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Research Article

Heterogeneity of Green TFP in China's Logistics Industry under Environmental Constraints

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In the context of China's supply-side structural reform and the concept of green development, we introduce the energy and environmental factors into the analytical framework of the total factor productivity (TFP) of the logistics industry and use the Global Malmquist–Luenberger index method to analyze the evolution trend and heterogeneity of green TFP in the logistics industry of 30 provinces (cities and districts) in China from 2003 to 2017. The results show that, firstly, the green TFP and traditional TFP of China's logistics industry are both on the rise and the absence of energy and environmental factors will lead to the overestimation of TFP of the logistics industry. Whether it is green TFP or traditional TFP, the main source of its growth is technical progress. Secondly, there is obvious regional heterogeneity in green TFP of logistics industry. Under the three regional division standards, the average annual growth rate of green TFP is from high to low in the order of eastern, western, and central regions. Under the eight regional classification standards, the eastern coastal economic zone, the southern coastal zone, the northern coastal zone, the northeast region, the middle reaches of the Yellow River, the southwest region, the middle reaches of the Yangtze River, and the northwest region are in order from high to low. Thirdly, there is obvious interprovincial heterogeneity in green TFP of the logistics industry. The highest growth rate of green TFP is in Zhejiang, followed by Jiangsu and Guangdong, and the slowest growth rate is in Chongqing. The technical progress of logistics industry in most provinces contributes more to the growth of green TFP. Fourthly, the differences of green TFP in the three regions of the east, center, and west are shrinking, which may be σ convergence, but the differences among the three regions are expanding. Compared with the existing literature, this paper applies the measurement framework of green TFP to China's logistics industry and investigates the regional and provincial heterogeneity of green TFP in logistics industry. The conclusions are significant to understand and grasp the heterogeneity of green TFP growth in China's logistics industry under environmental constraints and how to promote the development of green logistics in China.

1. Introduction

Since the beginning of the new century, China's logistics industry has been developing rapidly. The added value of the industry has gradually increased from 616.19 billion yuan in 2000 to 4280.21 billion yuan in 2019, with an average annual growth rate of 10.7% (data source: National Bureau of Statistics). The logistics industry in this paper refers to the transportation, storage, and postal industry in the "National Economic Industry Classification." However, the rapid development of the logistics industry has also brought great negative externalities to the society, and the problems of energy consumption and pollutant emission caused by its economic activities have become increasingly prominent. National statistics show that, in 2017, the terminal energy consumption of the logistics industry reached as high as 421.191 million tons of standard coal, accounting for 9.41% of the total national energy consumption and far exceeding the 4.46% of its added value in GDP. It can be seen that the problem of energy consumption caused by the production activities of China's logistics industry is becoming increasingly serious, and the CO_2 emission caused by it cannot be ignored. In the context of low-carbon economy and green development in the new era, reducing energy consumption and pollutant emission is not only a part of the theme of ecological civilization construction, but also a mandatory requirement of sustainable economic development [1–3]. In fact, China faces enormous pressure on carbon emission reduction. Therefore, China has set the ambitious goal of reducing CO_2 emissions per unit of GDP by 17% in the 12th Five-Year Plan. In order to reduce carbon emissions and achieve the stable economic growth, it is necessary to transform into a "resource-saving and environment-friendly" society. The transformation of economic growth mode from extensive form to intensive form is imminent. In this context, low-carbon economy is increasingly becoming a hotspot in the world. The development of low-carbon economy is in line with China's basic national policy of implementing sustainable development strategy and building a harmonious society. Low-carbon economy has gradually become a "new normal" of China's economic growth. Similar to the situation faced by the industrial industry, the service sector such as the logistics industry should adhere to the concept of green development while stimulating economic growth, to minimize the negative impact of industrial development on resources and environment [4, 5]. How to realize the green growth of logistics industry is a difficult problem for China, and the effective way to solve this problem is to improve the green total factor productivity (green TFP) of logistics industry [6, 7]. Green TFP is an effective indicator to measure the quality of economic growth. Compared with the traditional total factor productivity (TFP) mentioned later, green TFP can scientifically reflect the energy consumption and undesired output of economic activities, which is a better explanation for economic growth performance. Therefore, we introduce the energy and environmental factors into the measurement framework of total factor productivity of logistics industry, measure the green TFP of this industry, and compare and analyze it with the traditional TFP. On this basis, empirical analysis of the regional heterogeneity and interprovincial heterogeneity of the TFP change, in addition to the evolution trend characteristics of regional differences. This study is not only conducive to evaluate the green growth performance of the logistics industry, but also conducive to analyze the regional differences and evolution of the growth of green TFP of the logistics industry. This paper is of great practical significance for China to formulate reasonable development policies and promote the green growth of the logistics industry.

The logistics industry is an important sector of the service industry. However, the current academic research on the total factor productivity of the logistics industry is relatively limited and mainly focuses on its traditional productivity. Jing et al. [8] estimated the traditional TFP of the logistics industry based on C-D production function and found that the TFP index of the logistics industry in different regions is significantly different, which is mainly attributed to the regional differences of input factors such as capital and technology. Chen [9] used the Malmquist index to evaluate the traditional TFP of China's logistics industry, and the results showed that the traditional TFP of the logistics industry decreased by 2.4% annually from 2005 to 2009, and the deterioration of pure technical efficiency was the source of the decline of TFP. At the same time, the traditional TFP growth rate of logistics industry presented the situation of east, middle, and west decreasing in turn. In recent years, some scholars have begun to pay attention to the energy and environmental problems of the logistics industry. For example, Jiang et al. [10] measured the total factor of energy efficiency of the logistics industry by using the super-efficiency nonexpected SBM model. Unfortunately, the current research on green TFP of China's logistics industry is still insufficient. In addition, scholars began to analyze the evolution trend or convergence of TFP in the service sector. For example, Yuan et al. [11] found that the subsectors of producer services show a trend of σ convergence, while absolute β and conditional β convergence exist within sectors. Xiao [12] also analyzed the convergence of traditional and green TFP in the service industry and found that the two types of TFP subsectors of China's service industry had only conditional β convergence but not absolute β convergence characteristics. During this period, scholars also made a preliminary discussion on the TFP convergence of the logistics industry, an important service sector. Studies such as Jing et al. [8] show that there is no σ convergence in the traditional TFP of China's logistics industry.

The previous literature has provided the possibility for this study, but there are still some deficiencies in the following aspects. Firstly, the existing studies are almost all to investigate the changes of traditional TFP in China's logistics industry, and the green TFP measurement research in the logistics industry under the constraints of energy and environment is lacking now, while the logistics industry has generated very serious environmental problems. Therefore, the traditional TFP cannot truly reflect the actual situation of TFP in the current logistics industry. Secondly, there are few literatures about the productivity convergence of logistics, but the TFP of China's logistics varies greatly, so it is necessary to study the evolution trend of its productivity, especially the green TFP. Thirdly, the existing studies have divided China into three regions, east, middle, and west, which cannot fully reflect the differences in the TFP growth of the logistics industry in the subdivided economic zones (such as the eight economic zones). In view of the above problems, the marginal contribution of this study includes the following. Firstly, we use the Global Malmquist–Luenberger index to estimate the green TFP in the logistics industry of 30 provinces (cities and districts) in China from 2003 to 2017 and compare it with the traditional TFP without considering the energy and environment constraints. Secondly, we study the regional and interprovincial heterogeneity of green TFP in logistics industry on the basis of overall analysis. Thirdly, when we analyze the evolution trend of green TFP in logistics industry on the basis of national level, we not only start from the traditional three regions of east, middle, and West, but also further analyze based on the eight economic regions.

2. Measurement Methods, Variables, and Data

2.1. Measurement Methods

2.1.1. Current and Global Production Possibilities Set. First, we need to build a set of production possibilities, called environmental technologies. This production probabilities set includes both "good" outputs such as GDP and "bad" outputs such as CO_2 emissions [13–15]. Suppose that, in different periods $t\,(t=1,\ldots,T)$, the logistics industry in any province $k\,(k=1,\ldots,K)$ uses N kinds of inputs $x=(x_1,\ldots,x_N)\in R_N^+$ to produce M kinds of "good" outputs $y=(y_1,\ldots,y_M)\in R_M^+$ and I kinds of "bad" outputs $b=(b_1,\ldots,b_I)\in R_I^+$. For each input vector x, environmental technologies can produce a combination of expected and unexpected outputs simultaneously (y,b). Based on the hypothesis of Wang et al. [16], we use the data envelopment analysis (DEA) method to convert the current environmental technology into

$$P^t\left(x^t\right)=\left\{\begin{array}{c}\left(y^t,b^t\right):\ \sum_{k=1}^{K} z_k^t y_{km}^t \geq y_{km}^t, \quad m=1,\ldots,M\\ \sum_{k=1}^{K} z_k^t b_{ki}^t = b_{ki}^t, \quad i=1,\ldots,I,\\ \sum_{k=1}^{K} z_k^t x_{kn}^t \leq x_{kn}^t, \quad n=1,\ldots,N,\\ z_k^t \geq 0, \quad k=1,\ldots,K.\end{array}\right\}. \tag{1}$$

In (1), z_k^t is the weight measurement index of the observed values of each cross section and $z_k^t \geq 0$ means the constant returns to scale. When measuring GML index, the current production possibility set $P^t(x^t)$ should be replaced by the global production possibility set $P^G(x)$, which can be expressed as formula (2) with DEA method:

$$P^t\left(x^t\right)=\left\{\begin{array}{c}\left(y^t,b^t\right):\ \sum_{t=1}^{T}\sum_{k=1}^{K} z_k^t y_{km}^t \geq y_{km}^t, \quad m=1,\ldots,M,\\ \sum_{t=1}^{T}\sum_{k=1}^{K} z_k^t b_{ki}^t = b_{ki}^t, \quad i=1,\ldots,I,\\ \sum_{t=1}^{T}\sum_{k=1}^{K} z_k^t x_{kn}^t \leq x_{kn}^t, \quad n=1,\ldots,N,\\ z_k^t \geq 0, \quad k=1,\ldots,K.\end{array}\right\}. \tag{2}$$

2.1.2. SBM Directional Distance Function. According to Fukuyama and Weber [17], the global SBM directional distance function incorporated into CO_2 emissions in the logistics industry is expressed as

$$\begin{aligned} S_V^G\left(x^{t,k'},y^{t,k'},b^{t,k'},g^x,g^y,g^b\right) &= \max_{s^x,s^y,s^b} \frac{1/N\sum_{n=1}^{N}\left(s_n^x/g_n^x\right)+\left(1/(M+I)\right)\left(\sum_{m=1}^{M}\left(s_m^y/g_m^y\right)+\sum_{i=1}^{I}\left(s_i^b/g_i^b\right)\right)}{2},\\ \text{s. t.} \sum_{t=1}^{T}\sum_{k=1}^{K} z_k^t x_{kn}^t + s_n^x &= x_{k'n}^t, \quad \forall n,\\ \sum_{t=1}^{T}\sum_{k=1}^{K} z_k^t y_{km}^t - s_m^y &= y_{k'm}^t, \quad \forall m,\\ \sum_{t=1}^{T}\sum_{k=1}^{K} z_k^t b_{ki}^t + s_i^b &= x_{k'i}^t, \quad \forall i,\\ \sum_{k=1}^{K} z_k^t &= 1, z_k^t \geq 0, \quad \forall k;\\ s_n^x &\geq 0, \quad \forall n,\\ s_m^y &\geq 0, \quad \forall m,\\ s_i^b &\geq 0, \quad \forall i. \end{aligned} \tag{3}$$

In (3), $(x^{t,k^t}, y^{t,k^t}, b^{t,k^t})$ is the input and output vector of logistics industry in province k. (g^x, g^y, g^b) is a direction vector, which represents the decrease of input, the increase of "good" output, and the decrease of "bad" output. (s_n^x, s_m^y, s_i^b) is a relaxation vector reflecting the input and output. If the relaxation vectors of both inputs and outputs are positive numbers greater than 0, it means that the actual input and carbon emission of logistics industry in each province are larger than the input-output value of the boundary, while the actual output value is smaller than the boundary output value. To sum up, s_n^x, s_m^y, s_i^b represents the situation of excessive input, relatively insufficient "good" output, and excessive pollution emissions in the logistics industry of each province [16].

2.1.3. Global Malmquist–Luenberger Productivity Index. After the construction of the SBM directional distance function, we need to construct output-oriented GML index to measure green TFP. According to Oh [18], the GML index can be expressed as

$$\mathrm{GML}_t^{t+1} = \frac{1 + S_C^G\left(x^t, y^t, b^t; g\right)}{1 + S_C^G\left(x^{t+1}, y^{t+1}, b^{t+1}; g\right)}. \quad (4)$$

Furthermore, the GML index can be divided into two parts: the efficiency change index (GEC) and the technology change index (GTC):

$$\mathrm{GML}_t^{t+1} = \frac{1 + S_C^t\left(x^t, y^t, b^t; g\right)}{1 + S_C^{t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}; g\right)} \times \left[\frac{\left(1 + S_C^G\left(x^t, y^t, b^t; g\right)\right)/\left(1 + S_C^t\left(x^t, y^t, b^t; g\right)\right)}{\left(1 + S_C^G\left(x^{t+1}, y^{t+1}, b^{t+1}; g\right)\right)/\left(1 + S_C^{t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}; g\right)\right)}\right]. \quad (5)$$

When the GML_t^{t+1} (GEC or GTC) index is greater than 1, the green TFP (technical efficiency or technical progress) of the logistics industry shows an increasing trend. When the index is equal to (or less than) 1, the green TFP (technical efficiency or technical progress) remains unchanged (or decreases).

2.1.4. Global Malmquist Productivity Index. In order to more intuitively reflect the constraints of environmental factors such as energy and pollution emissions on China's logistics industry, we also estimate the traditional TFP of this industry and apply the DEA-Malmquist productivity index method (Global Malmquist index method) based on the Global technology and compare it with the GML index. The Global Malmquist index can be expressed as

$$\mathrm{GM}\left(y^{t+1}, x^{t+1}, y^t, x^t\right) = \frac{D^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D^t\left(x^t, y^t\right)} \left[\left(\frac{D^g\left(x^{t+1}, y^{t+1}\right)}{D^{t+1}\left(x^{t+1}, y^{t+1}\right)} \times \frac{D^t\left(x^t, y^t\right)}{D^g\left(x^t, y^t\right)}\right)\right] = \mathrm{EC} \times \mathrm{TC}. \quad (6)$$

For the reelated materials of the decomposition methods, refer to Ang [19], Ang and Liu [20], Zhang et al. [21], Zhang et al. [22], Wang et al. [23], and Zhang et al. [24].

2.2. Variable Selection and Data Sources. We collected the input-output data of the logistics industry from 2003 to 2017 in 30 provinces, autonomous regions, and municipalities in China (Tibet is not included as a sample due to a large amount of missing data). We took capital, labor, and energy as input indicators and the added value and CO_2 emissions as "good" output and "bad" output, respectively. The data are collected from the website of the National Bureau of Statistics, China Statistical Yearbook, and China Energy Statistical Yearbook.

2.2.1. Logistics Output: "Good Output". Learning from Chen [9], we regard the added value of the logistics industry as a "good" output and use the added value index of the tertiary industry of each province to convert it into real value (2003 as the base period).

2.2.2. Logistics Output: "Bad Output". At present, there is no uniform definition of "bad" output in the academic circles, and the "bad" output adopted in measuring green TFP is also different. We measure a total factor green productivity index considering CO_2 emissions, so we take CO_2 emissions as "bad" output. CO_2 emissions of logistics industry can be calculated by the following formula:

$$CO_2 = \sum_{i=1}^{8} CO_{2,i} = \sum_{i=1}^{8} E_i \times \mathrm{NCV}_i \times \mathrm{CEF} \times \mathrm{COF}_i \times \frac{44}{12}. \quad (7)$$

Among them, i is the type of final energy consumption (fossil fuels); E_i represents the consumption of type i fossil fuels. NCV_i represents the low calorific value of type i fossil fuels. CEF_i is the carbon content of type i fossil fuels. COF_i is the oxidation rate of type i fossil fuels. Accordingly, the carbon emission coefficient calculation formula of various fossil fuels can be obtained: carbon emission coefficient = low calorific value × carbon content × oxidation rate. The carbon emission coefficients for each type of fossil fuels are shown in Table 1.

Table 1: The carbon emission coefficients for each type of fossil fuels.

Fossil fuel type	Low calorific value	Carbon content	Oxidation rate	Carbon emission coefficient
The raw coal	20908	26.4	0.94	0.5183
Coke	28435	29.5	0.93	0.7801
Crude oil	41816	20.1	0.98	0.8237
Gasoline	43070	18.9	0.98	0.7978
Diesel	42652	20.2	0.98	0.8443
Fuel oil	41816	21.1	0.98	0.8647
Natural gas	38931	15.3	0.99	0.5897
Kerosene	43070	19.5	0.98	0.8231

Compiled according to China Energy Statistics Yearbook.

2.2.3. Capital Investment. We use the capital stock of logistics industry in each province to express the capital investment and use the perpetual inventory method to estimate it:

$$K_{it} = K_{i,t-1}\left(1 - \delta_{i,t}\right) + \frac{I_{it}}{P_{it}}. \quad (8)$$

In (8), K_{it} and $K_{i,t-1}$, $I_{i,t}$, respectively, represent the capital stock of t year and $t-1$ year and the nominal fixed capital investment of t year of the logistics industry in province i. $\delta_{i,t}$ is the capital depreciation rate, and P_{it} is the price indices of fixed assets investment. The base year capital stock adopts the steady-state method proposed by Harberger [25]. Based on the assumption that "the ratio of capital output in steady state is constant or the growth rate of physical capital is equal to the growth rate of total output," the estimation formula of the physical capital stock in the base year (2003) is deduced:

$$K_{i,t-1} = \frac{I_{i,t}}{\left(g_{i,t} + \delta_{i,t}\right)}. \quad (9)$$

This method has a clear and reasonable economic basis, so it has been applied widely, such as Lee and Hong [26], Barro and Lee [27], and Wu [28]. Meanwhile, according to Harberger's suggestion [25], $g_{i,t}$ is expressed in terms of the average annual growth rate of the real added value of the logistics industry in the sample period to control the impact of the economic cycle fluctuations and short-term output fluctuations. Nominal fixed capital investment $I_{i,t}$ represented fixed assets investment of the whole society. Subject to limited data, P_{it} is represented by the industry-wide fixed asset investment price index. In accordance with the existing studies, the depreciation rate $\delta_{i,t}$ was set at 6%, but the 4% and 9.6% depreciation rates were also adopted for robustness tests.

2.2.4. Labor Input. Theoretically, labor input should comprehensively consider factors such as labor size, labor time, and labor quality (efficiency), but the selection of indicators in actual research will ultimately depend on the availability of data. In fact, some scholars have considered the quality of labor input in their studies. For example, Fox and Smeets proposed four methods to measure the labor quality when using Danish enterprise level data to examine whether the input quality affects the enterprise productivity dispersion [29]. Zheng et al. adjusted the quality of labor by using the number of years of education per worker while examining China's growth model [30]. In order to consider the impact of the labor input quality on results, we also try to adjust the quality of the number of employees of the logistics industry in each region. Unfortunately, the relevant data on the quality adjustment of labor input cannot be accessed through the existing statistical data, no matter which method is adopted. Therefore, the "number of employees at the end of the year" of logistics industry is selected as the proxy variable of labor input index.

2.2.5. The Energy Input. As energy resource is an intermediate input, the traditional TFP of logistics industry has not been regarded as an input variable in the existing research. However, energy consumption is in fact the key factor to undesirable outputs such as CO_2 emissions [16]. Based on this, we also introduced energy into the green TFP measurement system and adopted the terminal energy consumption of the logistics industry in each province as the measurement index of this variable. The basic data were taken from the China Energy Statistics Yearbook.

Table 2 reports the descriptive statistical results for each variable.

3. Temporal Characteristics and Heterogeneity Analysis of Green TFP in Logistics Industry

3.1. Overall Temporal Characteristics. Table 3 reports the TFP index and its decomposition results of China's logistics industry. Without the introduction of energy and environmental factors, the average annual growth rate of TFP (TFPC) in China's logistics industry from 2003 to 2017 was 2.22%, in which the average annual improvement rate of technical progress (TPC) was 2.85%, while the average annual decrease rate of technical efficiency (TEC) was 0.61%. After the introduction of energy and environment factors, the average annual growth rate of green TFP in the logistics industry dropped to 1.93%, in which the average annual growth rate of technical progress declined to 2.1%, and the average annual growth rate of technical efficiency was still negative, dropping by 0.16%. Comparing the two sets of data, we can find that the growth rate of TFP in logistics industry and the growth rate of technical progress under the constraints of energy and environment are 0.29 and 0.75 percentage points lower than those without energy and

Table 2: Descriptive statistical results of input-output variables.

Variable types	The variable name	Unit	Sample size	Mean	Median	Standard deviation	Minimum	Maximum
"Good" output	Real added value	One hundred million yuan	450	880.08	665.89	773.76	38.91	5141.41
"Bad" output	CO_2 emissions	Ten thousand tons of	450	1679.39	1377.87	1268.89	90.03	7958.30
Input	The number of labor	Ten thousand people	450	23.52	21.44	14.22	2.81	85.40
	The capital stock	One hundred million yuan	450	3614.44	2813.75	2911.78	229.66	16844.09
	Energy consumption	Ten thousand tons of	450	942.29	765.91	645.80	51.05	3495.89

Table 3: TFP index of logistics industry and its decomposition (2003–2017).

Year	Energy and environmental factors are not introduced			Introduce energy and environmental factors		
	TEC	TPC	TFPC	TEC	TPC	TFPC
2004	1.0076	1.0290	1.0368	0.9839	1.0057	0.9896
2005	1.0105	1.0350	1.0459	1.0193	1.0179	1.0376
2006	0.9930	1.0418	1.0344	1.0035	1.0266	1.0301
2007	0.9963	1.0431	1.0392	1.0079	1.0297	1.0379
2008	1.0178	1.0081	1.0261	0.9879	1.0270	1.0146
2009	0.9813	1.0233	1.0042	0.9824	1.0572	1.0386
2010	0.9793	1.0362	1.0148	0.9900	1.0106	1.0004
2011	0.9897	1.0439	1.0332	0.9935	1.0138	1.0072
2012	0.9925	1.0403	1.0325	1.0016	1.0051	1.0067
2013	0.9347	1.0000	0.9347	0.9941	1.0008	0.9949
2014	1.0017	1.0000	1.0017	1.0196	1.0070	1.0267
2015	1.0212	1.0000	1.0212	0.9979	1.0274	1.0252
2016	1.0314	1.0116	1.0434	1.0023	1.0386	1.0410
2017	0.9624	1.0897	1.0487	0.9944	1.0277	1.0220
Mean	0.9939	1.0285	1.0222	0.9984	1.0210	1.0193

environment factors, respectively, while the growth rate of technical efficiency increased by 0.45 percentage points after the introduction of energy and environmental factors. However, the increase rate of technical efficiency cannot offset the negative impact of the decline rate of technical progress on TFP growth rate, and finally the Green TFP growth rate declined. It can be seen that China's logistics industry TFP estimation is influenced by energy and environment factors, and neglecting energy and environment factors will lead to an overestimation of TFP growth rate and technical progress growth rate.

From 2003 to 2017, green TFP and traditional TFP in China's logistics industry have positive growth trend in most years. Further analysis shows that the green TFP of the logistics industry increased negatively in 2004 and remained positive after 2005 (except for a slight decrease of 0.51% in 2013), which may be caused by the stricter policy of energy saving and consumption reduction during the 11th Five-Year Plan period and the 12th Five-Year Plan period. Both the 11th Five-Year Plan and the 12th Five-Year Plan emphasize the need to vigorously promote energy conservation and reduce consumption and reduce pollutant emissions. According to the outline of the 11th Five-Year Plan, China's total emission of major pollutants will be cut by 10% on the 2005 level. In 2008, both TFP indexes showed a significant decline, indicating that the logistics industry has also been negatively impacted by the financial crisis [31]. From 2013 to 2015, the green TFP index was higher than the traditional TFP index. Combined with the research of Fare et al. [32], it shows that the reduction rate of "bad" output in China's logistics industry exceeds the growth rate of "good" output, and the environmental management efficiency of China's logistics industry has been improved, moving towards the direction of green growth.

According to the decomposition in terms of TFP index, the technical progress index in both cases is greater than 1, while the technical efficiency index is less than 1 in most years, which means that the technical progress of logistics industry shows a continuous rising trend, but the technical efficiency fails to show an obvious growth pattern. It can be seen that, on the whole, technical progress is the main source of TFP growth in China's logistics industry, whether or not energy and environmental factors are introduced. This shows that China's logistics industry has not fully tapped the potential of existing resources and technologies, and there is still a great room to promote the performance growth of the logistics industry through efficiency improvement.

3.2. Investigation of Regional Heterogeneity. In order to investigate the regional heterogeneity of TFP change in logistics industry, respectively, the country is divided into three areas (the east, central, and west) and the eight economic zones (the northeast economic zone, the northern coastal economic zone, the eastern coastal economic zone, the southern coastal economic zone, economic zone in the middle reaches of the Yellow River, the Yangtze River economic zone, the southwest economic zone, and the northwest economic zone) standard based on the division of the National Development and Reform Commission: the country is divided into the eastern region (including 11 provinces and cities, namely, Beijing, Shanghai, Tianjin, Hebei, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan, and Liaoning), the central region (including eight provinces, namely, Shanxi, Henan, Anhui, Jiangxi, Hubei, Hunan, Heilongjiang, and Jilin), and west (including 11 provinces, Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang). At the same time, we drew lessons from the criteria in the report strategies and Policies for Coordinated Regional Development released by the Development Research Center of the State Council to the national integrated into the northeast economic zone (including Heilongjiang, Liaoning, and Jilin), the northern coastal economic zone (including Shandong, Hebei, Beijing, and Tianjin), east coastal economic zone (including Jiangsu, Zhejiang, and Shanghai), southern coastal economic zone (including Guangdong, Fujian, and Hainan), economic zone in the middle reaches of the Yellow River (including Inner Mongolia, Henan, Shanxi, and Shaanxi), economic zone in the middle reach of Yangtze River (including Anhui, Jiangxi, Hunan, and Hubei), southwest economic zone (including Guangxi, Sichuan, Chongqing, Guizhou, and Yunnan), and the northwest zone (including Qinghai, Gansu, Ningxia, and Xinjiang). Because of the availability of data, the above two categories do not include Xizang. It can be seen from Table 4 that the two types of TFP indexes and their decomposition in China's logistics industry have great regional differences.

Under the three regional classification standards, without the introduction of energy and environmental factors, the regional ranking of average annual growth rate of TFP in the logistics industry from high to low is in the western, eastern, and central regions. After the introduction of energy and environmental factors, it follows the eastern, western, and central regions. The growth rate of green TFP in the eastern region is higher than that in the central and western regions, which is closely related to the relatively developed economy and natural geographical advantages of the eastern region. In addition, the eastern region pays more attention to the introduction of talents and invests more in the research and development of clean technology and environmental protection technology [31]. The growth rate of green TFP in central region is lower than that in western region, mainly due to the lower growth rate of technical progress in central region. The relative rank of TFP index (TFPR) in each region will be affected by energy and environment factors, so failure to take energy and environment factors into account will misjudge the relative level of green growth performance in each region. In addition, regardless of the introduction of energy and environmental factors, technical progress is the main driving factor for the growth of TFP in the logistics industry in each region, and the technical efficiency has a negative impact on the growth of TFP.

Under the eight regional classification standards, when energy and environmental factors are not taken into account, the regional ranking of the average annual growth rate of TFP in the logistics industry from high to low is the eastern coastal economic zone, the southwest region, the middle reaches of the Yangtze River, the middle reaches of the Yellow River, the northwest region, the southern coastal region, the northern coastal region, and the northeast economic zone. After considering the energy and environment factors, the TFP growth rate of the eastern coastal economic zone still ranks the first, followed by the southern coastal region, the northern coastal region, the northeast region, the middle reaches of the Yellow River, the southwest region, the middle reaches of the Yangtze River, and the northwest region. It can be seen that, after the introduction of energy and environment factors, the ranking of TFP of various economic zones has changed again. The logistics industry in the southwest region, the middle reach of the Yangtze River, and the northwest region is more constrained by energy and environmental factors, and the TFP index and its ranking drop significantly. The traditional TFP index in most areas is larger than the green TFP index, which again indicates that if energy and environmental factors are ignored, the measurement results will deviate from the actual situation. In addition, regardless of the introduction of energy and environmental factors, the main driving factor of TFP growth in each region is technical progress, which is consistent with the research conclusions of the three regions.

3.3. Investigation of Interprovincial Heterogeneity. Table 5 reports the TFP index and its decomposition results of logistics industry in various provinces of China. It can be found that the TFP index of China's logistics industry has great interprovincial differences. Without the introduction of energy and environmental factors, the fastest growth rate of TFP was in Yunnan province, followed by Zhejiang and Inner Mongolia, and the lowest growth rate was in Liaoning (with an average annual decrease of 2.67%). After the introduction of energy and environment factors, the province with the highest TFP growth rate was Zhejiang, followed by Jiangsu and Guangdong, and the lowest growth rate was Chongqing (with an average annual decrease of 0.46%). From the numerical comparison of TFP index, after the introduction of energy and environment factors, there are 15 provinces (Beijing, Tianjin, Shanxi, Liaoning, Jilin, Heilongjiang, Shanghai, Hubei, Guangdong, Guangxi, Hainan, Chongqing, Shaanxi, Gansu, and Ningxia) of TFP index which rose, the TFP index rank also has some promotion mostly (except in Guangxi, Ningxia, and Chongqing).

From the decomposition of the TFP index, the technical progress of logistics industry in most provinces contributes more to the TFP index. When the energy and

Table 4: Mean of national and regional TFP index and its decomposition terms (2003–2017).

Province	Energy and environmental factors are not introduced			Introduce energy and environmental factors		
	TEC	TPC	TFPC	TEC	TPC	TFPC
National average	0.9939	1.0285	1.0222	0.9984	1.0210	1.0193
Eastern	0.9938	1.0283	1.0220	1.0037	1.0226	1.0264
Central	0.9979	1.0148	1.0127	0.9984	1.0145	1.0128
Western	0.9895	1.0379	1.0270	0.9918	1.0235	1.0151
Northeast	0.9818	1.0059	0.9876	1.0059	1.0124	1.0184
Northern coast	0.9932	1.0205	1.0135	1.0013	1.0211	1.0225
East coast	1.0122	1.0431	1.0559	1.0093	1.0308	1.0403
Southern coast	0.9847	1.0323	1.0165	1.0050	1.0210	1.0261
Mid- Yellow River	1.0022	1.0228	1.0250	0.9988	1.0178	1.0166
Mid-Yangtze River	1.0054	1.0229	1.0284	0.9968	1.0175	1.0143
Southwest	0.9846	1.0446	1.0285	0.9901	1.0247	1.0146
Northwest	0.9893	1.0310	1.0199	0.9883	1.0220	1.0100

Table 5: TFP Index and its decomposition of logistics industry in all provinces of China (2003–2017).

Province	Energy and environmental factors are not introduced				Introduce energy and environmental factors			
	TEC	TPC	TFPC	TFPR	TEC	TPC	TFPC	TFPR
Beijing	0.9764	1.0020	0.9784	28	1.0000	1.0173	1.0173	17
Tianjin	1.0063	1.0183	1.0247	13	1.0147	1.0201	1.0350	4
Hebei	1.0000	1.0442	1.0442	9	1.0000	1.0321	1.0321	7
Shanxi	0.9904	1.0048	0.9952	26	1.0001	1.0103	1.0104	23
Inner Mongolia	1.0134	1.0594	1.0736	3	1.0017	1.0308	1.0325	6
Liaoning	0.9697	1.0036	0.9733	30	0.9926	1.0092	1.0018	28
Jilin	0.9876	1.0115	0.9990	23	1.0069	1.0156	1.0226	12
Heilongjiang	0.9882	1.0026	0.9908	27	1.0185	1.0123	1.0310	8
Shanghai	1.0221	1.0096	1.0319	11	1.0173	1.0156	1.0332	5
Jiangsu	1.0193	1.0402	1.0602	5	1.0056	1.0309	1.0368	2
Zhejiang	0.9956	1.0808	1.0760	2	1.0049	1.0459	1.0511	1
Anhui	0.9924	1.0194	1.0117	17	0.9913	1.0201	1.0112	20
Fujian	0.9831	1.0715	1.0534	7	1.0000	1.0306	1.0306	9
Jiangxi	1.0183	1.0376	1.0567	6	0.9982	1.0192	1.0174	16
Shandong	0.9901	1.0181	1.0081	18	0.9908	1.0152	1.0058	26
Henan	1.0138	1.0162	1.0302	12	0.9890	1.0137	1.0025	27
Hubei	0.9939	1.0118	1.0056	20	1.0044	1.0130	1.0175	15
Hunan	1.0174	1.0228	1.0406	10	0.9934	1.0179	1.0111	21
Guangdong	0.9862	1.0124	0.9984	25	1.0130	1.0220	1.0353	3
Guangxi	0.9803	1.0222	1.0021	22	0.9935	1.0176	1.0111	22
Hainan	0.9848	1.0141	0.9987	24	1.0021	1.0104	1.0125	19
Chongqing	0.9606	1.0164	0.9764	29	0.9777	1.0181	0.9954	30
Sichuan	0.9757	1.0421	1.0168	15	0.9854	1.0225	1.0076	24
Guizhou	1.0058	1.0585	1.0647	4	0.9982	1.0316	1.0298	10
Yunnan	1.0013	1.0851	1.0865	1	0.9959	1.0336	1.0294	11
Shaanxi	0.9915	1.0115	1.0029	21	1.0044	1.0166	1.0211	13
Gansu	0.9976	1.0083	1.0059	19	1.0017	1.0140	1.0156	18
Qinghai	0.9747	1.0714	1.0443	8	0.9638	1.0364	0.9989	29
Ningxia	0.9909	1.0270	1.0176	14	0.9934	1.0250	1.0182	14
Xinjiang	0.9941	1.0184	1.0123	16	0.9948	1.0128	1.0075	25
Mean	0.9939	1.0285	1.0222		0.9984	1.0210	1.0193	

environmental factors are not taken into account, only Shanghai's growth rate of technical efficiency is higher than that of technical progress. After accounting for energy and environmental factors, the number of provinces where technical efficiency has grown faster than technical progress has risen to two, namely, Shanghai and Heilongjiang. This shows that, in the vast majority of provinces, through improving technical efficiency to further enhance the logistics industry productivity, there is a large space.

Table 6: Robustness tests of two kinds of TFP index measurement results.

Depreciation rate (%)	Index indicator	Energy and environmental factors are not introduced		Introduce energy and environmental factors	
		Method 1	Method 2	Method 1	Method 2
6.0	EC	0.9939	0.9936	0.9984	0.9984
	TC	1.0285	1.0271	1.0210	1.0206
	TFPC	1.0222	1.0205	1.0193	1.0190
4.0	EC	0.9943	0.9939	0.9984	0.9984
	TC	1.0273	1.0261	1.0208	1.0205
	TFPC	1.0214	1.0198	1.0192	1.0189
9.6	EC	0.9936	0.9932	0.9979	0.9984
	TC	1.0302	1.0287	1.0215	1.0209
	TFPC	1.0237	1.0218	1.0194	1.0192

3.4. Robustness Test of TFP Results. To investigate the influence of the capital depreciation rate and base year capital stock on the calculation results, we make a robust analysis by changing the capital depreciation rate and the estimation method of the base year capital stock. The specific measures are as follows: first, keeping the depreciation rate unchanged (6%) and adopting the base year capital stock estimation method of Hall and Jones [33] (Method 2 in Table 6); secondly, keeping the estimation method of the base year capital stock unchanged (method 1 in Table 6), and setting the depreciation rate as 4% in Wu [28] and 9.6% in Zhang [34], respectively; finally, changing the depreciation rate and the estimation method of the base year capital stock simultaneously. The measurement results of all combinations are listed in Table 6. Due to space limitation, only the average results for various combinations are given here. According to the average value and the specific results of each province and year, after changing the capital depreciation rate and the estimation method of the base year capital stock, the results only change slightly in the specific value, but these changes do not change the basic conclusion of this paper. Therefore, the results of this paper are robust.

3.5. Analysis of the Evolution Trend of Regional Differences. Since green TFP can better reflect the green growth performance of the logistics industry, we only analyze the regional variation trend of green TFP. Referring to the practice of Rezitis [35] and Teng et al. [4], we use the variable coefficient to measure the degree of regional difference, and the formula is as follows:

$$S = \sqrt{\frac{\left[\sum_i \left(\mathrm{TFP}_{it} - tfp_t\right)^2\right]}{N}},\quad V = \frac{S}{tfp_t}, \tag{10}$$

where S represents the standard deviation, TFP_{it} represents the green TFP of the logistics industry of i province in the t year, tfp_t represents the average value of the t year green TFP of the sample provinces, N represents the number of provinces, and V represents the variation coefficient of TFP.

Figure 1 depicts the evolution characteristics of regional difference degree of green TFP index of logistics industry in the whole sample and the three regions of east, middle, and west. It can be found that the regional difference degree of green TFP in the national logistics industry generally decreases with the passage of time, which means that the green TFP in the national logistics industry may have σ convergence on the whole. In terms of the evolution of the internal differences of green TFP in the three regions, the differences of green TFP in the eastern, central, and western regions show a decreasing trend on the whole, and the evolution trajectory is consistent with the national samples, indicating that the differences of green TFP in each region is shrinking, and there may also exist a σ convergence. The mean value of the variation coefficient from high to low is in western, eastern, and central regions. From the perspective of interregional differences, the difference of variation coefficient among the three regions in 2017 is greater than that in 2004, indicating that the interregional differences are expanding.

According to the variation of the degree of difference of green TFP in the eight economic zones (Figure 2), similar to the situation in the whole sample and the eastern, central, and western regions, the variation coefficient of most economic zones also shows a decreasing trend, and there may be a σ convergence. Specifically, in 2017, the variation coefficients of the eastern coast, the southern coast, the middle reaches of Yangtze River, the middle reaches of the Yellow River, the southwest, and the northwest area relative to the variation coefficient of 2004 decreased by 81.7%, 89.2%, 85.5%, 76.9%, 84.5%, and 10%. Thus, the largest decline was in the southern coastal areas, while the smallest decline was in the northwest region, indicating that the differences of green TFP index among the provinces in these economic zones are narrowing. In 2017, the variation coefficient in northeast China and the northern coastal economic zone increased by 11.3% and 286.3%, respectively, compared with 2004, indicating that the internal differences between the two regions are continuously expanding. Comparing with the mean value of the variation coefficient of green TFP, we can find that the difference of green TFP among the provinces in the middle reaches of the Yellow River economic zone is the greatest.

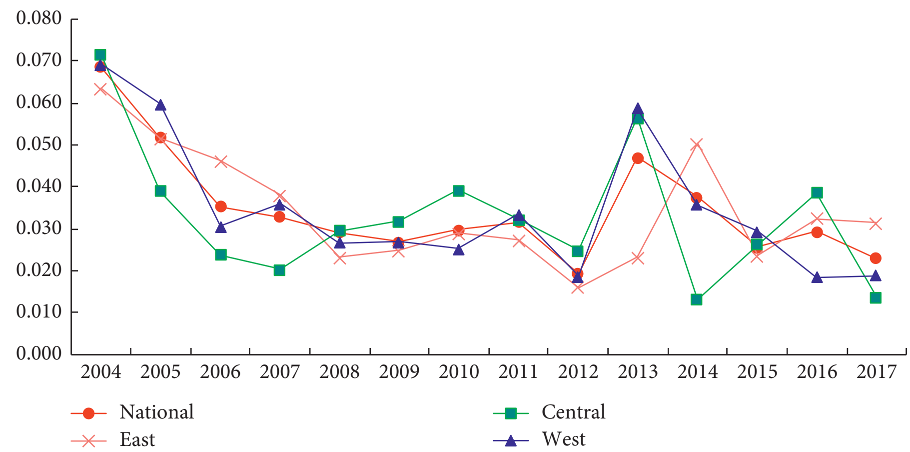

Figure 1: The change trend of regional differences in green TFP of logistics industry in China and three regions.

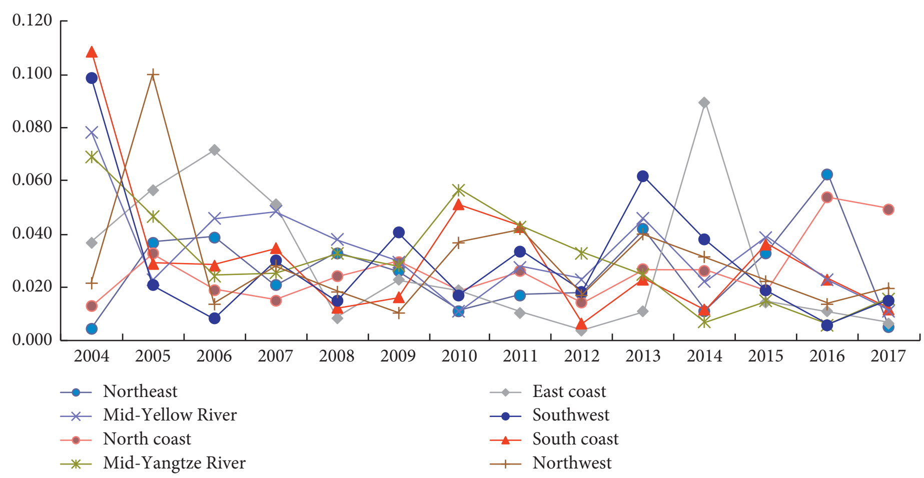

Figure 2: Variation trend of regional differences in green TFP of logistics industry in the eight economic zones.

4. Conclusions

This paper introduces the energy and environmental factors into the TFP measurement framework of China's logistics industry and compares it with the traditional TFP without considering energy and environmental factors. The main conclusions are as follows.

First, the green TFP and traditional TFP of China's logistics industry are both on the rise, with an average annual growth rate of 1.93% and 2.22%, respectively. It can be seen that the absence of energy and environmental factors will lead to the overestimation of TFP of the logistics industry, and energy and environmental factors will have a significant impact on the TFP estimation of the logistics industry. Whether green TFP or traditional TFP, the main source of its growth is technical progress, and there is still much room for further enhancing the TFP in the logistics industry through the improvement of technical efficiency.

Second, the growth of green TFP in China's logistics industry has great regional heterogeneity. Under the three regional division standards, the average annual growth rate of green TFP is from high to low in the eastern, western, and central regions. Under the eight regional classification standards, the average annual growth rate of green TFP is successively from high to low in the eastern coastal economic zone, the southern coastal zone, the northern coastal zone, the northeast region, the middle reaches of the Yellow River, the southwest region, middle reaches of the Yangtze River, and the northwest region. The logistics industry in the southwest region, the middle reach of the Yangtze River, and the northwest region is more constrained by energy and environmental factors, and its TFP index and ranking decline significantly after considering energy and environmental factors.

Third, the growth of green TFP in China's logistics industry has great interprovincial heterogeneity. The province with the highest growth rate of green TFP is Zhejiang, followed by Jiangsu and Guangdong, and the slowest growth rate is Chongqing, with an average annual decrease of 0.46%. From the perspective of the decomposition term of the green TFP index, the technical progress of the logistics industry in most provinces contributes more to the green TFP index, indicating that there is a large space for the vast majority of provinces to further improve the green productivity of logistics industry by improving the technical efficiency.

Fourth, from the evolution trend of the internal differences of green TFP in the logistics industry of the three regions, the regional differences of green TFP in the east, the middle, and the west are generally decreasing, and the evolution trajectory is consistent with the national samples, indicating that the differences of green TFP in the logistics industry within each region are shrinking, and there may be σ convergence. However, from the perspective of the differences among the three regions, the difference of the variation coefficient among the three regions in 2017 is greater than that in 2004, indicating that the differences among the three regions are expanding. From the results of the eight economic regions, the variation coefficients of most economic regions also show a downward trend.

Based on the above conclusions, the main implications are as follows: firstly, in the context of China's supply-side structural reforms and the concept of green development, we should pay more attention to the role of logistics industry TFP (especially green TFP) in the green growth and sustainable development of the logistics industry, to promote the growth pattern of China's logistics industry from factor-driven to green TFP-drive, to further promote the development of green logistics. Secondly, while maintaining the contribution level of technical progress to TFP of logistics industry, we can further focus on improving technical efficiency of logistics industry to promote the growth of green TFP. Thirdly, the government can formulate regional difference policies to promote the growth of green TFP and the development of green logistics according to the factor endowments of different regions. By promoting the introduction, R&D, and application of green and low-carbon technologies, the government can strengthen the regional exchanges and cooperation on green technologies to gradually reduce the regional differences in the growth of green TFP in the logistics industry. Fourthly, the efficiency of R&D innovation in transforming scientific and technological achievements into final productivity is low due to some problems in the use of R&D expenditure in logistics industry in China. Therefore, it is necessary to pay attention to the structure of R&D investment in the use of logistics R&D expenses to prevent the phenomenon of industry university research disconnection in the future. Fifthly, under the constraints of energy and environmental factors, in order to improve the green TFP of China's logistics industry, how to achieve CO_2 emission reduction without damaging economic benefits needs to be paid more attention. This requires that the proportion of high carbon energy consumption must be reduced as far as possible, such as vigorously developing new energy, improving energy utilization efficiency, and product innovation, so as to fundamentally promote the green TFP growth of China's logistics industry. Finally, it should be pointed out that although we have carefully studied the change trend of green productivity and the interprovincial and regional differences in China's logistics industry by using existing methods, due to careful consideration, deeper reasons and policy interpretation are yet to be further analyzed in the future.

Data Availability

The data that support the findings of this study are openly available in China Statistical Yearbook and China Energy Statistical Yearbook at http://www.stats.gov.cn/tjsj.

Conflicts of Interest

The authors declare no conflicts of interest.

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