specific industry or enterprise perspective. Secondly, in empirical research, the scope and segmentation of regional heterogeneity are limited to coastal and inland regions, which needs to be improved. These two deficiencies should be considered in future research.

Acknowledgements

This paper was supported by the National Social Science Found Project of China (22BTJ072).

Conflict of Interest

The authors declare no conflict of interest.

References

1. CHEN Q.Y., WEI F., CAO H. Minimum wage adjustment and the activities of foreign-owned enterprises: micro evidence from national enterprise credit information. Statistical Research, **39** (03), 83, **2022**.
2. HAILU A., VEEMAN T.S. Environmentally Sensitive Productivity Analysis of the Canadian Pulp and Paper Industry, 1959-1994: An Input Distance Function Approach. Journal of Environmental Economics & Management, **40** (3), 251, **2000**.
3. CAI W.G., ZHOU X.L. Dual effect of Chinese environmental regulation on green total factor productivity. Economist, **225** (09), 27, **2017**.
4. ALLEN B., LI Z., LIU A.A. Efficacy of Command-and-Control and Market-Based Environmental Regulation in Developing Countries. Annual Review of Resource Economics, **10**, 381, **2018**.
5. TANG K., QIU Y., ZHOU D. Does command-and-control regulation promote green innovation performance? Evidence from China's industrial enterprises. Science of the Total Environment, **712**, 136362, **2020**.
6. LIN B., Xu M. Exploring the green total factor productivity of China's metallurgical industry under carbon tax: A perspective on factor substitution. Journal of Cleaner Production, **233** (10), 1322, **2019**.
7. LI W.B., LIU F.W., WANG B. Can environmental regulation promote GTFP: evidence from the Two Control Zones Policy. Journal of Huazhong University of Science and Technology (Social Science Edition), **33** (01), 72, **2019**.
8. ZHANG Y.Z., QIAO Y.H. Research on the influence effect of different types of environmental regulation green total factor productivity in manufacturing industry: an empirical analysis based on DEA-Malmquist index method and spatial error model. Ecological Economy, **38** (05), 177, **2022**.
9. PORTER M.E., LINDE C. Toward a New Conception of the Environment-Competitiveness Relationship. Journal of Economic Perspectives, **9** (04), 97, **1995**.
10. DOMAZLICKY B.R., WEBER W.L. Does environmental protection lead to slower productivity growth in the chemical industry? Environmental & Resource Economics, **28** (03), 301, **2004**.
11. SPANG E.S., HOLGUIN A.J., LOGE F.J. The estimated impact of California's urban water conservation mandate on electricity consumption and greenhouse gas emissions. Environmental Research Letters, **13**, 014016, **2018**.
12. GUO L.L., QU Y., Tseng M.L. The interaction effects of environmental regulation and technological innovation on regional green growth performance. Journal of Cleaner Production, **162** (09), 894, **2017**.
13. GHOSAL V., STEPHAN A., WEISS J.F. Decentralized environmental regulations and plant-level productivity. Business Strategy and the Environment, **28** (1), 998, **2019**.
14. GUAN H.L., WU Z.N. Local environmental regulation and green total factor productivity: Is technological progress or technical efficiency change? On Economic Problems, **486** (02), 118, **2020.**
15. ZHANG D. Marketization, environmental regulation, and eco-friendly productivity: A Malmquist–Luenberger index for pollution emissions of large Chinese firms. Journal of Asian Economics, **76**, 101242, **2021**.
16. YU D.H., YAN Y.T. Environmental regulation, technology innovation and green total factor productivity of manufacturing. Urban and Environmental Studies, **32** (02), 58, **2022**.

17. KEMP R., PONTOGLIO S. The innovation effects of environmental policy instruments — A typical case of the blind men and the elephant? Ecological Economics, **72** (12), 28, **2011**.
18. SANCHEZ-VARGAS A., MANSILLA-SANCHEZ R., AGUILAR-IBARRA A. An empirical analysis of the nonlinear relationship between environmental regulation and manufacturing productivity. Journal of Applied Economics, **16** (2), 357, **2013**.
19. WANG Y., SHEN N. Environmental regulation and environmental productivity: The case of China. Renewable & Sustainable Energy Reviews, **62** (9), 758, **2016**.
20. WU L., JIA X.Y., WU C., PENG J.C. Impact of heterogeneous environmental regulation on green total factors productivity. China Population, Resources and Environment, **30** (10), 82, **2020**.
21. ZHANG H., YANG X.M., ZHENG Y.P. Study on the impact of environmental regulation on green total factor productivity. Price: Theory & Practice, (10), 196, **2022**.
22. AL-MULALI U., TANG C.F. Investigating the validity of pollution haven hypothesis in the Gulf Cooperation Countries (GCC). Energy Policy, **60**, 813, **2013**.
23. RAFINDADI A.A., MUYE I.M., KAITA R.A. The effects of FDI and energy consumption on environmental pollution in predominantly resource–based economies of the GCC. Sustainable Energy Technologies Assessments, **25**, 126, **2018**.
24. WU M.J., CHENG Z.H., XU C.P. Empirical analysis of the impact of R&D, FDI, and export on total factor productivity in manufacturing industry. Statistics & Decision, **34** (14), 132, **2018**.
25. SUN D.Y., WU X.Y., GU J.R., XU L.Y., WANG H.M. Green total factor productivity measurement and influencing factors of industrial enterprises in Yangtze river delta urban agglomeration. Forum on Science and Technology in China, **308** (12), 91, **2021**.
26. LIOBIKIENĖ G., BUTKUS M. Scale, composition, and technique effects through which the economic growth, foreign direct investment, urbanization, and trade affect greenhouse gas emissions. Renewable Energy, **132**, 1310, **2019**.
27. ABDO AL-B., LI B., ZHANG X., LU J., RASHEED A. Influence of FDI on environmental pollution in selected Arab countries: a spatial econometric analysis perspective. Environmental Science and Pollution Research, **27** (8), 28222, **2020**.
28. CUI X.H., LIN M.Y. How does foreign direct investment affect the green total factor productivity of enterprises? empirical analysis based on Malmquist-Luenberger index and PSM-DID model. Business and Management Journal, **41** (03), 38, **2019**.
29. ZHANG X.X., CAO Z.X., XU S.Y. Research on the dynamic evolution and influence mechanism of industrial green total factor productivity of industries in the Yangtze river economic belt. Journal of China University of Geosciences (Social Sciences Edition), **21** (05),137, **2021**.
30. FU J.Y., HU J., CAO X. Different sources of FDI, environmental regulation and green total factor productivity. Journal of International Trade, (07), 134, **2018**.
31. ASCANI A., BALLAND P.A., MORRISON A. Heterogeneous foreign direct investment and local innovation in Italian Provinces. Structural Change and Economic Dynamics, **53** (06), 388, **2020**.
32. YANG Y., NIU G., TANG D., ZHU M. Does Environmental Regulation Affect the Introduction of Foreign Direct Investment in China? – Empirical Research Based on the Spatial Durbin Model. Polish Journal of Environmental Studies, **28** (1), 415, **2019**.
33. QIU S., WANG Z., GENG S. How do environmental regulation and foreign investment behavior affect green productivity growth in the industrial sector? An empirical test based on Chinese provincial panel data. Journal of Environmental Management, **287**, 112282, **2021**.
34. XIE Y.Z., ZOU D., TANG X.Y. Different Types of Environmental Regulation, FDI, and Green Development of China's Industry: An Empirical Test Based on Dynamic Spatial Panel Model. Finance & Trade Economics, **42** (04), 138, **2021**.
35. LI J., WU M. Dual Environmental Regulation, FDI, and Green Total Factor Productivity: A Case Study of the Three Major City Clusters in the Yangtze River Economic Belt. East China Economic Management, **36** (01), 31, **2022**.
36. TONE K. A slacks-based measure of efficiency in data envelopment analysis. European Journal of Operational Research, **130** (03), 498, **2001**.
37. FUKUYAMA H., WEBER W.L. A directional slacks-based measure of technical inefficiency. Socio-Economic Planning Sciences, **43** (04), 274, **2010**.
38. FENG J., ZHANG S.Q. The Measurement of China's Provincial Green Total Factor Productivity Based on DEA Method: Does the Choice of DEA Model Make Difference. Acta Scientiarum Naturalium Universitatis Pekinensis, **53** (01), 151, **2017**.
39. CHUNG Y., FARE R. Productivity and Undesirable Outputs: A Directional Distance Function Approach. Microeconomics, **51** (03), 229, **1997**.
40. ZENG W.Y., ZHAO Y.K. Re-estimation of China's Stock of Capital. Journal of Xiamen University (Arts & Social Sciences), (02), 49, **2019**.
41. HU Z.C. Research on the path of different types of environmental regulations to promote carbon emission reduction: structural change and clean technology innovation. Journal of Industrial Technological Economics, **41** (12), 61, **2022**.
42. HU D.S., PAN Z.Y., ZHANG Y.L. Heterogeneous environmental regulation, technological innovation and high-quality economic development. Statistics & Decision, **37** (13), 96, **2021**.
43. YE Q., ZENG G., DAI S.Q., WANG F.L. Research on the effects of different policy tools on China's emissions reduction innovation: based on the panel data of 285 prefectural-level municipalities. China Population, Resources and Environment, **28** (02), 115, **2018**.