

## Research Article

# The Influence Study on Environmental Regulation and Green Total Factor Productivity of China's Manufacturing Industry

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Green development is the theme of the current era. Environmental regulation is an essential means to achieve environmental benefits and improve the total green factor productivity of manufacturing facing a series of problems brought by the development model of “high investment, high pollution, and high consumption.” Appropriate environmental regulations need to be implemented to achieve economic and environmental harvest. Based on the panel data of 25 manufacturing industries from 2003 to 2016 in China, this thesis constructs a comprehensive indicator of environmental regulation and calculates the green total factor productivity, and its decomposition applied SBM directional distance function and Malmquist–Luenberger productivity index. Besides, this thesis conducts an empirical analysis of environmental regulation's effect on green productivity in China. The main conclusions showed that the green total factor productivity of China's manufacturing industry maintains an upward trend on the whole, and the growth of GTFP mainly depends on technological progress rather than the improvement of technical efficiency. The great differences have significant industrial heterogeneity characteristics of GTFP. A single threshold in the whole manufacturing industry, environmental regulation, and GTFP of industries are shown to be “U shape,” and the left of the inflection point is not significant. Environmental regulations and GTFP of moderation and slightly pollution industries are “U shape,” and there is no nonlinear relationship between environmental regulation intensity and GTFP in light pollution industries. Therefore, the government's optimal environmental regulation intensity should be implemented according to the industry's heterogeneity to prevent the phenomenon of “ineffective regulation;” it is necessary to pay attention to both technological innovation and technical efficiency.

## 1. Introduction

Since the reform and opening up, the economy has continued to develop at a high speed. Material and spiritual conditions have been greatly improved and enriched. The industrialization process has been gradually accelerated and has developed into the largest country in the manufacturing industry. The manufacturing industry is the lifeblood of China's development and the top priority of economic revitalization and has been given high priority to national security. However, along with the continuous enhancement of competitiveness, the manufacturing industry is facing the dual pressure of excessive consumption of energy and resources [1]. China is still an extensive growth model driven by factor input [2]. Excessive consumption of resources and energy and negative environmental impacts have become

essential factors restricting the economy's sustainable green development. Therefore, comprehensively improving the manufacturing industry's green total factor productivity and reducing environmental pollution are the fundamental ways to achieve economic growth and sustainable development. Some scholars point out that the improvement of environmental regulation intensity will impose mandatory “fine cleaning” on the industry and then affect the green total factor productivity (GTFP) of the industry [3]. Therefore, it is necessary to deeply research the impact of environmental regulations on green total factor productivity in manufacturing, and it is of great practical significance for implementing good environmental regulation intensity to promote the improvement of green total factor productivity in the context of “green development” as the central theme in China.

This thesis has the following marginal contributions. First, consider the measurement method of the intensity of environmental regulations (wastewater and waste gas discharge fees) comprehensively and use the entropy method to construct a comprehensive index. Second, the manufacturing industry is divided into heavy, moderate, and light polluting industries according to the pollution intensity, and the industrial heterogeneity of green total factor productivity caused by environmental regulation is analyzed. Third, the manufacturing industry's environmental regulation threshold value and each subindustry are empirically tested, and a threshold model with environmental regulation as the threshold variable was established. The internal relationship between environmental regulation and GTFP in the manufacturing industry is analyzed from a practical and theoretical aspect. Fourth, taking the panel data of Chinese manufacturing industries as the sample, this study focuses the impact of environmental regulation on GTFP of the manufacturing industry, which complements the existing literature.

## 2. Literature Review

Scholars have presented three different views on environmental regulation and green total factor productivity for the past. First, environmental regulation is an additional cost imposed by the government on enterprises, which will reduce enterprises' competitiveness, implement environmental regulations hurt enterprises, and indirectly hinder green total factor productivity. For example, Li and Wei [4] investigated the GTFP in China's manufacturing industry by using ML productivity index during the period 2000–2008 and decomposed, and they found that the increase in the intensity of environmental regulations would weaken the total factor productivity of industries. He and An [5] demonstrated that insufficient environmental regulation due to competition is not conducive to the improvement of green development efficiency. Lei and Yu [6] analyzed the factors influencing the growth of total factor productivity of carbon cycle and found that environmental regulation indicators significantly inhibited the growth of green total factor productivity. Sun et al. [7] tested the impact of environmental regulations on total factor productivity by establishing a long-term equilibrium model and showed that the appropriate improvement of environmental regulation standards failed to improve total factor productivity. Yuan and Xie [8] pointed out a negative linear relationship between investment-oriented environmental regulations and green industrial productivity. Chintrakarn [9] explored the relationship between environmental regulations and technological inefficiency that used the manufacturing data of 48 United States from 1982 to 1994, and their finding indicated that the relationship between environmental regulations and technological innovation is significantly negative. Filbeck and Raymond [10] found that the increase in the intensity of environmental regulation makes a negative correlation between financial return and environmental regulation. Paul et al. [11] made an empirical analysis on the data of manufacturing industry in eastern Canada from 1996 to

2008, and the study showed that environmental regulation was detrimental to the improvement of total factor productivity.

The second view is that reasonable environmental regulatory policies can stimulate enterprises' competitiveness in the long term, which will positively impact enterprises and improve green total factor productivity. Many scholars verified the view subsequently, and instead, the conclusion is heterogeneous depending on the indicators, data, and models. For example, Fu et al. [12] used SBM directional distance function and Luenberger productivity index to measure green total factor productivity in China's provinces and found that environmental regulations can effectively improve green total factor productivity through FDI. Yana et al. [13] employed a panel data of 17 European manufacturing, positing that implementing environmental regulations can enhance enterprise technology innovation and strongly support the "Porter Innovation Hypothesis." Wu and Zhang [14] measured the total factor productivity of 28 manufacturing industries from 2001 to 2013, and the results showed that environmental regulation promoted the growth of overall total factor productivity of the manufacturing industry. Use the panel data of manufacturing industry in 29 provinces in China except for Xinjiang and Chongqing; Li and Liu [15] found that environmental regulations can significantly promote green economic efficiency in the long run, and strengthening environmental regulations can achieve a win-win situation for both the economy and the environment. Feng et al. [16] used the ML index to measure China's provincial green total factor productivity and found that environmental regulation and innovation drive have a synergistic effect in promoting the total green factor production rate. Debnath [17] proposed that environmental regulation could promote technological innovation. He also confirmed that environmental regulation effectively promoted GTFP by the compensation effect. Hamamoto [18] found that strict environmental regulation policies will stimulate enterprises' innovation activities actively, thereby promoting total factor productivity. Wu and Wang [19] used the ML productivity index to measure the green total factor productivity of 17 countries and regions APEC from 1980 to 2004. The results showed that environmental regulation was proportional to GTFP. Liu and Yang [20] confirmed that ERI effectively promoted GTFP by overseas technology introduction and domestic technology introduction.

With the deepening of green development, some research shows a nonlinear relationship between environmental regulations and green total factor productivity of the manufacturing industry. Li and Tao [21] applied microdata at the Chinese manufacturing industry's enterprise level and found that the influence of environmental regulations on green total factor productivity presented an inverted U-shaped relationship. Chen et al.' [22] finding indicated the existence of a significant "inverted U" relationship between them. Liu and Tang [23] found that environmental regulations positively affected China's GTFP growth using the DEA Malmquist index technique. Wang et al. [24] believed that environmental regulation promotes environmental

quality and increases GTFP of the service industry. Yin [25] applied the SBM model to investigate GTFP in China and found that the relationship between GTFP and environmental regulation intensity is a “U” type. Brannlund [26] empirically tested the impact of environmental regulation on the productivity of manufacturing enterprises in Sweden. The study showed no significant relationship between the two. Ravetti et al. [27] believed that it is difficult for environmental regulation to improve enterprise technological innovation and further prove that the effect of environmental regulation on enterprise technological innovation is almost negligible.

The above literature provides a solid foundation for studying environmental regulation’s impact on green total factor productivity, but there are still the following shortcomings. First, most of the construction of environmental regulation intensity is based on a single index or a single dimension, and the measurement of environmental regulations is not sufficient. Second, existing research studies primarily focus on the provincial and industrial sectors, which fails to provide a more abundant theoretical and practical basis for the manufacturing industry. Therefore, this study adopts the Malmquist–Luenberger productivity index to estimate the GTFP change of China’s 25 manufacturing industrial subsectors covering the period 2003–2016. Subsequently, a threshold effect model is applied to analyze the heterogeneous effects of ERI on GTFP in China. It is hoped to provide a realistic basis for the green and sustainable development of China’s economy.

### 3. Mechanism Analysis

Reasonable environmental regulations can effectively correct system failures and promote the efficient allocation of environmental resources [28]. In general, environmental regulations impact green total factor productivity by technological innovation, industrial structure, and FDI. Figure 1 shows the analysis framework of environmental regulation mechanism on green total factor productivity in manufacturing.

**Technological innovation:** environmental regulations impact green total factor productivity by technological innovation. The “Porter Hypothesis” [29] believes that reasonable environmental regulation policies can reduce innovation compensation effects by stimulating enterprise technological innovation and environmental protection technology upgrades, making up or exceeding the costs of environmental regulations, thereby enabling green total factor productivity to increase and achieve green development [30–35].

**Industrial structure:** industrial structure and environmental regulation affect industrial structure upgrading, changing the market structure through industrial behavior [36], which acts on GTFP. Liu et al. [37] found the decline in GTFP mainly derived from optimization and upgrading of the industrial structure rather than energy efficiency. The impact of environmental regulation on the industrial structure can be categorized into the following three aspects. First, environmental regulations can affect green total factor

productivity changing the industrial structure by affecting investment and consumption demand. On the one hand, the costs of enterprises will be increased if implemented environmental regulations; squeeze the funds used by enterprises to expand reproduction, and there are higher thresholds for enterprises with high energy consumption and high pollution, which will change the investment direction more willing to invest in the clean industry. On the other hand, consumers will buy more green products with less pollution and high technology with the increased income and the environmental awareness, which will change demand structure and promote the development of the tertiary industry, and thus promote the greening of industrial structure [38]. Second, environmental regulations can affect green total factor productivity changing the industrial structure through interindustry competition and entry and exit barriers [39]. Environmental regulations will put pressure on heavy industry companies in terms of environmental governance costs and technology. Companies will be eliminated if they cannot afford higher costs. Companies with environment friendly products have more advantages than other companies with the enhancement of living and awareness, and enterprise’s profit rate has risen to achieve scale expansion and industrial structure upgrading and optimization. The main change in the industrial structure is the transfer of production factors such as labor, capital, and land to the tertiary industry. There are differences in output efficiency between different industries before reaching equilibrium economic growth. When production factors are transferred from lower to higher, it will promote economic growth. Chanary calls it the “total allocation effect,” which is considered to be a fundamental reason for the growth for green total factor productivity [40], and some scholars have also confirmed the positive impact [41–44].

FDI, environmental regulations have raised the environmental threshold of foreign-funded enterprises through market access, pollution taxes, and fees [45]. Advanced green technology and environmental protection technology were brought to the country by high-quality foreign-funded enterprises, which stimulated technological innovation and technology upgrades of enterprises, and promoted green total factor productivity [32]).

### 4. Empirical Test of the Influence of Environmental Regulations on the GTFP

**4.1. Measuring the ERI.** Given that the current investigation object was the ERI of manufacturing sectors, special requirements were imposed on manufacturing data availability and industry statistics’ caliber. Therefore, 31 manufacturing industries need to be classified according to the national economic industry classification standard (GB/T4754-2002). Considering the absence of data on individual industry segments, six segments (manufacture of rubber and manufacture of plastics, manufacture of textile and manufacture of textile wearing apparel, footwear, and caps are a combined industry. Manufacture of transport equipment still includes manufacture of automobiles. Besides, other manufactures\*, utilization of waste resources, repair service

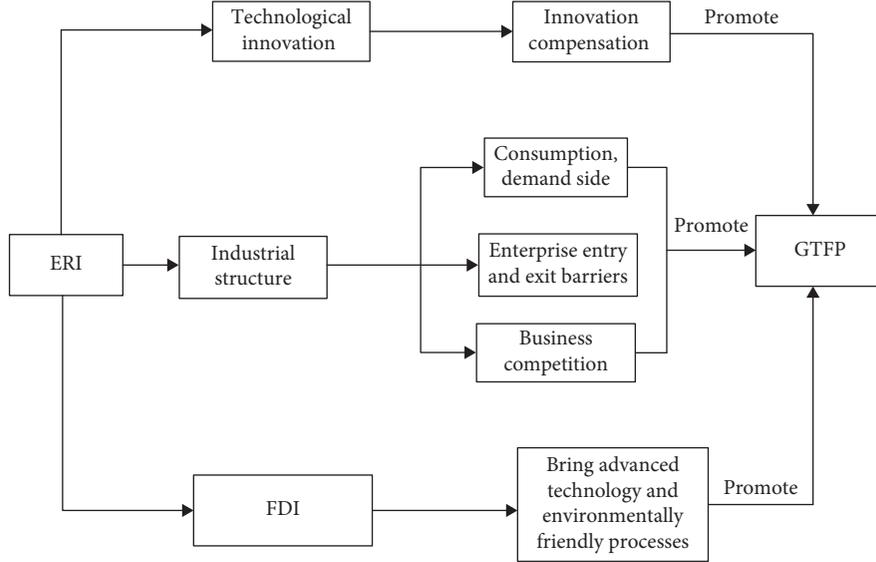


FIGURE 1: An analysis framework of the mechanism of ERI on GTFP of manufacturing.

of metal products, machinery, and equipment have incomplete data in the sample range studied) were removed and combined from the existing 31 industry segments to yield the final 25. The study samples drew on panel data on 25 segments of the Chinese manufacturing industry in 2003–2016. The original data were taken from the China Statistical Yearbook, China Economic Census Yearbook, China Urban Life And Price Yearbook, Development Research Center Of The State Council, China Industry Economy Statistical Yearbook, China Energy Statistical Yearbook, and China Statistical Yearbook on the Environment for the relevant years, as well as from relevant data released by the National Bureau of Statistics.

To further reflect the influence of environmental regulations on the GTFP and industry differences in environmental regulations and green total factor productivity, the 25 manufacturing industries will be divided according to pollution emissions. Given the method of Li [46], an industry's pollution intensity is determined by summing up various pollution emissions. Linear standardization and equal weight sum average of various pollutant emission data are carried out to calculate each industry's pollution emission intensity. First, calculate the pollution emission value of each industrial pollutant unit output value, and it can be expressed as

$$UE_{ij} = \frac{E_{ij}}{O_i}, \quad (1)$$

where  $UE_{ij}$  represents the pollution emission, where  $i$  represents each industry,  $j$  represents the pollutant source,  $O_i$  represents the total industrial output, and  $E_{ij}$  is the emission of each pollutant.

Second, the standardized pollution emission value is defined as

$$UE_{ij}^s = \frac{[UE_{ij} - \min(UE_j)]}{[\max(UE_j) - \min(UE_j)]}, \quad (2)$$

where  $\min(UE_j)$  and  $\max(UE_j)$  represent the maximum emission and minimum emission of each pollutant, respectively,  $UE_{ij}$  represents the current year emission of each pollutant in each industry, and  $UE_{ij}^s$  represents the standardization value.

Third, weighted and averaged the above pollutant emission scores, the average scores of waste water, waste gas, and solid waste were calculated, and it can be described using the following equation.

$$NUE_{ij} = \sum_{j=1}^n \frac{UE_{ij}^s}{n}, \quad (3)$$

where  $NUE_{ij}$  represents the pollution emission intensity index of the industry.

Finally, the average score is summarized to get the average of the total pollution emission intensity coefficient  $\gamma$  of the industry over the years.

The pollution emission intensity is calculated according to the above method and formulas (1)–(3) as given in Table 1. This study classifies industries based on the intensity of total pollution emissions. If  $\gamma > 0.125$ , the industry is heavy pollution industry; if  $0.125 < \gamma < 0.0225$ , the industry is moderate pollution industries; if  $\gamma < 0.0225$ , the industry is slight pollution industry.

From Table 1, we can find that the main characteristics of heavy pollution industries composed of capital-intensive industries and traditional heavy chemical industries are high energy consumption and strong pollution emissions. The moderate pollution industries are mainly slight, and the energy consumption and pollution emission intensity are lower than those of heavy industries. The slight pollution industries are mainly high-tech industries and clean industries which have technical advantages, the high added value of products, low energy consumption, and low pollution emissions that make the lowest energy consumption and pollution emission intensity. It can be found that the

TABLE 1: Industry classifications based on pollution emission intensity.

Pollution emission intensity index	Group	Industry
$\gamma > 0.125$	Heavy pollution industries	Manufacture of liquor, beverages, and refined tea; papermaking and paper products; processing of petroleum; coking and processing of nuclear fuel; raw chemical materials and chemical products; manufacture of chemical fibers; nonmetal mineral products; smelting and pressing of ferrous metals; smelting and pressing of nonferrous metals
$0.125 < \gamma < 0.0225$	Moderate pollution industries	Farm products processing; food manufacturing; leather, furs, down, and related products, timber processing; medical and pharmaceutical products; metal products; textile industrial and garments; shoes and hats manufacturing
$\gamma < 0.0225$	Slight pollution industries	Tobacco products; furniture manufacturing; printing and record medium reproduction; manufacture of general purpose machinery; special purpose equipment manufacturing; manufacture of transport equipment; manufacture of computers; communication and other electronic equipment; manufacture of measuring instruments and machinery

heavy pollution industries are showing a stable and rising trend, the moderate pollution industries are on the rise, and the slight pollution industries remain stable, as shown in Figure 2. Table 2 provides the pollution emission intensity values of various industries.

There is no consistent conclusion for the influence of environmental regulation on GTFP due to the difference in ERI measurement by reviewing past literature. There are mainly the following methods: (1) use sewage charges to measure ERI [47, 48]; (2) measure the ERI by the proportion of pollution costs in total industrial output value or sales output value [46–49]; and (3) use a comprehensive pollutant index to measure the ERI [50]. We used the comprehensive indicators to measure the ERI [51], constituting the waste water pollutant discharge fee and exhaust pollutant discharge fee. Due to the lack of public statistical data, this study adopted the “levy standards and calculation methods for pollutant discharge fee” specified in both the Administrative Regulations on Levy and Use of Pollutant Discharge Fee (hereinafter referred to as “the Regulations”), issued by the State Council, and the Circular on Adjusting the Levy Standards for Pollutant Discharge Fee and Other Issues (hereinafter referred to as “the Circular”), issued by the National Development, estimating the pollutant discharge fee except a solid waste of 25 segments of the Chinese manufacturing industry in 2003–2016. First, the emissions of the main pollutants of various industries were calculated. Second, the calculation of each type of pollutant’s pollution equivalent was undertaken (as shown in Formula (4)). Step three involved identifying the top three ( $\leq 3$ ) representative fee factors according to the pollution equivalent sequence of various pollutants (from high to low). Finally, the pollutant discharge fees of waste water and exhaust in various industries were calculated according to the “levy standards for pollutant discharge fee” specified in the circular (formulas (5) and (6)). Last, the objective weight-based entropy method was adopted to derive the comprehensive index of ERI.

$$PEP = \frac{EP}{EVA}, \quad (4)$$

where PEP represents the pollution equivalent of a pollutant, EP represents the pollutant’s emission, and EVA represents the pollutant’s equivalent value.

$$WPDF = 1.4 \cdot \sum (PEPW_i), \quad i = 1, 2, 3. \quad (5)$$

where WPDF represents the waste water pollutant discharge fee, and PEPW represents the pollution equivalents of pollutants in waste water.

$$EPDF = 1.2 \cdot \sum (PEPE_i), \quad i = 1, 2, 3. \quad (6)$$

where EPDF represents the exhaust pollutant discharge fee, and PEPE represents the pollution equivalents of pollutants in the exhaust.

Following these steps, the objective weight-based entropy method was adopted to derive the comprehensive index of ERI.

We plot the average value of the three major industries’ environmental regulation intensity over the years in Figure 3. ERI of heavy pollution industries was the highest, followed by moderate pollution industries, with ERI of slight polluting industries being the lowest from 2003 to 2016, as shown in Figure 3. It shows that industries dominated by traditional heavy industries have always been the national pollution control targets, and the overall intensity of environmental regulations is on the rise. However, the ERI of heavy pollution industries has declined from 2008 to 2010. It can be attributed primarily to the financial crisis, with lower profit margins and lower output, which reduces the environment’s impact. ERI of moderate pollution industries has also shown an upward trend, indicating that the moderate pollution industries’ regulation was paid more attention, and the slight polluting industries have been maintained at a low level with minimal fluctuations. In general, the ERI of the three categories of industries is consistent with the conclusions obtained from pollution intensity.

## 4.2. Measuring the ETFP of Chinese Manufacturing Industries

### 4.2.1. Measurement Methods.

This study uses the production frontier analysis tool, SBM directional distance function, and Luenberger productivity index proposed by Chung et al. [52], which incorporate energy consumption and environmental pollution into a TFP unified analysis framework, using a comprehensive approach to measure the TFP of manufacturing and its decomposition in the Chinese

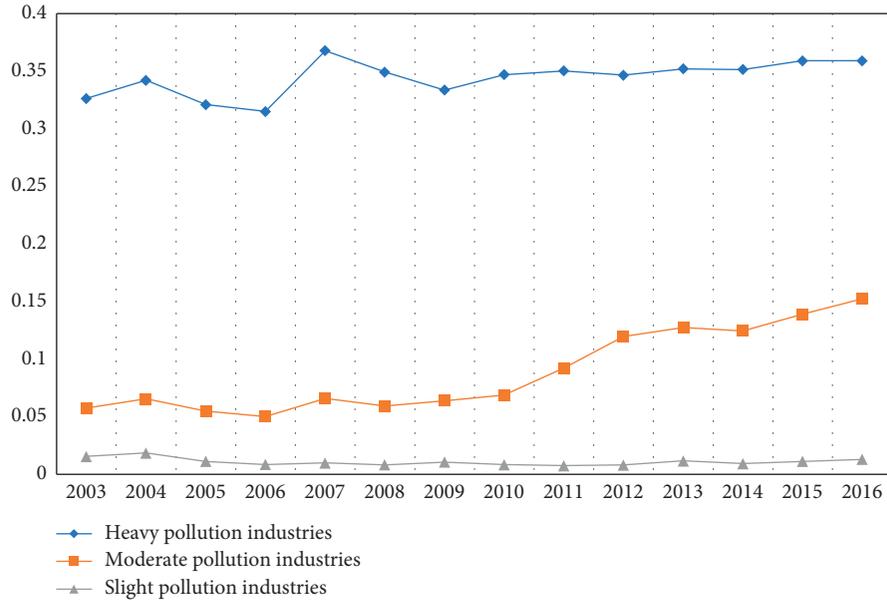


FIGURE 2: Changes in the average pollution intensity of the three pollution industries.

TABLE 2: Pollutant emission intensity values of various industries.

Groups	Industries	Index value
Heavy pollution industries	Manufacture of liquor, beverages, and refined tea	0.1245
	Papermaking and paper products	0.4759
	Processing of petroleum	0.2334
	Coking and processing of nuclear fuel	0.3475
	Manufacture of chemical fibers	0.1606
	Nonmetal mineral products	0.4136
	Smelting and pressing of ferrous metals	0.6614
	Smelting and pressing of nonferrous metals	0.3367
	Tobacco products	0.0136
	Furniture manufacturing	0.0076
Slight pollution industries	Printing and record medium reproduction	0.0059
	Manufacture of general purpose machinery	0.0108
	Special purpose equipment manufacturing	0.0126
	Manufacture of transport equipment	0.0225
	Manufacture of computers	0.0036
	Communication and other electronic equipment	0.0081
	Measuring instruments and machinery	0.0118
	Farm products processing	0.1017
	Food manufacturing	0.0862
	Leather, furs, down, and related products	0.0324
Moderate pollution industries	Timber processing	0.0529
	Medical and pharmaceutical products	0.0624
	Metal products	0.0383
	Textile industrial and garments	0.1202
	Shoes and hats manufacturing	0.1241

manufacturing industry from 2003 to 2016. Provide objective data for the empirical test, and provide objective data for the later empirical test. Put each industry as the decision-making unit, construct the best production frontier in each period, using  $N$  types of inputs,  $x = (x_1, \dots, x_n) \in \mathbb{R}n^+$ , to

produce  $M$  types of desirable outputs  $y = (y_1, \dots, y_m) \in \mathbb{R}m^+$  and  $i$  types of undesirable outputs  $b = (b_1, \dots, b_i) \in \mathbb{R}i^+$  at the same time, where the superscripts  $n, m, t$  denote periods  $n, m, t = 1, 2, \dots, T$ . Environmental technology can be described as

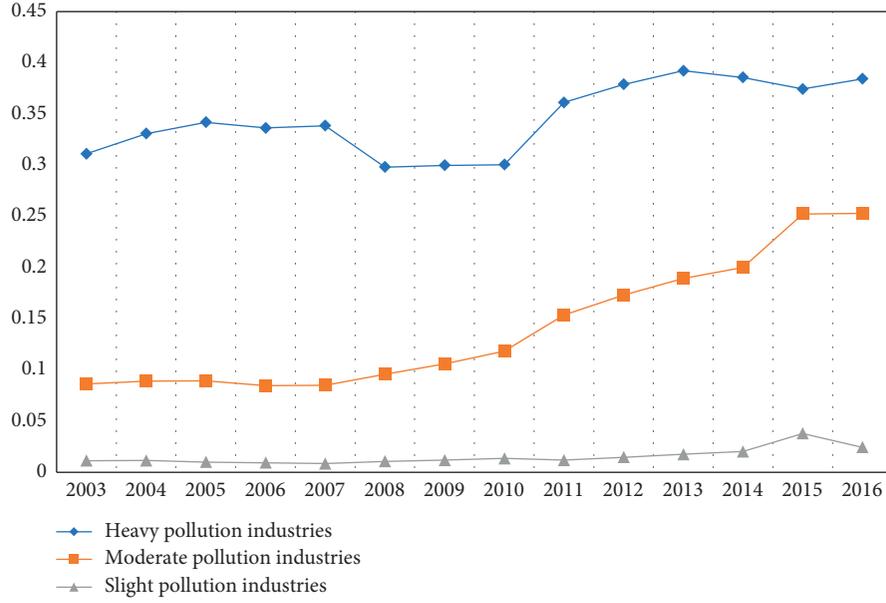


FIGURE 3: Changes in the intensity of environmental regulations in the three major categories of industries.

$$p^t(x^t) = \left\{ (y^t, b^t) \sum_{k=1}^K \alpha_k^t y_{km}^t \geq y_{km}^t, \quad \forall m; \sum_{k=1}^K \alpha_k^t b_{ki}^t = b_{ki}^t, \quad \forall i; \sum_{k=1}^K \alpha_k^t y_{kn}^t \leq x_{kn}^t, \quad \forall n; \sum_{k=1}^K \alpha_k^t = 1, \alpha_k^t \geq 0, \quad \forall k \right\}. \quad (7)$$

According to SBM directional distance function of energy environment proposed by Tone [53],

$$\begin{aligned} \overrightarrow{S^{G,k}} &= (x^{G,k}, y^{G,k}, b^{G,k}, g^{G,k,x}, g^{G,k,y}, g^{G,k,b}) \\ &= \max \frac{1/N \sum_{n=1}^N s_n^{G,k,x} / g_n^{G,k,x} + 1/M + I(\sum_{m=1}^M s_m^{G,k,y} / g_m^{G,k,y} + \sum_{i=1}^I s_i^{G,k,b} / g_i^{G,k,b})}{2}, \quad (8) \\ \text{s.t. } \sum_{k=1}^K \alpha_k^t x_n^{t,k} + s_n^{G,k,x} &= x_n^{t,k}, \quad \forall n; \sum_{k=1}^K z^{t,k} b_i^{t,k} + s_i^{G,k,b} = b_i^{t,k}, \quad \forall i; s_n^{G,k,x} \geq 0, \forall n; s_m^{G,k,y} \geq 0, \forall m; s_i^{G,k,b} \geq 0, \forall i, \end{aligned}$$

where  $\overrightarrow{S^{G,k}}$  represents the global directional distance function,  $x^{G,k}, y^{G,k}, b^{G,k}$  is the factor input vector, desirable output vector, and undesirable output vector for each industry, respectively,  $g^{G,k,x}, g^{G,k,y}, g^{G,k,b}$  is the input shrinking direction vector, expected output expansion direction vector, and directional vector for shrinking direction vector, respectively,  $s_n^{G,k,x}, s_m^{G,k,y}, s_i^{G,k,b}$  represents the input slacks, desirable outputs slacks, and undesirable output slacks, respectively, slacks vector refers to the distance from

the best production frontier,  $s_n^{G,k,x}$  stands for the investment redundancy,  $s_m^{G,k,y}$  is the insufficient expected output, and  $s_i^{G,k,b}$  is the undesired output redundancy. When the slacks scalar is a zero, the SBM directional distance function is equal to the traditional directional distance function. The larger the value, the lower the efficiency level. Luenberger productivity index of period  $t$  and period  $t+1$  ( $GTFP_t^{t+1}$ ) is proposed by Chambers et al. [54]:

$$GTFP_t^{t+1} = \frac{1}{2} \left\{ [s_c^t(x^t, y^t, b^t, g) - s_c^t(x^{t+1}, y^{t+1}, b^{t+1}, g)] + [s_c^{t+1}(x^t, y^t, b^t, g) - s_c^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}, g)] \right\}. \quad (9)$$

Green total factor productivity index (GTFP) can be further broken down into technological efficiency change

(GEC) and technical progress (GTC) [55]. Changes in factors such as system innovation, experience accumulation,

and economies of scale in production can be expressed by technical efficiency changes (GEC). The innovation and improvement of technology can be expressed by technological progress (GTC). If  $GTFP > 1$ , it indicates that GTFP improves; otherwise, it decreases. If  $GEC > 1$  is equivalent to technological efficiency progress, it deteriorates. If  $GTC > 1$ , it indicates green technological progress; otherwise, it regresses.

*4.2.2. Related Data Processing.* To measure the ETFP, calculated by a data envelopment analysis method, we first need

$$K_t = (M_t - M_{t-1}) + \{1 - [(M_t - N_t) - (M_{t-1} - N_{t-1})]/M_{t-1}\} \cdot K_{t-1}. \quad (10)$$

Among them,  $(M_t - M_{t-1})$  represents the current investment,  $[(M_t - N_t) - (M_{t-1} - N_{t-1})]/M_{t-1}$  represents the depreciation rate,  $K_t$  represents the current capital stock, and  $K_{t-1}$  represents the previous capital stock. At the same time, we use the fixed asset price index to deflate the investment in fixed assets (the base year is 2003) to obtain the manufacturing capital stock. Energy consumption: this index is measured by industrial enterprises' total energy consumption above the industry scale.

- (2) Output variables. desirable output: this study selected the total industrial output value instead of the industrial added value as the desired output and use the industrial producer price index to deflate the total industrial output value (the base year is 2003) Undesirable output: we use waste water, exhaust, solid waste discharge, and  $CO_2$  emissions to express undesirable output for the respective sector [51, 59]. The formula for the total amount of  $CO_2$  emissions is as follows:

$$C_t = \sum_{i=1}^3 C_{i,t} = \sum_{i=1}^3 E_{i,t} \cdot NCV_i \cdot CEF_i \cdot COF_i \cdot \left(\frac{44}{12}\right). \quad (11)$$

Among them,  $C$  denotes the  $CO_2$  emissions,  $i$  denotes the energy type,  $E$  denotes the energy consumption,  $NCV$  represents the average lower heating value of various energy sources,  $CEF$  denotes the  $CO_2$  emission factor of the energy, and  $COF$  indicates the energy's carbon oxidation rate. Energy types include coal, crude oil, and natural gas. The coefficients of different energy types are given in Table 3.

*4.2.3. Calculation Results and Analysis.* This study uses MaxDEA software to measure the GTFP of the manufacturing industry considering energy consumption and undesired output; it is decomposed into the following: technical efficiency index (GEC) and technological progress index (GTC). Table 4 reveals the industry differences in GTFP and the decomposition of the manufacturing sectors. The average value of China's GTFP of manufacturing was 1.0555 from 2003 to 2016, green TFP in overall manufacturing shows an upward trend, and the average

to define input, desirable output, and undesirable output [56].

- (1) Input variables. Labor input: this index is measured by the annual average number of persons employed by manufacturing enterprises above industry scale. Capital stock ( $K_t$ ): the perpetual inventory method is generally used to calculate manufacturing capital stock [57, 58]. The calculation formula is as follows:

annual growth rate of GTFP in Chinese manufacturing is 5.6%. In terms of decomposition, the technical progress index has the largest contribution to GTFP. The average annual growth rate of GEC is 1.3% and GTC is 4.3% from 2003 to 2016. Figure 4 shows the steady trend of the overall GTFP of the manufacturing industry and its decomposition items. GTFP and GTC show simultaneous changes and are higher than GEC. We can see that the GTFP is featured by a declining trend and is affected by the deterioration of technical efficiency and weak technological progress, especially in the period 2007-2008. The GTFP declined from 1.1% to 0.95%. Considering its external factors may be that in the 2008 global financial crisis, the global economy fell into a trough, which harmed the manufacturing industry.

In terms of the industry type, both slightly polluting and moderate pollution industries presented relatively significant regression on GTFP. However, only heavy pollution industries have achieved a slight increase. In the sample period, the GTFP of heavy, moderate, and slightly polluting industries increased 1.3%, -0.2%, and -0.5%, respectively; this means that there is a positive effect of the country's environmental regulation policy on heavy pollution industries and slight and moderate pollution industries should be strengthened. Heavy pollution industries have the highest average value of GTFP, second only to GTFP of the whole industry, and the growth during the study period is positive, followed by moderate polluted industries and slight polluted industries. However, the green total factor productivity growth is negative. Compared with GEC, GTC is a more important reason for the increase of GTFP in China's manufacturing industry from the perspective of its decomposition term. Therefore, we can see that the GTFP of the heavily polluting industries has been dramatically improved due to the "energy," imposed by the government. Therefore, the government's attention should be shifted to the promotion of GTFP in the moderately and slight pollution industry.

Further analysis from (Figure 4) fluctuation trends of GTFP and its decomposition in the industries are consistent. In terms of heavy pollution industry, there is a significant decline during the period 2007-2008, and the possible reason is that the outbreak of the financial crisis in 2008 hurt the

TABLE 3: Coefficients of different energy.

Energy type	Net heat value (kJ/kg)	Carbon emission factor (kg C/GJ)	Carbon oxidation rate
Raw coal	0.7143	2.763	0.99
Crude oil	1.4286	2.145	1
Natural gas	1.3300	1.642	1

TABLE 4: Average GTFP and its decomposition in the industry from 2003 to 2016.

Groups	Industry	Green total factor productivity (GTFP)	Technical efficiency (GEC)	Technological progress (GTC)
Heavy pollution industries	Manufacture of liquor, beverages, and refined tea	0.9570	0.9336	0.9626
	Manufacture of paper and paper products	1.0299	0.9654	0.9887
	Processing of petroleum, coking, and processing of nuclear fuel	0.9971	0.9286	0.9971
	Manufacture of raw chemical materials and chemical products	1.0575	0.9629	1.0218
	Manufacture of chemical fibers	0.9679	0.9790	0.9117
	Manufacture of nonmetallic mineral products	1.0541	0.9846	0.9860
	Smelting and pressing of ferrous metals	1.0434	0.9595	1.0103
	Smelting and pressing of nonferrous metals	0.9985	0.9475	0.9815
	Average	1.0131	0.9576	0.9824
Moderate pollution industries	Processing of food from agricultural products	0.9639	0.9256	0.9673
	Manufacture of foods	0.9468	0.9350	0.9446
	Manufacture of leather, fur, feather and related products, and footwear	1.0823	0.9290	1.0829
	Processing of timber and manufacture of wood, bamboo, rattan, palm, and straw products	0.9884	0.9148	1.0082
	Manufacture of medicines	0.9744	0.9438	0.9618
	Manufacture of metal products	0.9118	0.9269	0.9188
	Manufacture of textile, wearing apparel, and accessories	0.9690	0.9448	0.9593
	Manufacture of rubber and plastics products	0.9391	0.9180	0.9495
	Average	0.9720	0.9297	0.9740
Slight pollution industries	Manufacture of tobacco	0.8850	0.9286	0.8850
	Manufacture of furniture	1.0232	0.9289	1.0232
	Printing and reproduction of recording media	0.8819	0.9286	0.8819
	Manufacture of general purpose machinery	0.9646	0.9403	0.9520
	Manufacture of special purpose machinery	0.9722	0.9471	0.9542
	Manufacture of transport equipment	0.9958	0.9437	0.9791
	Manufacture of electrical machinery and apparatus	0.9205	0.9286	0.9205
	Manufacture of computers, communication, and other electronic equipment	1.0025	0.9286	1.0025
	Manufacture of measuring instruments and machinery	0.9767	0.9286	0.9767
Average	0.9580	0.9336	0.9528	
Manufacturing industry	Overall average	1.0555	1.0135	1.0436

manufacturing industry. With regard to moderate pollution industries, there is a significant increase during the period 2009-2010, and GTC has the same change. However, GEC is the opposite, proving that the changes in GTFP mentioned above are mainly from technological progress.

can be divided into classes based on an observed variable's value, called the threshold variable [61]. As the value of the threshold variable changes, the relationship between the dependent and independent variables varies nonlinearly. The threshold effect model with a single variable here is

4.3. Model Testing and Estimation Results

$$y_{it} = \partial_0 + x_{it}\partial_1 + \varepsilon_{it}, q_{it} \leq \gamma, \tag{12}$$

4.3.1. Model Introduction. Using the panel threshold model proposed by Hansen [60], individual observations

$$y_{it} = \partial_0 + x_{it}\partial_2 + \varepsilon_{it}, q_{it} > \gamma, \tag{13}$$

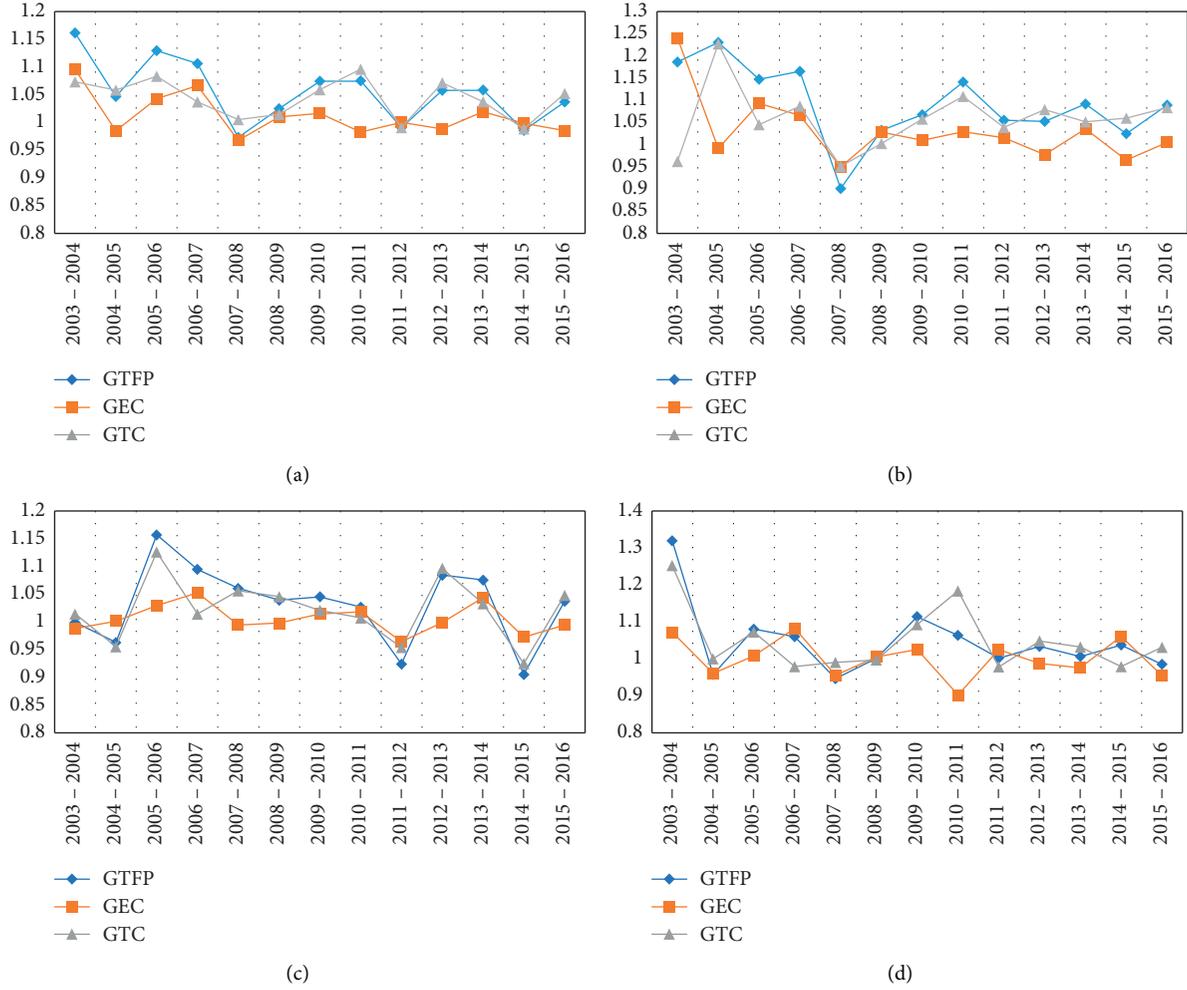


FIGURE 4: Industrial green total factor productivity and its decomposition. Manufacturing industry (a), heavy pollution industry (b), slight pollution industry (c), and moderate pollution industry (d).

where  $q_{it}$  is the threshold variable,  $\gamma$  is the threshold value of  $q$ ,  $i$  and  $t$  denote the geographical units and years, respectively,  $\partial_0$  and  $\varepsilon_{it}$  represent the constant term and stochastic error term, respectively, and  $\partial_i$  is the coefficient. Set the following panel model according to the basic model:

$$\begin{aligned} \text{GTFP}_{it} = & \partial_0 + \partial_1 \text{ERI}_{it} \cdot I(\text{ERI}_{it} \leq \gamma) + \partial_2 \text{ERI}_{it} \cdot (\text{ERI}_{it} > \gamma) \\ & + \partial_3 \text{SS}_{it} + \partial_4 \text{FDI}_{it} + \partial_5 \text{CP}_{it} + \partial_6 \text{ES}_{it} + \varepsilon_{it}, \end{aligned} \quad (14)$$

where  $\text{GTFP}_{it}$  represents the green total factor productivity, as explained variable;  $\text{ERI}_{it}$  represents the environmental regulation, as explanatory variable;  $i$  represents the industry;  $t$  represents the year;  $\text{SS}_{it}$  represents the scale structure;  $\text{FDI}_{it}$  represents the foreign direct investment;  $\text{CP}_{it}$  represents the capital per;  $\text{ES}_{it}$  represents the energy structure;  $\partial_i$  is the coefficient; and  $\varepsilon_{it}$  represents the stochastic error term.

#### 4.3.2. Index Selections

- (1) Explained variable: green total factor productivity (GTFP)

- (2) Core explanatory variable: environmental regulations intensity (ERI)
- (3) Control variables: scale structure and the economic proportions of multiple ownership within the industry tend to be reasonable if the manufacturing's scale structure is reasonable, and this will optimize the allocation of resources and have a positive impact on environmental protection. Therefore, select the proportion of the total industrial output value of state-owned and state-controlled enterprises in various industries in the total industrial output value of all industries above designated size as the proxy variable. FDI, the flow of transnational capital, is the external driving force for green economic growth. The proportion of all industries' total industrial output value above the designated size invested by foreign investors and Hong Kong, Macao, and Taiwan will be selected as a proxy variable [57]. Capital per, the development of a green economy will be affected by capital per capita through technological innovation and personal pollution emissions. Therefore, each industry's capital-labor ratio is

selected as the proxy variable of per capita capital in this study. The capital stock mentioned above and the average number of employees in each industry are used for labor [62]. Energy structure, introducing energy consumption into green total factor productivity, will inevitably impact green economic growth. On the one hand, the overuse of energy will affect the input factors. On the other hand, excessive energy emissions will indirectly affect undesired output, and the proportion of primary energy has gradually decreased, and clean energy such as natural gas and hydropower has increased with the development of the economy. Referring to Chen et al. [22], this study chooses the proportion of total electric power consumption in total industrial energy consumption in each industry as the proxy variable. Table 5 presents the indexes selected.

**4.3.3. Model Testing and Estimation Results.** In line with the threshold model-based estimation method, the value of environmental regulation was adopted as the threshold variable. The self-sampling frequency was set at 300 times, and the bootstrap method was used to calculate the critical value of the F-statistics and thus determine the number of thresholds.

Table 6 provides the test results of the number of thresholds of the four industry groups; there is one threshold in the manufacturing industry, heavy pollution industries, and moderate pollution industries, thus indicating a nonlinear effect between ERI and GTFP. The three threshold values are 60.63%, 62.95%, and 3.86%, respectively, and all are significant at the 1% level. There is no threshold in the slight pollution industries.

Table 7 summarizes the estimation results of the panel threshold models. With regard to manufacturing, there was a “U-shaped” relationship between the environmental regulation and the GTFP, but insignificance left of the inflection point. Although the intensity of environmental regulation will have not a significant impact on the GTFP in the short term, it will increase the additional burden of enterprises with the intensity of environmental regulation increases, forcing enterprises to carry out technological innovation, which in turn produces an “innovation compensation effect” and improve the GTFP. It shows that the GTFP of the manufacturing industry has been significantly improved under the high environmental regulations, aching a win-win situation for the environment and benefits. To heavy pollution industries, environmental regulations are different and significant in two stages. Environmental regulation and green total factor productivity present a significant “U”-shaped relationship that will first decrease and then increase the impact on green total factor productivity as environmental regulation changes. Specifically, when ERI is less than 0.6295, the coefficient value is  $-1.4467$ , which is significant at the 1% significance level, which means every 1% increase in ERI, the impact on GTFP decreases by 1.4467%. When ERI is greater than 0.6295, the coefficient value rises back to 1.7550, which means every 1% increase in ERI, and the

impact on GTFP increases by 1.755%. Enhancing environmental regulations will promote the increase of green total factor productivity. The reason may be that companies often only spend a small amount of money on governance when the intensity of environmental regulations is weak. As the intensity of environmental regulations increases to the “inflection point” level, companies will face more significant pollution control, affecting corporate profit. It will pay attention to protecting the environment and improving technology to reduce energy consumption and pollutant emissions, thereby increasing green total factor productivity. For moderately polluting industries, the relationship between the intensity of environmental regulations and green total factor productivity is “U”-shaped, but it is not significant on the right side of the inflection point. The results above explanations are as follows: with the increase of environmental regulation intensity, green total factor productivity is impeded. In moderately polluted industries that are dominated by means of living manufacturing and some heavy industries with relatively weak technological foundations, the high environmental regulation intensity will squeeze out enterprises’ R&D input, affecting technological innovation and R&D, and not conducive to the improvement of green total factor productivity. In terms of slight polluting industries, environmental regulations’ coefficient is different in two stages and not significant, indicating that there is no nonlinear relationship between environmental regulation and green total factor productivity in lightly polluted industries. In analysis of other control variables, in terms of the FDI, the latter’s effect on the GTFP was found to be negative. This outcome supports the Pollution Haven Hypothesis. We must pay attention to the quality of foreign capital introduction, strengthen the capital introduction environment’s supervision, and prohibit western enterprises from shifting their high pollution industries to China and prohibit the transfer of some foreign high energy consumption and polluting industries to my country through foreign capital, thereby restricting the green development of the manufacturing industry. The energy structure’s regression coefficients were significantly positive, which shows that the energy structure has been improved and more reasonable. The source of energy consumption has been transformed from the primary energy sources based on coal and oil to clean energy based on electricity, which reduces the emission and undesired output, and realized the optimizing effect of energy structure and promotes the improvement of GTFP in the manufacturing industry indirectly. The capital per worker’s coefficient performed relatively well among heavy and slight pollution industries but was nonsignificant among moderate pollution industries. This indicates that per capita capital positively impacts the GTFP of the heavy pollution industries and proves that capital deepening and heavy industrialization are synchronized. Traditional heavy industries are characterized by high energy consumption and large emissions under unchanged technical conditions, but capital deepening will have technological progress and promote productivity, which is conducive to improving green total factor productivity. The coefficient of scale structure is negative in the manufacturing industry,

TABLE 5: Explanatory variable selection and definitions.

Variable	Abbreviation	Index definition
Scale structure	SS	The total output value of state holding industrial enterprises above the designated size/total output value of industrial enterprises above the designated size
Foreign direct investment	FDI	Total output value of foreign-funded and HK/Macao/Taiwan-funded industrial enterprises above the designated size/total industrial output value of industrial enterprises above the designated size
Capital per	CP	Total assets of the industry/year-end number of persons employed in the industry
Energy structure	ES	Power consumption/total energy consumption in each industry

TABLE 6: Threshold effect test.

Industry type	Threshold	F value	P value	F-critical value			Critical value
				10%	5%	1%	
Manufacturing industry	Single	64.81***	0.0067	32.1869	38.7840	53.8896	0.6063
Heavy pollution industries	Single	41.80***	0.0000	19.1182	22.9038	23.1817	0.6295
Moderate pollution industries	Single	62.07***	0.01	33.4110	41.0916	58.8345	0.0386
Slight pollution industries	No	12.86	0.1800	16.4522	19.9639	23.0009	0.0001

\*, \*\*, and \*\*\* are significant at the levels of 10%, 5%, and 1%, respectively.

TABLE 7: Test results for the threshold effects of manufacturing and sectors.

Variables	ERI is threshold variable			
	Manufacturing industry	Heavy pollution industries	Moderate pollution industries	Slight pollution industries
One step	-0.6440963	-1.44666***	-28.64005***	-17679.08
Two-step	1.683985***	1.754965***	0.0115814	1.457588
SS	-0.011081	-1.434119***	-2.535244***	0.0477941
FDI	-0.2118817	-1.545412	0.004708	-1.040166***
CP	0.0198497***	0.0226288***	-0.0132586	-0.0178023***
ES	3.609595***	2.998984	4.011365***	7.740971***
Cons	0.74884	2.13412	1.277074	0.2564002
F value	34.62	25.45	20.25	14.28
R2	0.3944	0.6091	0.5536	0.4356

\*, \*\*, and \*\*\* are significant at the levels of 10%, 5%, and 1%, respectively.

moderately pollution industries, and heavy pollution industries and is significant in the moderate and heavy pollution industries and nonsignificant in the slight pollution industries. It shows that state-owned enterprises' vitality has not been further released in the manufacturing industry, and the effect on GTFP is not apparent. The reform of state-owned enterprises should be further strengthened. The development of state-owned enterprises and other ownership enterprises should be coordinated to promote factor flow, market competition, and optimal allocation of resources to promote the improvement of GTFP.

## 5. Conclusions and Prospects

This study uses the entropy method to construct a comprehensive environmental regulation index including wastewater and waste gas discharge fees and also calculated the GTFP of 25 manufacturing industries and subsectors in China from 2003 to 2016 through MaxDEA software. On this basis is an empirical analysis of the impact and heterogeneity of environmental regulations on the manufacturing industry's overall green total factor productivity and subsectors.

The main conclusions are as follows: (1) ERI presented a pattern of progressive decrease going from heavy pollution industries to moderate pollution industries and finally to slight pollution industries; (2) China's overall manufacturing industry GTFP exhibited an increasing trend during the study period; technological progress rather than efficiency promotion was the main contributor to the improvement of industrial GTFP in China; the effects are heterogeneous in GTFP across different types of industries, heavily polluting industries grow relatively fast, while moderate and light polluting industries are regressive; it shows that the economic development model of the heavily pollution industries is gradually shifting to the technology innovation-driven mode, while the moderate and light industries still have room for improvement in the technological innovation, and there is a problem of low technical efficiency; (3) the overall manufacturing industry and the moderately polluting industries have a single threshold, but the threshold is significant on one side. There is a single threshold in the manufacturing industry, and the relationship between environmental regulation and GTFP presents a "U" shape. It means that environmental regulations have a negative inhibitory effect on the growth of the green total factor

productivity in manufacturing and exceeding the critical value; it will positively affect the GTFP of the heavily polluting industry. There is no nonlinear relationship between environmental regulations in lightly polluting industries and green total factor productivity.

Given the above conclusions, this study proposes the following countermeasures.

First, the industry heterogeneity of environmental regulation should be fully considered to implement environmental regulation's optimal intensity, to maintain the intensity of environmental regulation in heavily polluting industries, and to appropriately elevate environmental regulation intensity in moderate and light polluting industries within a reasonable range. The "extensive" environmental regulations adopted by China before are mainly aimed at high pollution, high energy consumption in heavily polluting industries. According to the research results, environmental policies have achieved positive results but still pose a threat to the environment for moderate and slight pollution industries. Therefore, based on the existing environmental regulatory intensity, it is necessary to increase further the medium and light polluting industries' regulatory intensity, stimulating the industry's green innovation power and increasing total factor productivity.

Second, focus on technological innovation while improving technical efficiency. Technical efficiency is an important factor restricting the promotion of green total factor productivity in the manufacturing industry. Therefore, we should pay more attention to the accumulation of experience in the production process, build a management sharing platform, integrate interindustry technical resources, improve the level of comprehensive technical efficiency, play the role of scale economy, and realize the joint development of technological efficiency and technological innovation.

Third, pay attention to the implementation of environmental regulations, control the intensity of environmental regulations to the "right side of the turning point," and prevent the phenomenon of "ineffective regulations." Establish a real-time monitoring mechanism for environmental regulations, conduct regular comprehensive evaluations of the company's implementation effects, and adjust the intensity of regulations based on the results to ensure the rationality and effectiveness of environmental regulations. Simultaneously, the company conducts satisfaction surveys, actively receives feedback, and makes appropriate adjustments based on them to ensure its green production enthusiasm.

This study empirically tests the impact of environmental regulations on green total factor productivity based on measuring the overall and subdivided industry green total factor productivity and its decomposition from 2003 to 2016. However, several limitations of this study should be considered. First, the comprehensive index of wastewater and waste gas discharge fee is adopted to select environmental regulation indicators, which cannot fully reflect the intensity of environmental regulation and has the problem of incomplete consideration. Second, in the decomposition of green total factor productivity, it is only decomposed into technological progress and technical efficiency, which may

cause incomplete analysis of the change of green total factor productivity. Therefore, there may be some errors. Given the above shortcomings, the author believes that comprehensive indicators can be constructed from a more multidimensional perspective when selecting environmental regulation indicators, and the regulatory policies can be quantified into the index system. The limitations of this study need to be considered and improved in future research.

However, there are some limitations in this study that should be pointed out. First, the GTFP can be further divided into several aspects; only decomposing it into technical progress and technical efficiency may not comprehensively analyze for changes in green total factor productivity. Second, more comprehensive indicators can be used to measure environmental regulations intensity, since changes in the intensity of environmental regulations in various industries can be more fully reflected. Therefore, comprehensive indicators can be constructed from more dimensions when selecting environmental regulatory indicators, considering to include the quantification of indicators implemented by the government into the indicator system. GTFP can be decomposed into technical efficiency, technological progress, and scale efficiency to improve the accuracy of problems.

## Data Availability

The original data used to support the findings of this study are available in the China Statistical Yearbook, China Economic Census Yearbook, China Urban Life and Price Yearbook, Development Research Center Of The State Council, China Industry Economy Statistical Yearbook, China Energy Statistical Yearbook, and China Statistical Yearbook on the Environment for the relevant years, as well as from relevant data released by the National Bureau of Statistics.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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