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Research Article

Industrial Structure, R&D Staff, and Green Total Factor Productivity of China: Evidence from the Low-Carbon Pilot Cities

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Using data of 26 cities in China from 2004 to 2017, the green total factor productivity is investigated by the SMM-GML method. The corresponding empirical analysis is conducted with the DID model. This paper investigates the relation between low-carbon pilot policy (LCC) and green total factor productivity and discusses the mediating effect of industrial structure and the number of R&D staff (RDS). First, we find that LCC has a significant effect on pilot cities' GTFP. And, it also promotes GTFP via industrial structure. Second, LCC can improve industrial structure optimization and realization, and industrial structure realization affects GTFP significantly, while optimization cannot. Third, LCC cannot attract more RDS, and RDS harms local GDFP because of talent misallocation. At last, the rate of GTFP presented different upward trends in the order of non-eastern cities and eastern cities. The effect of LCC on GTFP is significant in non-eastern cities, but not eastern ones, which clearly demonstrates the imbalanced development of the green economy. Therefore, the governments of eastern and non-eastern regions should adopt different measures based on local conditions in industrial structure transformation and recruitment and strengthen environmental regulations to make the effect of the low-carbon policy lasting and promote GTFP growth balance in all regions.

1. Introduction

United Nations Secretary-General Guterres and World Meteorological Organization Secretary-General Taras held a press conference on September 9 and released a new report on global climate change in 2020. The report shows that in the first half of 2020, the greenhouse gas concentration has exceeded 410 parts per million, the highest level in three million years, and this number is still rising. And, according to the Global Carbon Budget Report 2019, in 2018, the main contributors to global CO_2 emissions were China (28%), the United States (15%), the 28 EU countries (9%), and India (7%). The growth rates of China, the United States, the 28 EU countries, and India in 2019 are predicted to be 2.6% (0.7%~4.4%), −1.7% (−3.7%~0.3%), −1.7% (−3.4%~0.1%), and 1.8% (0.7%~3.7%). China is clearly an important country responsible for reducing carbon emissions. According to the "China's Policies and Actions to Address Climate Change 2019 Annual Report," the national carbon emission intensity in 2018 has been reduced by 45.8% compared with 2005, and it has reached the international commitment of reducing carbon emission intensity by 40% to 45% in 2020 compared with 2005.

The traditional economic growth model of China relies heavily on factor input, which has caused resource exhaustion and environmental deterioration and is difficult for economic development sustainable. In the process of carbon emission reduction, has it promoted green economic growth? The "green growth," a term rarely heard before 2008, has burst onto the international policy scene over recent years [1]. The "green growth" and low-carbon economy is a sustainable economic development model, which helps the transformation of economic development from relying on high-carbon emissions to low-carbon emissions [2]. The Chinese government has issued a series of policies to reduce carbon emissions and promote economic transformation, such as the low-carbon pilot policy. China has launched the first 8 low-carbon pilot cities in 2010, released the second batch of pilot cities in 2012 which include 24 cities, and the third batch was launched in 2017. Currently, there are 67 low-carbon pilot cities nationwide. It has been nearly 10 years passed since the first pilot cities had been launched. Does the low-carbon policy contribute to the green growth of these cities?

An appropriate measure of green growth is essential for assessing the effectiveness of the reform conducted by the government. Productivity is one of the most important factors to measure economic growth and quality of life improvement. But productivity is not directly observable; many researchers focus on estimating the total factor productivity (TFP). Solow [3] indicates that the extensive growth pattern based on the continued expansion of inputs was unsustainable and that only the intensive growth pattern, which relied on TFP growth, was sustainable in the long run. However, traditional TFP evaluations fail to take resource and environmental factors into consideration, which can lead to distorted TFP implications [4]. Especially, the concept of Green Total Factor Productivity (GTFP) came out; it is drawn from the integration of two important developmental strategies: productivity improvement and environmental protection [5]. This means the GTFP determines the economic development pattern's transformation which in turn will affect the sustainable development of China's economy. Therefore, the GTFP is an appropriate index to evaluate the policies' effectiveness, and we use the SBM-GML method to measure GTFP. The Chinese city-level data collected by the National Bureau of Statistics and Provincial Statistics Bureau of China from 2004 to 2017 are considered. Considering its incompletion, the data of 26 cities are selected and used for our modeling. Then, another question arises. How the low-carbon policy affects GTFP.

Many researchers pay their attention to industrial structure [6]. In this paper, we decompose the effect of industrial structure into two parts—industrial structure upgrading effect and industrial structure transformation effect—and use industrial structure optimization (SO) and industrial structure rationalization (SR) to measure these two indexes [7]. Because environmental regulations significantly facilitate local industrial structure upgrading [8] and industrial development is one of the key drivers of economic growth. So, we believe that the industrial structure is an important mediating variable between low-carbon policy and GTFP. The proposed DID-based empirical analysis clearly presents the evidence that the low-carbon pilot policy promotes the growth of GTFP through rationalization of the industrial structure.

Besides the industrial structure, the number of employed R&D personnel (RDS) also affects economic development. According to the "National Low-Carbon Provinces and Low-Carbon City Pilot Work Notice," local governments should "strengthen the building of low-carbon development capacity and talent team." This means from the perspective of city governments, to improve the low-carbon development capabilities in the region, they should pay attention to the accumulation of talents in related fields when low-carbon pilot policy is implemented. Noticing that the labor with higher skills can improve productivity [9], we can rationally presume the low-carbon policy increases the number of employed R&D personnel to strengthen the economy. With the same method, we find that the number of R&D staff (RDS) hurts GTFP, and the low-carbon policy cannot increase the number of R&D staff. This blames to the misallocation of talents—concentrated in nonmarketable sectors.

At last, we investigate whether the difference of the economic foundation of the cities would bring different outcomes. The green economy growth rate of non-eastern cities is higher than that of eastern cities. We conduct a heterogeneity analysis for these two kinds of cities. The result shows the low-carbon pilot policy cannot affect the green total factor productivity of eastern cities due to the poor environmental foundation and large industrial volume. Different from non-eastern cities, it is difficult for the eastern cities to conduct a fast green transformation. The low-carbon pilot policy promotes the green total factor productivity of non-eastern cities.

The novelty of this paper lies in three aspects. First, different from She et al. [10], the rate of industrial solid waste is taken into consideration and incorporated into the SMB-GML method. Under the low-carbon policy, with the rise of environmental consciences and technique, the comprehensive utilization rate of industrial solid waste rise, which can be regarded as the outcome of green growth. This is a novel and effective framework for measuring GTFP. Second, the human capital is considered as a new pathway from the low-carbon policy to green total factor productivity. Apparently, according to our theory, human capital is a crucial factor in economic growth and environmental protection. However, this factor is usually ignored in the existing literature, not to mention considering it as a pathway between the low-carbon policy and GTFP. Third, the number of R&D staff is used to represent the high-level human capital. It is noted that the innovative consciousness of R&D individuals also benefits the research and innovation in green developments. Therefore, we can reasonably infer that the misallocation of talents would decelerate the development of the green economy.

The rest of the paper is organized as follows. The literature on low-carbon policy, GTFP, industrial structure, and labor structure relevant to our research is briefly reviewed in Section 2. Section 3 presents the methodology, data, and theoretical framework. Section 4 gives the empirical results. Some further discussions and conclusions are provided in Section 5.

2. Literature Review

2.1. Low-Carbon Policy and GTFP. Green total factor productivity (GTFP) is a more appropriate index than traditional total factor productivity (TFP) for evaluating the low-carbon pilot cities' economic growth. The traditional index is not capable of reflecting the value of natural resources and the negative externality of environmental pollution [11]. While GTFP incorporates resource and environmental issues into total factor productivity (TFP) analytical framework that pursues both quantity and quality in economic growth and has been proved to be a scientific indicator for measuring green development [12, 13]. The measurement methods for GTFP are developed based on those for TFP and classified into two categories, i.e., parametric and nonparametric. Compared with parametric methods, nonparametric ones such as DEA are not restrained by the functional forms and can take various variables into consideration. However, the DEA method is not efficient enough for GTFP due to the biases caused by radial and oriented selection [14]. But, DEA is not effective enough to measure GTFP unbiasedly (bias caused by radial or oriented selection); Oh [15] proposed the global ML (GML) productivity index. And, Fukuyama and Weber [16] formulated a more general SBM directional distance function following the nonradial and nonoriented basis proposed by Tone [17]. Furthermore, the GML index based on SBM directional distance function is developed to solve the problems that exist in the literature. The SBM-GML can efficiently relieve the radial and oriented problems, achieve global comparability in the production frontier simultaneously, and has been received a lot of attention recently. Wang et al. [13] utilized the SBM-DEA method and found the GTFP of China's provinces presents an overall upward trend from 2004 to 2008. She et al. [10] based on the SBM-DEA method found, overall in China, the annual average value of GTFP is in the range of 0.2 to 0.7, which is at a low stage of development.

Environmental problem has a complex relationship with economic growth. And, addressing them simultaneously poses a dilemma. There is much research about the effect of China's environmental policy on GTFP. She et al. [10] show that the low-carbon pilot policy can directly promote urban green total factor productivity. This result is still significantly positive after the robustness test. This means that tightening environmental regulation is an effective measure of guaranteeing economic growth and optimizing environmental quality [18]. Using data of 36 industrial sectors from 2000 to 2014, Chen et al. [19], found that, in general, despite a significant carbon reduction effect by current policy, there is still much space for potential abatement to be developed. Li and Wu [20] show that the effect of local environmental regulation on green total factor productivity of China is significantly positive in high political attribute cities but negative in lower political attribute cities. Chen [11] analysis with 36 industrial sectors data from 2000 to 2014 of China found that considering energy consumption and environmental undesirable outputs; the industrial GTFP goes backward by 0.02% per year on average. These previous research illustrate that the environmental protection policy has an unclear clue on GTFP. Since the low-carbon pilot policy is a comprehensive environmental policy under the interaction between the central government and local governments, the impact on pilot cities is more reflected in the multiple policy welfare effects and the "halo effect" and "target restraint effect." This implies that the local government can receive policy support from central government, which increases the incentives to implement low-carbon pilot projects for completing the assessment of carbon emission reduction targets. In addition, the support policies prompt the pilot cities to transfer the local industrial structure, develop the low-carbon industries, and attract amounts of R&D people. Based on the above analysis, this study attempts to propose the following 2 hypotheses.

Hypothesis 1. The low-carbon policy promoting GTFP directly.

Hypothesis 2. The low-carbon policy promoting GTFP indirectly;

2.2. Mediation of Industrial Structure. Lu et al. [21] provide empirical evidence based on the PSM-DID method to show that the implementation of low-carbon pilot policies has significantly promoted the upgrading of industrial structure. Zhang et al. [8] indicate that, in the long term, strict environmental regulations increase the proportion of the tertiary industry and promote the upgrading of the industrial structure. However, Zhao and Sun [22] believe that environmental regulations are not conducive to the sustainable development of the industry since severe environmental regulations may increase the production costs of companies and reduce their production activity [23, 24]. According to the policy, most of the low-carbon pilot construction plans announced by the government propose that low-carbon pilot cities should focus on optimizing their structure and improving energy efficiency and vigorously developing low-carbon industries. Enterprises that are difficult to transform will choose to move out of the region and conduct location migration and spatial reconfiguration [25]. Zheng and Shi [26] investigated the pollution haven hypothesis at the domestic level in China using panel data of 30 provincial-level regions for the period 2004 to 2013. And, it was found that the implementation of environmental regulations prevents polluting industries from relocating to other regions making the low-carbon and high tech industries remain with structure improved. This paper confers that the low-carbon policy does encourage local industrial structure upgrading.

An effective way to reduce a region's carbon dioxide emissions is to promote the upgrading and optimization of industrial structure [6], and the industrial structure adjustment is a vital driver of economic growth. Thus, the industrial structure is essential to GTFP. Recently, SO and SR are used to measure industrial structure adjustment [7, 27]. SR refers to the reconfiguration of production resources to higher-level industries and the upgrading of dominant industries of the economy; SO refers to the flow and allocation of production factors and resources between different industrial sectors to achieve the goal of coordinated development and benign interaction [28]. Some related researches show that these two indexes may have different influences. In Lu, both SO and SR significantly promote the development of GTFP of China. Zhou et al. [29] recognize that SR and SO both have a positive effect on green development efficiency. Compared with SR, SO has a greater effect on green development efficiency. Han et al. [30] reveal SR has a positive impact on local ecological efficiency, and the improvement of ecological efficiency brought by SO is even more impressive. Treating industrial structure as mediation, She et al. [10, 17] argue low-carbon policy cannot impact GTFP through SR, but SO can. The low-carbon pilot policy can increase the SO, thereby affecting the improvement of urban GTFP. Chen et al. [27] tested the effects of environmental regulation and industrial structure changes on carbon dioxide emissions, and the results demonstrated that environmental regulation is able to reduce emissions with change of SR, when SO is high. Environmental regulation even promotes carbon dioxide emissions when the level of SO is low. These two results are diametrically opposite, and the reason is the dependent variables are different. She et al. focus on the GTFP, but Chen et al. care about carbon dioxide emissions. Compared to CO_2 emission, GTFP is a comprehensive index that includes capital input, economic growth, and a series of environmental variables. Considering that the secondary industry still occupies an important part of the national economy of China [31], the process of the SO will not be obvious in short term. The effect of the interactive relationship between low-carbon policy and the SO is not clear for GTFP. We have hypotheses 3 and 4:

> *Hypothesis 3*. The low-carbon policy can increase GTFP by promoting SR.
>
> *Hypothesis 4*. The low-carbon policy cannot increase GTFP by promoting SO.

2.3. Mediation of R&D Staff. To evaluate sustainability transition pathways, the approach of Higher Education Advancing Development for Sustainability (HEADS) has been developed. Horan et al. [32] applied this HEADS approach to analyze the High Education Institution in Ireland as the leader in facilitating national low-carbon society transitions. It is conceivable that high human capital can accelerate low-carbon economic transformation. R&D staff as a group of labor with high human capital is crucial for local green total factor productivity and low-carbon policy. There are two paths that the R&D staff increased by the low-carbon policy: (1) the path of industrial structure adjustment. The construction of low-carbon cities accelerates the elimination of pollution-intensive and energy-intensive industries. Thus, decrease the low-skilled labor and create demand for high-knowledge and high-skilled labor. This motivates local governments to improve the mechanism of recruiting, attracting, and using talents/R&D staff, enlarging the scientific and technological talent team, and improving labor quality. (2) The path of green-tech innovation and application. Green innovation is required by the low-carbon economy. The higher level of education of community members, the higher the chances of implementing innovative ideas [33]. New products, high-tech products, and new product technologies development also need research and development (R&D) staff. Besides, Human capital is utilized to adopt new pollution-free methods and technologies in industries. Higher education is important in industrial structure upgrades, cultivating talent for industries, since firms with large amount of human capital can reduce environmental costs significantly [34]. For a region, it may bring the same effect. Thus, the low-carbon policy helps to improve the green economy, which needs more high-level human capital for the cause. Therefore, the number of R&D staff could be increased by the low-carbon pilot policy.

Du and Li [35] suggested that green technology innovations improve human capital which is commonly regarded as the key factor in economic growth. Jones [36] found the U.S. economy has benefited from increasing in both educational attainment and research intensity. In the long run, the increase in available ideas will bring greater population gains, which will decisively dominate the negative effects of resource shortages [37]. That is important to an economy-transforming country. Ma and Cheng [38] use the data of R&D staff, human capital stock, and innovation efficiency in 30 provinces and cities in China from 2009 to 2011 and show that the employment of R&D personnel plays a significant role in promoting regional economic development. China's human capital structure advanced index maintains a steady upward trend in general and illustrates a significant positive correlation with sustainable economic development [39]. Combining these two ideas, the number of R&D staff (RDS) can promote GTFP. Based on the theoretical analysis presented above, a hypothesis is formulated as follows:

> *Hypothesis 5*. The low-carbon policy increases GTFP by increasing RDS.

Based on the above analysis, the main influence mechanism of each element is shown in Figure 1.

3. Methodology and Data

3.1. Model of This Paper

3.1.1. DID Model. This paper employs the DID method to evaluate the effects by implementing the low-carbon policy. The low-carbon pilot project could be treated as a quasi-natural experiment. The pilot cities and nonpilot cities are set as experimental and control group, respectively. Compare the spatial and temporal differences in the implementation results of the pilot policy. By comparing the differences between the treatment group and the control group, we can get the actual effect of the policy shock [40]. The DID model is set as

$$\log \mathrm{CTFP}_{\mathrm{it}} = \alpha_0 + \alpha_1 \mathrm{LCC}_{\mathrm{it}} + \alpha_2 X_{\mathrm{it}} + \eta_i + \gamma_t + \mu_{\mathrm{it}}, \tag{1}$$

where LCC is the core independent variable, representing the crossover between the low-carbon pilot city and the pilot time, X is the control variables, i is the city, t is the year, η is the city fixed effect, γ is the time fixed effect, and μ is the time disturbance term.

3.1.2. Mediating Effect Model. Based on Hypothesis 3 (2.4), to investigate whether the low-carbon pilot policy will indirectly affect urban GTFP by affecting the industrial structure and the number of R&D staff, this article draws on the mediation effect model of Baron and Kenny [41] and

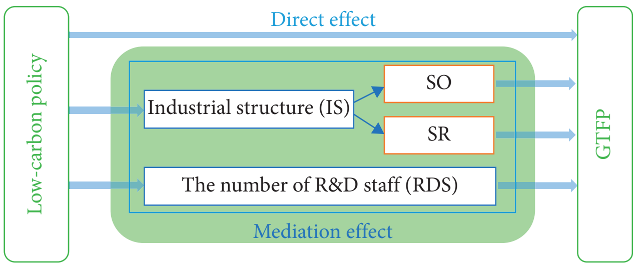

Figure 1: The influence of low-carbon policy on CTFP.

uses the gradual return method. The corresponding model is given as follows:

$$S_{it} = \lambda_0 + \lambda_1 \mathrm{LCC}_{it} + \lambda_2 X_{it} + \eta_i + \gamma_t + \mu_{it}, \quad (2)$$

$$\log \mathrm{CTFP}_{it} = \beta_0 + \beta_1 S_{it} + \beta_2 X_{it} + \eta_i + \gamma_t + \mu_{it}, \quad (3)$$

where S is the main variable of IS and RDS. IS is the industrial structure, analyzed with the variable of SO and SR. RDS is the number of R&D staff. If the low-carbon pilot policy affects the industrial structure, which in turn affects green total factor productivity, and then β_1 and λ_1 will be significant. If the signs of β_1 and λ_1 are consistent with the signs of α_1 in (1), it indicates that the mediating effect of industrial structure is $\beta_1 \times \lambda_1$. If the signs of β_1 and λ_1 are opposite to the signs of α_1, the possible indirect effects of industrial structure will cover the actual impact of low-carbon pilot policy on green total factor productivity to a certain extent, and the masking effect is also $\beta_1 \times \lambda_1$.

Furthermore, to investigate whether the mediating effect of industrial structure and R&D staff is complete, one can refer to the practices of She et al. [10, 17] and establish the following model to examine the impact of low-carbon pilot policy on urban green total factor productivity after controlling two intermediate variables:

$$\log \mathrm{CTFP}_{it} = \theta_0 + \theta_1 \mathrm{LCC}_{it} + \theta_2 S_{it} + \theta_3 X_{it} + \eta_i + \gamma_t + \mu_{it}, \quad (4)$$

where S is the same as above. If the low-carbon pilot policy has both a direct impact on GTFP and an indirect impact through industrial structure and the number of R&D staff, then the coefficients θ_1, θ_2 will both pass the significance test. The indirect effects of industrial structure and R&D staff are $\lambda_1 \times \theta_2$. If θ_1 is not significant, while θ_2 is significant, it indicates the industrial structure and the number of R&D staff are completely intermediary variables.

3.2. Samples and Measurement of Variables and Data Source

3.2.1. Samples. The data utilized in our analysis is from "China City Statistical Yearbook," "China Statistical Yearbook," and "Statistical Year book" from 2004 to 2017. Considering the completion, the data of 26 cities are used for our modeling. 17 cities are low-carbon pilot cities launched in 2010 and 2012, and 10 are non-pilot cities during that period. The chosen cities are listed as in Table 1.

3.2.2. Measurement of GTFP and Data Source. This paper adopts the SBM-GML productivity index [42] to measure the GTFP growth. The software we use is MaxDEA8.0. The result we get from MaxDEA8.0 is the growth rate of the GTFP index. In order to obtain the absolute value of GTFP in Chinese cities, this paper uses 2003 as the base period (counting is 1) for cumulative calculations [43]. The factors to calculate GTFP are shown in Table 2:

For capital stock, the formula is

$$K_{it} = K_{it-1}(1-\delta) + I_{it}, \quad (5)$$

where K_{it} and K_{it-1} represent the capital stock of city i in year t, δ_{it} represents the depreciation rate of city i in year t, and I_{it} is the total fixed-asset investment of city i in year t, and we collected its data from China City Statistical Yearbook. Since it is better to use the total fixed capital formation index to measure the capital stock, this article uses this index as the capital investment index. To guarantee the continuity and comparability of the data, we use 2003 as the base period and deflate with the fixed-asset price index (collected from China Statistical Yearbook) to measure the capital stocks at constant prices. The formula is

$$K_{0i} = \frac{(I_{0i} \times g_i))}{((g_i - 100\%) + \delta)}, \quad (6)$$

where K_0 represents the initial capital stock growth rate, I_0 represents the capital investment in base-year (2003 in this paper), and g is the capital investment price index in 2003. In this paper, supposes δ is a constant value and adopted as 10.96% [43, 44].

The data of labor input, energy input, GDP, urban green coverage rate of the city, and comprehensive utilization rate of industrial solid waste were collected from China City Statistical Yearbook. The data of industrial wastewater, waste gas, and waste solid production were collected from the Statistical Yearbook of each city.

3.2.3. Measurements of Independent Variables and Data Source. The low-carbon policy city (LCC) is a dummy variable; this paper uses it to represent whether it is a low-carbon pilot city multiplied by the time when it is approved as a pilot city. This data is from the official website of the National Development and Reform Commission of China. The nonpilot city in the non-pilot year is set to 0; otherwise, it is set to 1.

The industrial structure optimization (SO) is measured by the ratio of the added value of the tertiary industry to secondary industry. Data were collected from the China City Statistical Yearbook. For the industrial structure rationalization (SR) indicator, refer to She et al. [10, 17] and use the Theil index to measure the level of industrial structure rationalization according to the following formula:

$$\mathrm{SR}_{it} = \sum_{i=1}^{n} \frac{Y_i}{Y} \ln\left(\frac{(Y_i/L_i)}{(Y/L)}\right) = \sum_{i=1}^{n} \frac{Y_i}{Y} \ln\left(\frac{(Y_i/L_i)}{(Y/L)}\right), \quad (7)$$

where (Y_i/Y) and (L_i/L) represent the proportion of the output value of the primary, secondary, and tertiary

Table 1: List of sample cities (according to the official website of the National Development and Reform Commission).

Pilot year	Sample city
2010	Tianjin, Hangzhou, Shenzhen, Xiamen, Nanchang, Chongqing
2012	Shanghai, Shijiazhuang, Suzhou, Ningbo, Wenzhou, Guangzhou, Wuhan, Jincheng, Kunming, Urumqi, Zunyi
Nonpilot city	Nanjing, Dalian, Dongguan, Wuxi, Taizhou, Hefei, Changsha, Zhengzhou, Chengdu

Table 2: The input and output factors of GTFP.

Indicator	Secondary indicator	Measurement
Input 27	Labor input	Number of nonagricultural employments of the city at the end of the year (million)
	Capital investment	Capital stock calculated by Goldsmith's perpetual inventory method (million yuan)
	Energy input	Total annual electricity consumption of the city (billion kWh)
Desirable output 10	Economic output	Real GDP calculated based on 2003 (million yuan)
	Ecological benefits	The urban green coverage rate of the city
		The comprehensive utilization rate of industrial solid waste
Undesirable output 10	Pollution index	Comprehensive calculation of industrial wastewater, waste gas, and waste solid's production (million ton) based on the entropy method

industries in the total local output value and the proportion of the labor force in the primary, secondary, and tertiary industries in the total local employments. These data come from the China City Statistical Yearbook. The number of R&D staff is from the Statistical Yearbook of each city; we use the logarithm of it for our modeling.

3.2.4. Measurement of Control Variables and Data Source. For the control variables, this paper refers to She et al. [10, 17] and Zhou and Qin [43]. There are five control variables: foreign investment level (FDI), measured by the proportion of foreign investment in local GDP, the data of which come from the China City Statistical Yearbook; the regional GDP per capita measured by logarithm of the number (lnPGDP), the data of which is from the Statistical Yearbook of each city; the degree of government intervention (GI) measured by the proportion of government expenditures in local GDP, the data of which is from the Statistical Yearbook of each city; energy intensity (EI) is the ratio of the total energy consumption of each city to local GDP, the data of which is from the Statistical Yearbook of each city; the rate of industrialization (IR) adopts Yin's [45] formula:

$$\mathrm{IR}_{\mathrm{it}} = N_{\mathrm{it}} \times S^{*}_{\mathrm{it}} \times T^{*}_{\mathrm{it}}, \tag{8}$$

where N is the proportion of nonagricultural industries and S^* and T^* are the contribution points of the secondary and tertiary industries:

$$N_{it} = \mathrm{SP}_{\mathrm{it}} + \mathrm{TP}_{\mathrm{it}}, \tag{9}$$

where SP and TP are the proportions of secondary and tertiary industries' output in the local GDP:

$$\begin{aligned} S^{*}_{\mathrm{it}} &= \min\left(\frac{1, \mathrm{Sm}_{\mathrm{it}}}{0.48}\right),\\ T^{*}_{\mathrm{it}} &= \min\left(\frac{1, \mathrm{Tm}_{\mathrm{it}}}{0.70}\right), \end{aligned} \tag{10}$$

where Sm and Tm are the maximum proportion of the secondary and tertiary industries during the sample period and 0.48 and 0.70 are the possible turning points of China's secondary and tertiary industries based on the development experience of developed countries and China's development history. These data come from the Statistical Yearbook of each city.

Except the green total factor productivity index, the other variables are calculated by Excel using the formulas presented accordingly.

3.3. Description of Variables. The variable description, model analysis, and robustness test are conducted by Stata16. Descriptive statistics of the main variables are shown in Table 3:

4. Results

4.1. Result of the Low-Carbon Policy on GTFP. Based on formula (1), the impact of the implementation of the low-carbon pilot policy on China's low-carbon economic transformation is investigated in this section. To show the impacts, two models, ordinary fixed effect model and multidimensional fixed effect model, are utilized. The results are shown in Table 4. Columns (1) and (2) are the results of the ordinary fixed effect model; column (3) and (4) are the results of the multidimensional fixed effect model.

Table 3: Descriptive statistics table.

Variable	Obs.	Mean	Std.	Min.	Max.
Log GTFP	364	0.0137	0.0613	−0.1485	0.2209
LCC	364	0.3736	0.4844	0.0000	1.0000
SO	364	1.0165	0.3456	0.4615	2.4890
SR	364	4.3442	0.1991	3.7832	5.0723
RDS	364	10.0773	1.1641	7.0901	12.4503
FDI	364	0.0193	0.0159	0.0001	0.0943
ln PGDP	364	10.8374	0.6995	8.4030	13.0784
GI	364	0.1239	0.0501	0.0308	0.3469
EI	364	0.0576	0.0827	0.0018	0.5811
IR	364	0.6036	0.0824	0.2899	0.7402

Table 4: Low-carbon pilot policy on GTFP of China.

Variable	log GTFP (1)	log GTFP(2)	log GTFP (3)	log GTFP (4)
LCC	0.014^{**}(0.006)	0.013^{**} (0.006)	0.014^{**} (0.006)	0.013^{**} (0.006)
FDI		0.166 (0.169)		0.166 (0.169)
ln PGDP		0.021^{**} (0.010)		0.021^{**} (0.010)
GI		0.324^{**} (0.137)		0.324^{**} (0.137)
EI		−0.038 (0.080)		−0.038 (0.080)
IR		-0.142^{***} (0.047)		-0.142^{***} (0.047)
Constant	-0.039^{***} (0.01)	-0.233^{*} (0.122)	0.008^{***} (0.003)	−0.177 (0.122)
η	Yes	Yes	Yes	Yes
γ	Yes	Yes	Yes	Yes
R-squared	0.7780	0.8000	0.7780	0.8000
N	364	364	364	364

Note: the values in parentheses are robust standard errors. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

As seen from Table 4, considering time fixed effects and urban fixed effects, the double-difference coefficients in columns (1) to (4) are all significantly positive, even with control variables, indicating that the low-carbon pilot policy leads to significant impact on the green total factor productivity of Chinese cities. The significant positive impact implies that the pilot policy has promoted the growth of green total factor productivity. The low-carbon pilot policy's direct impact on green total factor productivity is 0.013. It reveals the green total factor productivity of pilot cities are 1.3% higher than nonpilot cities. Besides, the coefficients are the same between these two models which illustrates the rational of our estimation method. Hypothesis 1 is proved.

Except for the policy effect, many other control variables significant impact GTFP, especially the government intervention (GI) with an impact of 0.324. Since the local governments take the greatest pressure from this policy, there is no wonder that government intervention is significant to GTFP at the level of 1%. The government intervention is measured by the proportion of government expenditures in local GDP. The main government expenditures involved are environmental protection expenditure and business services expenditure. From Table 4, we can see the local governments try their best to improve the green total factor productivity. On the one hand, a lot of efforts have been made on environmental protection, such as environmental monitoring and supervision expenditure, pollution control expenditure, natural forest protection project expenditure, and other expenditures; on the other hand, they introduce supporting policies to attract environment-friendly enterprises, high-tech enterprises, and recruit talents. All of these expenditures are beneficial to local green total factor productivity.

The rate of industrialization (IR) harms green total factor productivity. It indicates that the higher rate of industrialization, the more pollution products and more waste of resources. This is a problem left over from the extensive economic development earlier. It also shows there is still a long way to go for the green economy. The regional GDP per capita (lnPGDP) promotes local green total factor productivity, and the richer cities have a better foundation to promote the growth of green total factor productivity. The effects from FDI and EI are not significant.

4.2. Robustness Test

4.2.1. Parallel Trend Test. It is not enough to show the policy effect's stabilization by simply using two kinds of regress methods. Thus, we test the parallel trend based on column (2); the result is shown in Figure 2. The line reflects the marginal effect of the dual-interaction term on China's green total factor productivity. The figure also shows the 90% confidence interval of the regression coefficient for each year. The value 0 on the X axis is the year of policy adoption in the first period, specifically, 2010. We can see from Figure 2 that, before the low-carbon pilot policy was taken, the estimated coefficient of the double interaction terms fluctuate around 0, and most of them are not significant; after the adoption year (0 value), the GTFP of each year is significantly different from 0, and its influence is increasing. This fluctuating trajectory is consistent with the time interval

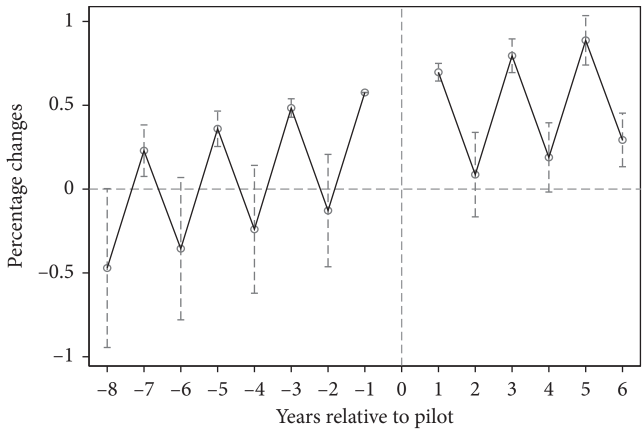

Figure 2: Parallel trend test results.

between the two phases of the pilot policy implementation. The 0 period is the year 2010, 2nd period is 2012, and the effect significantly promotes the green total factor production up after one year later. The first batch of pilot policies was effective in 2011 and was pulled down by the second batch of low-carbon policies in 2012, and this process goes repeatedly in the following years.

This shows that there is almost no difference in the growth rate of GTFP before the implementation of the pilot policy. It also shows that the low-carbon pilot policy has a significant positive impact on the city's green total factor growth rate, and the impact is getting stronger and stronger.

4.2.2. Other Robustness Tests. To further ensure the robustness of the results, this article also conducted some other tests. First, placebo test: in this part, we artificially advance the approval of the low-carbon pilot policy by one and three years and conduct the regression base on formula (1), without control variables (see column (5) and (6)). Second, reverse causality test: the test was conducted by controlling the initial GTFP level. Because in the process of selecting low-carbon pilot cities, the government may select cities with better economic foundation, which may create a two-way causal relationship between the approved low-carbon pilots and urban economic development. We include the sample lag term *l_loggtfp* of *loggtfp* in the model, and the dual-interaction term still has a significant impact on GTFP (column (7)). Third, performing a regression analysis after the data was processed with 1% tailing (column (8)). The LCC is still as significant to GTFP as before. The results are shown in Table 5.

4.3. Intermediary Mechanism Test

4.3.1. Mediation of Industrial Structure. The industrial structure is decomposed into two factors: industrial structure optimization (SO) and industrial structure rationalization (SR). We investigate the mediator effects by these two factors based on formulas (2), (3), and (4). The results are shown in Table 6.

From Table 6, the dual-interaction terms in model (1) and model (2) have a positive impact on SO and SR, indicating the low-carbon policies can help optimize and rationalize the industrial structure of pilot cities. Especially, industrial structure optimization can bring more benefits than industrial structure rationalization. In other words, industrial structure optimization progresses faster. Model (3) and model (4) describe the impact of industrial structure optimization and industrial structure rationalization on green total factor productivity. Industrial structure rationalization has a positive effect on green total factor productivity, while industrial structure optimization has none. When including the dual-interaction term to our model (model (5)), the low-carbon pilot policy and industrial structure rationalization have significant impacts on GTFP and industrial structure optimization has none. It indicates the industrial structure rationalization plays the role of half mediator between low-carbon policy and GTFP. The low-carbon pilot policy has an indirect effect of 0.004 (0.08×0.056) through promoting industrial structure rationalization and thus affecting green total factor productivity. The comprehensive impact of the low-carbon pilot policy on green total factor productivity is 0.016. Hypothesis 2 is verified.

The result can verify our assumptions, but the reason for the insignificant of the industrial structure optimization is not the slow optimization speed. Evidence can be seen from column (1). So, what is the reason? The industries are transforming and upgrading too fast in these cities. Some secondary industries are gone and the tertiary industries come up, but the tertiary industry can not contribute to local GDP as much as the secondary industry did before. Especially in a short term, the low-carbon pilot policy forces a number of secondary industries to move out due to the heavy pollution; while the introduction and development of enterprises in the tertiary industry need time. The undesirable output decreased, but the GDP has also decreased which makes industrial structure optimization unable to play its due role in green total factor productivity growth.

All in all, we find that the low-carbon pilot policy can encourage industrial structure rationalization and boost GTFP of pilot cities; the low-carbon pilot policy accelerates industrial structure optimization. However, the temporary drop of GDP caused by secondary industries' shut down cannot be compensated in a short time, even if the low-carbon pilot policy can accelerate industrial structure optimization. Hypothesis 3 and 4 are verified.

4.3.2. Mediation of R&D Staff. In this part, we test the mediation of the number of R&D staff based on formulas (2)–(4). We normalized the data to eliminate multicollinearity. The results in Table 7 indicate the low-carbon pilot policy can not attract more R&D staff. There reasons are as follows: first, the local governments are unable to provide higher subsidies due to their limited financial resources; second, there are few enterprises that need R&D staff in the short term, because they have not upgraded or established yet; third, the annual growth rate of R&D

Table 5: Other robustness test result.

Variable	log GTFP (5)	log GTFP (6)	log GTFP (7)	log GTFP_tr (8)
before_{-1}	0.013 (0.014)			
before_{-3}		0.00 (0.015)		
LCC			0.01^{*} (0.005)	0.013^{**} (0.006)
l_log GTFP			0.4235^{***} (0.0841)	
Constant	-0.016^{*} (0.008)	-0.016^{*} (0.008)	-0.0265^{***} (0.0061)	0.008^{***} (0.0026)
η	Yes	Yes	Yes	Yes
γ	Yes	Yes	Yes	Yes
R-squared	0.1121	0.1138	0.8373	0.7713
N	364	364	338	358

Table 6: The intermediary mechanism of industrial structure.

Variable	Model (1) SO	Model (2) SR	Model (3) log GTFP	Model (4) log GTFP	Model (5) log GTFP
SO			−0.007 (0.014)		−0.023 (0.016)
SR				0.052^{**} (0.023)	0.056^{**}(0.026)
LCC	0.128^{***} (0.028)	0.080^{***} (0.016)			0.012^{*} (0.007)
FDI	-2.161^{***} (0.700)	-0.824^{*} (0.445)	0.069 (0.158)	0.156 (0.164)	0.163 (0.172)
ln PGDP	-0.317^{***} (0.062)	-0.100^{***} (0.033)	0.019^{*} (0.011)	0.026^{***} (0.010)	0.020^{*} (0.011)
GI	−0.489 (0.422)	−0.228 (0.242)	0.354^{***} (0.135)	0.357^{***} (0.134)	0.325^{**} (0.139)
EI	0.846^{***} (0.245)	0.201^{*} (0.114)	−0.052 (0.081)	−0.062 (0.078)	−0.030 (0.078)
IR	-0.693^{**} (0.297)	0.099 (0.098)	-0.146^{***} (0.047)	-0.147^{***} (0.047)	-0.164^{***} (0.047)
Constant	4.875^{***} (0.727)	5.374^{***} (0.373)	−0.137 (0.142)	-0.453^{***} (0.169)	−0.115 0.111)
η	Yes	Yes	Yes	Yes	Yes
γ	Yes	Yes	Yes	Yes	Yes
R-squared	0.8837	0.9032	0.7978	0.8007	0.8036
N	364	364	364	364	364

personnel is limited, about 0.064 in this sample, and the total amount is insufficient. In addition, due to the long-term nature of project work for R&D personnel, it is difficult to move. The energy intensity and the rate of industrialization can attract more R&D staff. Thus, we can conclude that R&D staff would not move to a region just because of the low-carbon policy or the higher per capita; they move because of the resources. Therefore, among the above three reasons, the first and second points are more likely to be established.

The real interesting phenomenon shown in Table 7 comes from model (7) and model (8). The number of R&D staff decreased the green total factor productivity. This phenomenon is not impossible taking talent misallocation into consideration. Murphy et al. [46] claimed that if human resources entered the productive sector, then human capital can improve production efficiency, promote technological innovation, and promote economic growth; however, if human resources become rent-seekers and rent-seeking is only a redistribution of wealth and is not productive, the economic growth will be harmed. The R&D staff in this sample include those who work in government agencies and institutions and also include those who work in private enterprise. On the whole, the proportion of R&D personnel in government agencies is larger. The composition of rent-seekers could be greater, leading to a decline in economic growth. It indicates the distorted R&D staff allocation of these cities. The deviation of talent allocation in government departments has a negative impact on economic innovation and transformation [47]. Li and Yin [48] also indicate that China's limited human resources have been over-allocated in government departments, damaging the economic growth. For green total factor productivity, it has the same effect. Hypothesis 5 is not verified, and the number of R&D staff is not a mediator between low-carbon policy and green total factor productivity.

Why do these R&D personnel gather in government departments? Many scholars found that, in reality, the income of rent-seeking activities in most underdeveloped countries is higher than the income obtained in the corporate sector, and talent mismatch is an important factor that causes economic stagnation in underdeveloped countries [49]. This is true in China. Government departments can provide more superior and worry-free jobs. On the contrary, it is difficult for ordinary business sectors to meet these needs of R&D personnel.

4.4. Heterogeneity Analysis. The low-carbon pilot policy aims to reduce cities' carbon emissions and promote green economy. But, different cities have different economic foundations, such as the level of infrastructure, openness, and the number of talent pool. If these indexes are measured by a composite index, it is the level of economic development. This affects the carbon emission largely. The eastern region is the birthplace of China's modern economy, while the central and western regions are relatively backward in economic development. So, all of these differences are resulted from the location of the city, which leads to the

Table 7: The intermediary mechanism of the number of R&D staff.

Variable	Model (6) RDS	Model (7) log GTFP	Model (8) log GTFP
RDS		−0.022*** (0.006)	−0.022*** (0.005)
LCC	−0.031 (0.055)		0.012** (0.006)
FDI	−0.717 (1.454)	0.077 (0.149)	0.151 (0.159)
ln PGDP	−0.120 (0.126)	0.018* (0.009	0.019** (0.009)
GI	−1.065 (0.645)	0.330** (0.131)	0.301** (0.134)
EI	1.005*** (0.371)	−0.034 (0.077)	−0.017 (0.077)
IR	1.038*** (0.314)	−0.119*** (0.045)	−0.120*** (0.045)
η	Yes	Yes	Yes
γ	Yes	Yes	Yes
Constant	0.012*** (0.026)	0.000 (0.002)	0.005 (0.003)
R-squared	0.7187	0.4271	0.4332
N	364	364	364

Table 8: Eastern and non-eastern cities' low-carbon policy effect.

Variable	log GTFP (east 1)	log GTFP (east 2)	log GTFP (non-east 3)	log GTFP (non-east 4)
LCC	0.009 (0.007	0.007 (0.006)	0.018* (0.010)	0.027** (0.012)
FDI		−0.203 (0.144)		0.897 (0.682)
ln PGDP		0.024** (0.010)>		−0.048* (0.025)
GI		0.118 (0.133)		0.243 (0.200)
EI		−0.038 (0.080)		0.138* (0.080)
IR		−0.338*** (0.137)		−0.235*** (0.087)
Constant	−0.002 (0.003)	−0.177 (0.114)	0.022*** (0.005)	0.599** (0.288)
η	Yes	Yes	Yes	Yes
γ	Yes	Yes	Yes	Yes
R-squared	0.8436	0.8641	0.7685	0.7954
N	196	196	168	168

eastern cities having more economic and human resources advantages. They have more finance to carry on this policy, reduce carbon emission, and promote green economic growth. But, these eastern cities may also bear much more pressures because of their longer extensive development history and larger industrial volume.

We divide our sample into two groups, the eastern cities and non-eastern cities, to test the low-carbon pilot policy's effect based on formula (1). The results are shown in Table 8. From Table 8, we find that the low-carbon policy does not play a role in the green total factor productivity for the eastern cities, while it plays an important role for the non-eastern cities.

Figure 3 shows the difference of eastern and non-eastern cities in green total factor productivity. From 2004 to 2017, at the beginning of this period, the green total factor productivity of these two groups is at the same level. Then, it rises during 2006–2010. After a short decline, it rises again at 2012. The policy is implemented in 2010. The decline illustrates the short-term negative shock by the policy. The positive effects on green total factor productivity by low-carbon policy arised since 2012. During 2004–2017, the green total factor productivity for eastern and non-eastern cities keep on rising but at different rates. For the eastern cities, the growth rate is steady but at a lower level. It reveals the imbalance development of green economy.

It can be inferred from our previous discussions and the results in Table 8 that the low-level growth rate of green total factor productivity does not caused by the low-level input factors including capital investment, human resources and energy input, nor does it come from GDP. It is the undesired output that drags GTFP down. In the early years, China's economy developed rapidly at the cost of high resource input, high pollution, and high waste. The eastern cities are the main developing areas. After a long time developing, eastern areas have been planted a lot environmentally unfriendly factories compared with non-eastern cities. This makes the eastern cities much harder to transform in a short period. The non-eastern cities just like a sheet of blank paper, leaving more zoom to attract environmentally friendly

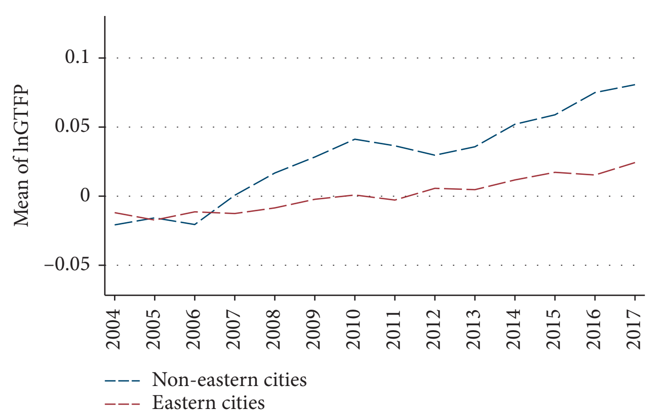

Figure 3: The trend of GTFP of eastern and non-eastern cities.

companies, making the industrial transformation of these cities relatively easier. Moreover, with a cleaner environment foundation, the growth rate of green total factor productivity is higher. The rate of industrialization (IR) also alludes to this conclusion: the higher level of industrialization, the lower the green factor productivity. The reduction effect of industrialization on the GTFP of eastern cities was 0.338; for non-eastern cities, it was 0.235.

5. Conclusions and Policy Implications

5.1. Conclusions. Under the international pressures of carbon emission reduction, China has implemented active emission reduction policies, including the low-carbon pilot policy. Carbon reduction means that China must transform its traditional resource-dependent economy and develop green one. China has achieved its carbon emission reduction target ahead of schedule, but has it promoted the development of green economy? This study analyzes the low-carbon pilot policy (LCC) on green total factor productivity (GTFP) and explains the issue through two mechanisms—the industrial structure (SO, SR) and the number of R&D staff (RDS). The main conclusions of this paper are as follows.

First, the low-carbon policy has a positive effect on green total factor productivity. This conclusion is consistent with most of existing studies [10, 18]. It shows that, in the process of China's carbon emission reduction, the green economy has also been developed. It is a good sign of economic low-carbon transition.

Second, low-carbon pilot policies can promote the rationalization and optimization of the industrial structure. The industrial structure rationalization has a positive effect on green total factor productivity; while industrial structure optimization does not, indicating that industrial structure rationalization is an important pathway for low-carbon policies to promote the development of green total factor productivity. With the realization of low-carbon emission reduction, the development of a green economy must be more rationalized in the industrial structure.

Third, regarding the number of R&D personnel, the results show that it is not affected by low-carbon policies and harms green total factor productivity. The main reason for this result is the misallocation of talents. Talents must be used in a reasonable position to maximize utility. The misallocation of talents is a problem that seriously slows down China's economic growth.

At last, the green total factor productivity of eastern and non-eastern cities is in a different level. It shows the regional imbalance of green economy. The rate of non-eastern cities is higher than that of eastern cities. The empirical result shows the low-carbon pilot policy cannot affect the green total factor productivity of eastern cities because of the poor environmental foundation and large industrial volume. It is more difficult for eastern cities to conduct green transform, compared with the non-eastern cities. The low-carbon pilot policy promotes the green total factor productivity of non-eastern cities.

5.2. Policy Implications. According to this study, the low-carbon policy is a good and effective measure for economy green transformation. However, it did not work very well. To release the policy potential, we must solve several problems.

The intensity of the low-carbon pilot policy should be reinforced rather than weakened, but the concrete implementation should be more scientific and diversified based on local conditions. From the results, we understand that this policy is effective, but the policy does not work in some areas. That is because these regions have different advantages and disadvantages compared with other regions. The eastern cities have good economic foundations, human resources, infrastructure, high-tech, and openness, but they show limited green-land coverage, free space, etc. The non-eastern cities are on the contrary, which makes the local governments must formulate more detailed policies and measures based on main policies:

(1) In terms of industrial structure. For the eastern cities, they should pay more attention to industrial structure optimization with their good foundation: ① encouraging high pollution enterprises to install sewage treatment equipments by tax subsidy; ② encouraging enterprises by financial reward to develop and utilize new tech and new equipment to produce in environment-friendly ways. For example, green supply chain management can improve corporate performance while protecting the environment Wang et al. [50]. For the non-eastern cities, they should focus on industrial structure realization. They do not have a large industrial volume, making them more efficient to attract environmental-friendly enterprises. They also have more sufficient rural surplus labor to work for these new enterprises. Specifically, local governments should use preferential tax policies and take advantage of the lower land rent and cheaper labor relative to the eastern cities to attract environment-friendly enterprises.

(2) In the terms of R&D staff. For the eastern cities, they already have enough R&D staff to serve their economic green-transform, and their enterprises also have many R&D persons. The next step for them is to build a rapid transformation mechanism of innovation achievements. For the non-eastern cities, their R&D persons are most concentrated in government agencies and institutions. There is a misallocation of talents. At the same time, there is a shortage of talents elsewhere. They should ① formulate reasonable policies to release the economic vitality of government R&D staff, market their research results, and avoid rent-seeking; ② issue talent allowances to attract more R&D persons and labor with high-level human capital to improve the quality structure of local workers; ③ strengthen infrastructure construction to help local enterprises recruit and keep talents; ④ encourage firms to cultivate their unique personnel training mechanism, making R&D staffs more efficient for economy growth.

(3) In terms of environmental regulation, the low-carbon policy is effective and the local governments should ① use mass supervision, establish teams of environmental protection volunteers, and call on environmental protection social organizations to strengthen environmental supervision and inspection; ② increase environmental pollution tax. Zhang et al. [51] indicate that the green governance capacity of government and the level of social supervision are important in achieving the green development. These measures will enhance the effect of the low-carbon policy.

By taking the measures discussed above, regional differences could be reduced, which corresponds to balanced development. Promoting the environmental protection and economic growth in the eastern and non-eastern regions will help to reduce the regional differences in GTFP and lead to achieve China's sustainable development.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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