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Tax Policies of Low Carbon in China: Effectiveness Evaluation, System Design and Prospects

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Fiscal and taxation policy tools play an important role in promoting green and low-carbon development. Based on classical tax theory, including the Potter hypothesis and the environmental Kuznets curve, this paper explores the impact of environmental tax regulation on economic growth and carbon emission reduction. We find that resource tax reform could promote green total factor productivity; however, the ad valorem reform of resource tax does not significantly raise the level of low carbon development. This effect varies among different regions as well as different tax cuts and fee reductions. Fiscal revenue decentralization has a reverse adjustment effect on the impact of resource taxes on green total factor productivity. We conclude that it is necessary to deepen the reform of the fiscal and taxation system to achieve the carbon neutrality and emission peak goal.

Keywords: carbon peak, carbon neutralization, tax reform, low carbon development, resource tax, green total factor productivity

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1 INTRODUCTION

The greenhouse effect represented by carbon dioxide emissions has led to global warming, melting glaciers, rising sea levels, frequent extreme weather and even land desertification, which directly threaten the survival of many species. The 1997 Kyoto Protocol provides for a shared obligation to reduce emissions between developed and developing countries under the principle of "common but differentiated responsibilities." The 2015 Paris Agreement proposes limiting the global average temperature increase to 2°C by the end of the century compared to the industrial era and working toward limiting warming to 1.5°C. In September 2020, President Xi proposed at the 75th session of the UN General Assembly that "China will adopt stronger policies and measures and CO_2 emissions' strive to peak by 2030 and work toward achieving carbon neutrality by 2060." In the process of promoting a green tax system, China's series of tax reforms have already played an important role, such as the change of resource tax from quantity-based to price-based, the introduction of environmental protection tax taking into account the positive incentives for high-quality development and the transformation and upgrading of high-energy-consuming industries, and the adjustment of consumption tax policies for large-emission small cars. A series of tax policy adjustments are constantly releasing positive signals to guide energy conservation and emission reduction. Therefore, to address the shortcomings of the current green tax reform in China and to find an optimal path, it is necessary to realize the vision of "peak carbon and carbon neutral" (hereinafter referred to as the "double carbon" vision) and to promote high-quality economic development, which is also the focus of this paper.

The concept of the "double dividend" was first formalised by Pearce (1991). The first dividend is that environmental taxation policies improve the environment; the second dividend is that environmental taxes improve the efficiency of the tax system and indirectly improve economic efficiency. The environmental Kuznets curve hypothesis suggests that there is an inverted U-shaped relationship between the trend of most pollutants and the trend of per capita national income, which means that the quality of the environment deteriorates with the increase in per capita income during industrialisation and is then treated and improved with a further increase in per capita income. The Porter hypothesis is that environmental regulation can raise the environmental awareness of firms to a certain extent and that firms will have a potential tendency to innovate technologically in the face of pressure from environmental regulation. A sound and effective environmental regulation policy instrument can stimulate technological innovation by firms, increasing productivity through the "innovation compensation effect" and compensating for the cost burden of environmental regulation.

The marginal contributions of this paper include the following: First, the "double dividend" effect of the "double carbon" vision adjustment tax is used as a research perspective to verify the "double dividend" effect and Porter's hypothesis in the context of China's low carbon tax policy. To enhance the contemporary characteristics of traditional theories, green total factor productivity is measured using CO_2 emissions as nondesired output, and the policy effects of resource taxes are tested through fixed effects models, taking full account of the individual characteristics of different low-carbon tax policies. Third, in the context of global warming and the realization of the "double carbon" vision, it is of practical significance to put forward suggestions on resource taxes and environmental protection taxes to improve the green tax system, promote the green transformation of industries and enhance the level of low-carbon development.

The remainder of this paper is organized as follows: **section 2** reviews the relevant literature and proposes our hypothesis; **section 3** introduces the data, variables and empirical methods; **section 4** presents our empirical results; and we conduct a further analysis in **section 5** and conclude in **section 6**.

2 LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

2.1 Literature Review

With the definition of the new development concept and the goal of high-quality economic development, the theme of "low carbon" is gradually concerned by more and more scholars, and the research direction and content are increasingly extensive. He et al. (2022a) based on the micro perspective, focused on the ESG performance of enterprises and its impact on enterprise investment risk and manager misconduct while fulfilling environmental responsibilities, and studied the regulatory effect of economic policy uncertainty and corporate social responsibility on Enterprise Green Innovation (He et al., 2020; He et al., 2022b; He et al., 2022c). Ren et al. (2022a) assessed the impact of climate risk on carbon emissions, focusing on the environmental performance of enterprises, and believed that climate risk would promote the carbon emissions of enterprises. In addition, scholars in the field of economics have also updated the measurement methods of indicators such as economic growth and economic development quality in the research process. One of the most important indicators is green total factor productivity (GTFP), which brings ecological and environmental factors into the assessment criteria of economic development quality and pursues the harmonious coexistence of economic growth and resources and the environment. For example, Xiao and You (2021) used the three-stage data envelopment analysis (DEA) method to calculate the green total factor productivity of 30 provinces in China and found that there were significant regional differences in China's green total factor productivity. Feng et al. (2021) also paid attention to the importance of environmental quality to the level of economic development. On the basis of studying the impact of environmental regulation policies on green total factor productivity, they put forward empirical evidence to improve green total factor productivity. In summary, the indicator of green total factor productivity has been widely used in research on the relationship between economic growth and the ecological environment. However, it is worth noting that although the measurement method of green total factor productivity is constantly improving, most scholars still use the emissions of three industrial wastes (waste water, waste gas and solid waste) as the unexpected output, and few scholars have introduced carbon dioxide emissions into the calculation of the model. That is, the "carbon" factor is not fully reflected due to the deficiency of the existing research.

The literature on the influencing factors of low carbon tax policies covers three main areas. First, in terms of the connotation and design of elements of low-carbon tax policy, Nordhaus (2017) define green low-carbon taxation as a tax credit granted to taxpayers who invest in pollution prevention or environmental protection, a tax levied on high-carbon-emitting industries or the use of excess carbon emission rights. Kuninori and Otaki (2016), based on the modified Ramsey optimal tax theory, suggest that carbon tax rates must be proportional to the per capita income and price elasticity of high-carbon products to achieve an effective intertemporal allocation of CO_2 emissions.

Second, in terms of the validation of classical low carbon taxation theory, the first is the "double dividend" effect, which Yuan and Zhang (2021) argue can be achieved by environmental regulation policies that can lead to economic growth and pollution reduction. From an economic perspective, Cao et al. (2021) conduct a multimodel comparison of a carbon tax policy in China and find substantial differences in the change in energy use and economic activity in response to a steadily rising carbon tax. However, there are important similarities. Oladosu and Rose (2007) analyses the local factor growth rate and industrial structure characteristics of the Susquehanna River and concludes that the short-term impact of a carbon tax on regional net output is very small, but the impact on the energy sector is significant. Hao and He (2022) think Green innovation is an important way for firms to achieve both economic benefits and environmental protection in the long term. From a social welfare perspective, Okonkwo (2021), using household survey data for the period 2009–2015, estimates the quadratic almost ideal demand system (QUAIDS) model to obtain elasticities and use them to simulate consumer responses to price changes resulting from carbon taxation. The paper argues that when there is a simultaneous increase in the prices of energy goods, the poorest and middle-income households disproportionately suffer a higher welfare loss compared to the richest households.

Berman and Bui. (2001) use data from the US oil industry and find that environmental supervision leads to an increase in firm productivity. Other scholars oppose Porter's hypothesis. For example, Duan et al. (2021) think thanks to the differences in energy sources and variability over their price distributions, the observed differential in carbon price-response is an indication of non-unique carbon market dynamics. Dension (1981) study of US data from 1972–1975 finds that an increase in the intensity of environmental supervision leads to a decrease in total factor productivity. Du et al. (2021) estimate the heterogeneous impacts of environmental regulation on green technology innovation and industrial structure in 105 Chinese environmental monitoring cities through partially linear functional-coefficient panel models. The results show that when the economic development levels are low, environmental regulation will restrain the development of green technology innovation but have insignificant impacts on the upgrading of industrial structure. Other scholars Rubashkina et al. (2015) examine the "weak" and "strong" versions of the Porter hypothesis using manufacturing in 17 European countries between 1997 and 2009.

Third, in terms of comparing low carbon tax policies with other environmental supervision policies, Pollitt et al. (2014) found that the carbon tax implemented in Japan in 2012 brought about a decline in GDP at the initial stage of reducing conventional energy use, but if combined with flexible adjustments in carbon market pricing and the rational use of related tax revenues, carbon emission reductions and long-term sustainable GDP growth could be achieved. In general, the combination of carbon tax and carbon emission trading framework is worth exploring, which requires us to pay attention to the research on carbon emission trading market while sorting out carbon tax policies. Ren et al. (2022b) used the quantile method to predict the carbon price, and studied the relationship between the carbon market and the green bond market Ren et al. (2022d). Dissou and Karnizova (2016) concludes that the impact of harmful pollution on households and businesses is direct, while carbon emissions are indirect, with no direct impact on economic growth and employment, making low carbon tax policies more effective than mandatory emission reduction measures.

2.2 Hypothesis Development

2.2.1 Reform of the Resource and Environmental Tax

China's low-carbon policy on resources and environmental taxation mainly includes resource taxes, environmental protection taxes and supporting policies. Compared to the resource tax, the environmental protection tax is a "new tax," and since its introduction in 2018, issues such as the application of taxable pollutants and the monitoring and calculation of emissions of taxable pollutants have been clarified. Since its inception in 1984, the resource tax has continued to adjust the levying scope and optimize the tax rate bands to ensure that its functions of adjusting the industrial structure and saving energy and protecting the environment are effectively performed. Since 2010, the ad valorem reform of resource tax by region and by tax item has been gradually promoted, and by 2016, the ad valorem reform of resource tax for all tax items at the national level was achieved.

The environmental effect of the resource tax comes mainly from its price regulation of specific taxable energy sources. The imposition of a resource tax on units and individuals who develop taxable energy increases upstream prices and conducts price transmission, increasing the costs of downstream enterprises and using the increased costs to guide them to adjust their energy consumption structure and increase the proportion of nontaxable energy demanded, thereby achieving the goal of reducing pollutant emissions. At the same time, the adjustment of the energy consumption structure and the innovation and upgrading of production technology caused by the cost effect have further improved the production efficiency of enterprises and finally realized the double improvement of the economy and the environment, that is, the improvement of green total factor productivity. Based on the above analysis, this paper proposes the following research hypothesis.

Hypothesis 1 Resource taxation can regulate the structure of energy consumption and improve green total factor productivity.

2.2.2 Significant Differences in Tax Sources Between Resource Tax Regions

As an important part of China's green tax system, the adjustment of the tax rate and the change in the tax amount can, to a certain extent, reflect China's energy consumption structure and carbon dioxide emissions. As shown in **Figure 1**, since 2014, resource tax revenues in the central and western regions have been significantly higher than those in the eastern regions, with significant differences in tax resources between regions. In addition, as a result of the implementation of the ad valorem resource tax reform for crude oil and natural gas in 2010 and its extension to mineral resources in 2016, with a simultaneous expansion of the scope of tax items, adjustments to elements of the tax regime have led to large fluctuations in the amount of resource tax. Therefore, the following research hypothesis is proposed in this paper.

Hypothesis 2 Resource tax ad valorem reform improves green total factor productivity.

2.2.3 Increasingly Optimized Energy Structure With Arduous Transformation Task

China is in a critical period of economic structure transformation. The corresponding energy production and consumption structure should also shift from traditional nonrenewable energy to renewable energy to promote the low-carbon transformation of the economic structure. On the one hand, low-carbon energy transformation can effectively alleviate energy poverty and is conducive to energy conservation and emission reduction (Dong et al., 2021); On the other hand, the role of energy consumption in promoting economic growth is closely related to the carbon emission reduction target (Ren et al., 2022c). Moreover, changes in energy prices will have a direct impact on carbon prices. As shown in **Figure 2**, from 2011 to 2019, the proportion of raw coal in China's total energy production decreased from 81.9% to 76.2%, and the proportion of coal in total energy consumption decreased from 73.4% to 62.8%. Although both showed a downwards trend year by year, the decline was not

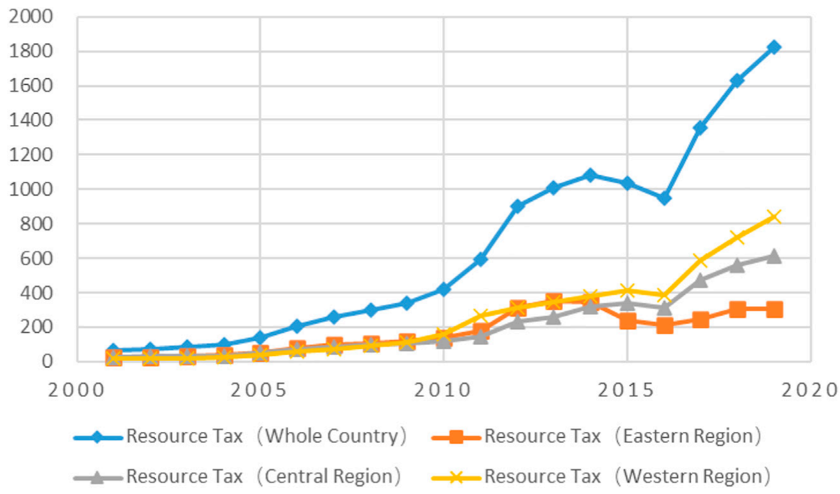

FIGURE 1 | China's resource tax revenues and regional differences.

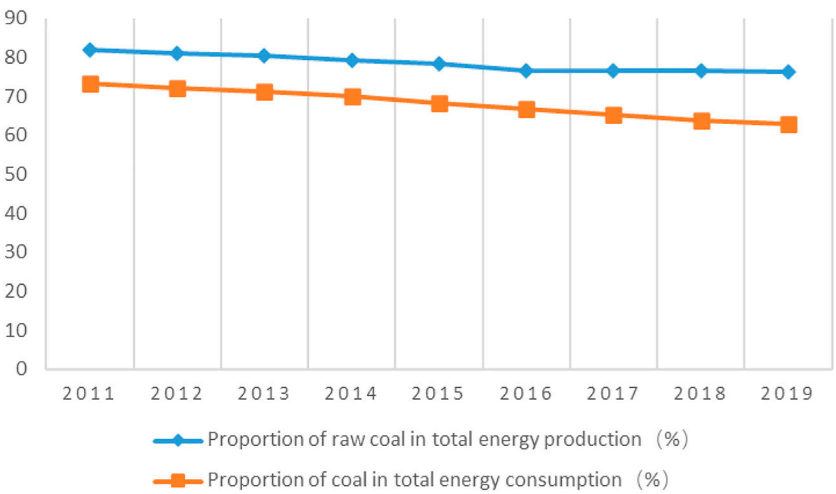

FIGURE 2 | China's energy production/consumption structure.

obvious. On the one hand, it reflected that the task of energy structure transformation and upgrading was still arduous; on the other hand, it also reflected that the current policies and measures to promote energy structure transformation were insufficient. In addition, the transformation of the energy production structure obviously lags behind the transformation of the energy consumption structure, indicating that policy tools such as resource tax acting on the production side need to be further optimized, and the coordination and complementarity between resource tax policy and other fiscal and tax policies, such as tax reduction and fee reduction, need to be further strengthened.

Hypothesis 3 The coordination and complementarity between diversified policy instruments can promote the effect of resource tax policy. Specifically, resource tax policy combined with tax reduction and fee reduction policy can further improve green total factor productivity.

3 RESOURCE TAX REFORM ON LOW CARBON DEVELOPMENT

3.1 Data Sources

The sample interval selected for this paper is 2001–2019, using data from the China Statistical Yearbook, China Taxation Yearbook, China Energy Statistical Yearbook, EPS Global Statistics/Analysis Platform, Wind database and provincial statistical yearbooks. Some of the missing data were filled in using linear interpolation. The descriptive statistical characteristics of the variables are shown in **Table 1**.

TABLE 1 | Descriptive statistical characteristics of variables.

Variables	Sample size	Average value	Standard deviation	Minimum value	Maximum value
GTFP	551	0.9598	0.0830	0.5455	1.8799
Tax	551	21.7926	39.4918	0.0740	383.0339
Reform	551	0.4428	0.4972	0.0000	1.0000
Compete	551	0.0236	0.0208	0.0001	0.1465
Ind	551	1.1480	0.3384	0.1935	2.0228
Gov	551	0.2084	0.0965	0.0772	0.6284
Fd	551	0.0318	0.0264	0.0019	0.1436
Er	551	0.0042	0.0035	0.0002	0.0285
Den	551	343.1315	292.8900	7.2653	1311.8180

TABLE 2 | Measures of green total factor productivity.

Type	Variables	Definition
Input elements	Labor input	Number of people working in society as a whole
	Capital investment	Capital stock calculated using the perpetual inventory method (based on 2000)
	Energy inputs	Total energy consumption
Desired output	Real GDP	Real GDP calculated using 2000 as the base period
Nondesired outputs	Carbon dioxide emissions	emissions by IPCC method

TABLE 3 | Results of green total factor productivity measures.

	2005	2010	2015	2019
Beijing	0.9624	0.9884	0.9731	1.1793
Tianjin	0.9960	0.9004	0.9342	0.7464
Hebei	0.9559	0.9627	0.8971	0.8561
Shanxi	0.9693	0.9718	0.9450	0.9426
Inner Mongolia	0.8749	0.9190	0.9225	0.9576
Liaoning	0.9962	0.9720	0.9874	0.8857
Jilin	0.9618	0.9342	1.0104	0.7682
Heilongjiang	0.9573	0.9650	0.9423	0.8167
Shanghai	0.9994	0.9993	0.9776	1.6655
Jiangsu	0.9460	1.1111	0.9160	1.0406
Zhejiang	0.9169	1.0164	0.9524	1.0277
Anhui	0.9358	0.9778	0.9265	1.1071
Fujian	0.9043	0.9771	0.9594	1.0885
Jiangxi	0.9412	0.9999	0.9270	0.9971
Shandong	0.9221	1.0068	0.9057	0.7895
Henan	0.9679	0.9502	0.9491	1.0722
Hubei	0.9939	0.9737	0.9705	1.0640
Hunan	0.8890	0.9661	0.9700	0.9931
Guangdong	1.1502	1.0279	0.9330	1.1325
Guangxi	0.9183	0.9352	0.9512	0.9439
Hainan	0.9400	0.9814	0.9299	1.0316
Chongqing	1.0164	0.9567	0.9844	1.0559
Sichuan	0.9761	0.9668	0.9720	1.0258
Guizhou	1.0527	0.9785	0.9519	0.9902
Yunnan	0.8502	0.9285	0.9540	1.1497
Shaanxi	1.0069	0.9776	0.8970	0.9497
Gansu	0.9762	0.9852	0.8746	0.9872
Qinghai	0.9517	0.9657	0.8928	0.9779
Ningxia	0.9323	1.0503	0.9385	0.9594
Xinjiang	0.9740	1.0442	0.8559	1.0034

3.2 GTFP Calculation

The dual dividend effect of environmental taxation policies implies that the level of low-carbon development requires that low-carbon taxation policies not only have the carbon emission reduction effect but also contribute to the achievement of economic growth objectives. Therefore, in this paper, to include both CO_2 emissions and the level of economic development in the analytical framework when evaluating the effects of low carbon tax policies, the global Malmquist–Luenberger (GML) index, i.e., green total factor productivity (GTFP), is calculated to represent the level of low carbon development using a nonradial, nonoriented nondesired output SBM model by referring to Tone and Sahoo (2003). As shown in **Table 2**, the input indicators include labor input, capital input and energy input. Considering the availability of data, labor input is represented by the number of employees in society, capital input is represented by the capital stock calculated using the perpetual inventory method, and energy input is represented by total energy consumption. Output indicators include desired output indicators and nondesired output indicators. To eliminate the influence of price factors, this paper takes 2000 as the base period and calculates the real GDP as the desired output indicator, which represents the level of economic development; CO_2 emissions are selected as the nondesired output indicator, and CO_2 emissions are calculated according to the United Nations Intergovernmental Panel on Climate Change (IPCC). emissions are calculated according to the methodology published by the Intergovernmental Panel on Climate Change (IPCC).

Corresponding to the uneven regional distribution of China's population structure, energy structure and industrial structure at this stage, China's green total factor productivity also shows significant regional differences. **Table 3** shows the results of green TFP measurements for 30 provinces, municipalities directly under the Central Government and autonomous regions (hereafter referred to as provinces, excluding Tibet and Hong Kong, Macao and Taiwan in view of the availability of data) in China, which show significant growth, but there are still

TABLE 4 | Definition of variables.

Variable name	Variable symbols	Variable definitions
Green Total Factor Productivity	GTFP	Superefficient SBM-GML method measured
Resource tax	Tax	Resource tax amount
Ad valorem resource tax reform	Reform	Dummy variables
Local competition	Compete	Actual utilization of foreign direct investment/regional GDP
Industrial structure	Ind	Value added in the secondary sector/value added in the tertiary sector
Level of government intervention	Gov	Fiscal expenditure/GDP
Financial decentralization	Fd	Provincial revenue/Central revenue
Environmental regulation	Er	Completed investment in industrial pollution control/industrial added value
Population density	Den	Total population at the end of the year/administrative area

obvious regional differences and optimized space. In 2019, the average green total factor productivity of 30 provinces in China was 1.0068. There were 13 provinces above the average. More than half of the provinces did not reach the average level. Before 2010, the difference in green total factor productivity in the eastern, central and western regions of China was small, but since 2010, the green total factor productivity in the eastern region has been significantly higher than that in the central and western regions, and this gap showed a growing trend.

3.3 Variable Descriptions

(1) Explanatory variables

Green Total Factor Productivity (GTFP): As a measure index of low carbon development, green total factor productivity, as measured by the ultra performance SBM model, captures the "double dividend" of economic growth and environmental protection.

(2) Core explanatory variables

①Resource Tax (Tax): The total resource tax revenue is used as an indicator to measure the resource tax in the green tax system as an example.

②Resource tax ad valorem reform (Reform): Taking the ad valorem reform of resource tax on crude oil and natural gas as an example, a dummy variable is constructed as the measurement index of the ad valorem reform of resource tax. The ad valorem reform of resource tax is carried out in sequence by year and region. Therefore, this paper assigns 0 to the year when the ad valorem reform of resource tax is not carried out in each province and 1 to the year when the ad valorem reform of resource tax has been carried out.

(3) Control variables

To avoid affecting the accuracy of the model regression results due to the omission of important variables, based on the practices of Tu et al. (2019), Yuan and Zhang (2021) and Yang et al. (2022) and combined with the characteristics of the sample data in this paper, local competition (Compete), industrial structure (Ind), the degree of government intervention (Gov), fiscal decentralization (Fd), environmental regulation (Er) and population density (Den) are used as control variables, and the specific definitions of the variables are shown in **Table 4**.

3.4 Model Setting

To study the impact of resource tax and resource tax ad valorem reform on the low carbon development in China and to verify the "double dividend" effect of low carbon tax policy, this paper constructs the following empirical model.

$$GTFP_{it} = \alpha_0 + \beta_1 lnTax_{it} + \beta_2 Reform_{it} + \sum_m \theta_m Controls_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{1}$$

where $GTFP_{it}$ denotes Green Total Factor Productivity; Tax_{it} denotes total resource tax revenue; $Reform_{it}$ is a dummy variable that takes the value of 1 if the ad valorem resource tax reform on crude oil and natural gas is implemented in year t in province i and 0 otherwise; $Controls_{it}$ is a set of control variables that include other important variables affecting Green Total Factor Productivity; β_1, β_2, and θ_m denote the influence degree of resource tax, resource tax ad valorem reform and control variables on Green Total Factor Productivity, respectively; μ_i denotes individual effects; λ_t denotes time effects; and ε_{it} denotes random errors.

4 EMPIRICAL RESULTS

4.1 Baseline Result

To mitigate heteroskedasticity, the core explanatory variables are treated by logarithm. Meanwhile, to eliminate dimensions, all variables are standardized. Due to the serious lack of data on Shanghai's resource tax revenue, Shanghai was further excluded from the sample interval, and finally, the data of 29 provinces in China were used in the regression model. Considering that low-carbon development means that the proportion of clean energy in the energy structure gradually increases until it finally becomes the main component, the tax system elements of resource tax will change in the process of low-carbon development; that is, the low-carbon development level will have a negative effect on the resource tax, and the endogenous problems that may be caused by this two-way causality will reduce the accuracy of the model regression results. Therefore, in this paper, the 2SLS estimation

TABLE 5 | Empirical regression results.

	(1)	(2)	(3)	(4)
lnTax	0.098*	0.125**	0.097*	0.122**
	(0.05)	(0.05)	(0.05)	(0.05)
Reform			−0.020	−0.017
			(0.02)	(0.02)
Compete		−0.064**		−0.065**
		(0.03)		(0.03)
Ind		0.023		0.025
		(0.02)		(0.02)
Gov		−0.203***		−0.199***
		(0.04)		(0.04)
Fd		0.092		0.096
		(0.08)		(0.08)
Er		0.048**		0.048**
		(0.02)		(0.02)
Den		−0.018		−0.020
		(0.06)		(0.06)
_cons	0.322***	0.364***	0.342***	0.381***
	(0.03)	(0.07)	(0.03)	(0.07)
R2	0.380	0.445	0.383	0.447
Individual effects	YES	YES	YES	YES
Time effects	YES	YES	YES	YES
N	522	522	522	522

*Note: Standard errors in brackets; ***, ** and * denote 1%, 5% and 10% significance levels, respectively.*

TABLE 6 | The test results of VIF.

Variable	lnTax	Reform	Compete	Ind	Gov	Fd	Er	Den
VIF	2.32	2.57	1.51	1.56	2.19	2.07	1.20	2.36

method is used to regress model (1), and the lag period of the core explanatory variable is used as the instrumental variable to reduce the interference of endogenous problems on the estimation results. The baseline regression results are shown in **Table 5**. Columns (1) and (2) only test the impact of resource tax on low-carbon development without considering the ad valorem rate reform of resource tax. When controlling the individual fixed effect and time fixed effect at the same time, regardless of whether the control variable is added to the model, the impact coefficient of the resource tax on green total factor productivity is significantly positive, indicating that the collection of resource taxes promotes the improvement of green total factor productivity and effectively promotes the low-carbon transformation of the economy and society. Columns (3) and (4) consider the ad valorem reform of resource tax. The empirical results show that the impact coefficient of resource tax on green total factor productivity is still significantly positive, and the coefficient is basically the same as that when the ad valorem reform of resource tax is not considered; however, there is no significant effect of resource tax ad valorem reform. In other words, the effect of resource tax on green TFP comes from the resource tax itself rather than the event of ad valorem reform. The mechanism of the effect of resource tax on green TFP is that the tax burden on taxpayers will stimulate taxpayers to increase the price of their products, while downstream consumers adjust the structure of energy demand to maximize cost avoidance. Therefore, it is the change in the amount of resource tax that is a direct factor in the impact of resource tax on green total factor productivity.

In terms of control variables, environmental regulation is positively related to green TFP; that is, the means of environmental regulation used to control industrial pollution can improve the level of low-carbon development. This is mainly because in the process of industrial development, due to the one-sided pursuit of economic interests and the neglect of environmental protection and resource conservation, the emissions of pollutants such as carbon dioxide are high. Industrial environmental regulation policies can guide the green transformation of industry and increase output value in a more energy-saving and environmentally friendly way. However, local competition and government intervention have an inhibitory effect on green TFP, with blind competition leading to a waste of resources and inefficiency, which is detrimental to the improvement of production and lifestyle, and excessive government intervention affects the effective functioning of the market mechanism, which is not conducive to the improvement of low-carbon development.

4.2 Robustness Tests

To further verify the accuracy of the regression results, this paper first carried out multicollinearity and heteroscedasticity tests. To avoid the model estimation inaccuracy caused by endogenous problems, the difference GMM method and System GMM method were used to re-estimate the model. Then, the robustness test was carried out by adding control variables and modifying the sample interval to exclude the impact of the environmental protection tax.

4.2.1 Multicollinearity and Heteroscedasticity Test

The economic system is a complex and organically connected whole, and many economic things have direct or indirect connections, which means that when building econometric models to analyse the impact effects of economic variables, we should fully consider the correlation between variables and avoid the possible multicollinearity interference between variables to estimate the results of the model. Therefore, before estimating equation (1), this paper first uses the VIF test to judge whether there is multicollinearity in the model. The VIF values of all variables are shown in **Table 6**. The VIF values of all variables are less than 10, which proves that there is no multicollinearity in the model. In addition, to avoid the inaccuracy of the estimation results caused by the heteroscedasticity of the model, the white test method is used to test the heteroscedasticity of the model before the estimation of equation (1). The results show that the p value is equal to $0.735 > 0.1$, and the original assumption of the same variance is accepted, which proves that the model does not have the heteroscedasticity problem.

4.2.2 Endogenetic Test

As mentioned above, there may be a two-way causal relationship between resource tax revenue and green total factor productivity, and the complexity and integrity of

TABLE 7 | The results of the Endogenetic test.

	(1) DIF-GMM	(2) SYS-GMM
lnTax	0.753***	0.143*
	(0.12)	(0.09)
_cons	/	0.236***
		(0.04)
Control variables	YES	YES
Sargan	0.969	0.295
Hansen	0.950	0.112
Individual effects	YES	YES
N	522	551

*Note: Standard errors in brackets; ***, ** and * denote 1%, 5% and 10% significance levels, respectively.*

economic variables also means that there may be missing variables in the process of model construction, which will lead to endogenous problems. The instrumental variable method used in the previous article has reduced the impact of endogenous problems to a certain extent. In this part, the lag order of the core explanatory variable is used as the instrumental variable to build a fixed effect model. The model is estimated by using the difference GMM method and the System GMM method. The estimation results are shown in **Table 7**. Whether using the DIF-GMM method or SYS-GMM method, the coefficients of core explanatory variables are significantly positive; that is, the collection of resource tax can effectively promote the improvement of green total factor productivity. The p values of the Sargan test and Hansen test are greater than 0.1, which proves that the model setting is reasonable and that the instrumental variables are also effective.

4.2.3 Addition of Control Variables

The omission of important variables may lead to endogeneity problems and reduce the credibility of the regression results. For this reason, this paper further adds the degree of openness to the outside world, urbanization rate and fiscal pressure to the set of control variables and reregisters the empirical model. The results are shown in column (1) of **Table 8**. The regression coefficient of the core explanatory variable of resource tax is still significantly positive, again verifying hypothesis 1.

4.2.4 Exclusion of Environmental Protection Tax

The introduction of an environmental protection tax in 2018 is an important part of China's sound green tax system, and the imposition of an environmental protection tax on units emitting taxable pollutants can effectively reduce the emissions of taxable pollutants and improve environmental quality. The tax burden brought by an environmental protection tax is also an important factor influencing taxpayers' behavioral choices. Therefore, this paper modifies the sample interval to 2001–2017 and regresses the empirical model. The results are shown in column (2) of **Table 8**. The variable coefficient indicating the amount of resource tax is still significantly positive, which again verifies the research results of this paper.

4.3 Heterogeneity Analysis

4.3.1 Regional Heterogeneity

In the above analysis, total resource tax revenue, total energy consumption and carbon dioxide emissions all showed significant regional differences, and the impact of resource tax policies on the level of low carbon development in different regions is likely to be heterogeneous as well. For this reason, this paper conducts subsample regressions on the eastern, central and western regions to test regional heterogeneity. As shown in columns (1)–(2) of **Table 9**, resource taxation has a positive impact on green total factor productivity in all regions, which is consistent with the results of the baseline regression, but this impact is not significant in the eastern region, probably because first, the level of low carbon development in the eastern region is inherently higher than that in the central and western regions, which leads to relatively less room for policy regulation; second, the eastern region is mainly the demand side of energy, although its total energy consumption and CO_2 emissions are higher than those of the central and western regions, it does not bear a heavier resource tax burden; third, the eastern region is relatively economically developed and can rely more on technological progress and industrial restructuring to improve

TABLE 8 | Robustness test results.

	(1)	(2)
	Adding control variables	Exclusion of environmental protection tax
lnTax	0.120**	0.126**
	(0.05)	(0.05)
Reform	−0.017	−0.019
	(0.02)	(0.02)
_cons	0.253**	0.333***
	(0.11)	(0.06)
Control variables	YES	YES
R^2	0.460	0.484
Individual effects	YES	YES
Time effects	YES	YES
N	522	464

*Note: Standard errors in brackets; ***, ** and * denote 1%, 5% and 10% significance levels, respectively.*

TABLE 9 | The test results of heterogeneity.

	(1)	(2)	(3)	(4)
	Eastern region	Central and western region	Areas with greater efforts to reduce taxes and fees	Areas with less tax and fee reduction
lnTax	0.087	0.133**	0.128*	0.020
	(0.13)	(0.06)	(0.07)	(0.05)
Reform	−0.049	0.004	−0.013	−0.020
	(0.05)	(0.01)	(0.01)	(0.02)
_cons	0.447***	0.295***	0.344***	0.488***
	(0.11)	(0.05)	(0.08)	(0.07)
Control variables	YES	YES	YES	YES
R2	0.500	0.481	0.566	0.464
Individual effects	YES	YES	YES	YES
Time effects	YES	YES	YES	YES
N	180	342	273	249

*Note: Standard errors in brackets; ***, ** and * denote 1%, 5% and 10% significance levels, respectively.*

environmental quality, and the coordination of multiple policies dilutes the impact of a single policy.

4.3.2 The Influence of Tax Cuts and Fee Reduction on Policy Effect

In recent years, China has vigorously implemented the policy of tax cuts and fee reduction to reduce the burden on enterprises and stimulate the vitality of market players. The policy of tax cuts and fee reduction is an important measure to promote industrial transformation and upgrading and high-quality economic development. It not only effectively promotes employment and scientific and technological innovation but also indirectly promotes the improvement of green and low-carbon development levels while giving play to the innovation incentive effect and structural transformation function. Moreover, as a restrictive tax policy, the resource tax, in the process of guiding the green transformation of enterprises, together with incentive tax preferential policies such as tax reduction and fee reduction, can avoid the excessive tax burden hindering the process of enterprise transformation and upgrading. Based on this, this paper takes the decline rate of tax revenue growth as the measurement index of tax reduction and fee reduction. According to the median value of the index, the sample areas are divided into areas with greater tax reduction and fee reduction and areas with less tax reduction and fee reduction. Regression is carried out by sample. The regression results are shown in columns (3)–(4) of **Table 9**. The impact coefficient of the resource tax on green total factor productivity is still significantly positive in areas with greater tax reduction and fee reduction but not in areas with less tax reduction and fee reduction. This may be because in areas with fewer tax cuts and fee reductions, enterprises bear a heavy tax burden; that is, there is a plan for low-carbon transformation under the guidance of resource taxes, but it cannot be smoothly promoted due to capital constraints. This also fully reflects the necessity of implementing the policy of tax reduction and fee reduction and verifies the establishment of hypothesis 3.

TABLE 10 | Regulatory effect test results.

	(1)	(2)
lnTax	0.173***	0.170**
	(0.07)	(0.07)
Reform		−0.017
		(0.02)
Fd	0.321**	0.323**
	(0.16)	(0.16)
lnTax*Fd	−0.265*	−0.262*
	(0.15)	(0.15)
_cons	0.297***	0.315***
	(0.08)	(0.08)
Control variables	YES	YES
R^2	0.451	0.453
Individual effects	YES	YES
Time effects	YES	YES
N	522	522

*Note: Standard errors in brackets; ***, ** and * denote 1%, 5% and 10% significance levels, respectively.*

5 FURTHER DISCUSSION

Under the background of the tax sharing system, the resource tax, as a kind of central and local shared tax, can balance the relationship between central and local fiscal revenue and expenditure to a certain extent, and it will also be affected by the degree of fiscal revenue decentralization. Therefore, fiscal revenue decentralization may affect the impact of resource taxes on green total factor productivity; that is, fiscal revenue decentralization has a regulatory effect on the impact of resource taxes on low-carbon development. To verify the existence of this regulatory effect, based on equation (1), this part introduces the interaction term of resource tax and fiscal revenue decentralization into the model to test whether fiscal revenue decentralization has a regulatory effect on the impact of resource tax on low-carbon development. The empirical results are shown in **Table 10**. After the introduction of the interactive item, the coefficient of the main effect of resource tax on green total factor productivity is still significantly positive, while the coefficient of the interactive item is significantly negative at the 10% level, which indicates that the decentralization of fiscal revenue will inhibit the positive effect of resource tax on green total factor productivity. This may be because the improvement of the decentralization of fiscal revenue of local governments means that local governments have more self-owned disposable income, and local governments have greater autonomy when coordinating economic activities. Under the action of special administrative systems and officials' promotion incentives, local governments that lack supervision may not consider too many low-carbon factors when allocating resources but focus on realizing explicit economic benefits, thus hindering the improvement of green total factor productivity.

6 CONCLUSION AND POLICY IMPLICATIONS

Green and low-carbon is the inevitable requirement for the transformation of the future economic development mode, and scientific and reasonable low-carbon tax policy is of great significance for the smooth realization of green and low-carbon transformation. This paper first constructs a superefficient SBM model to calculate the green total factor productivity of 30 provinces in China and then uses the panel data of 29 provinces in China from 2001 to 2019 to build a fixed effect model to test the impact of the ad valorem reform of resource tax and resource tax on green total factor productivity. There are obvious regional differences in China's green total factor productivity. The collection of resource tax is conducive to improving green total factor productivity. Compared with the eastern region and the regions with less tax reduction and fee reduction, this effect is more significant in the central and western regions and the regions with more tax reduction and fee reduction. However, the impact of ad valorem resource tax reform on green total factor productivity is not obvious. In addition, fiscal revenue decentralization has a reverse adjustment effect on the impact of resource taxes on green total factor productivity.

To give full play to the dual dividend effect of low-carbon tax policies and successfully achieve the goal of "carbon peaking and carbon neutrality," China should continue to improve the green tax system and strengthen the design of the "double carbon" Vision-regulated taxation system design.

First, we gradually include VOC_S organic gas emissions in the scope of the environmental protection tax. The petrochemical industry is the first sector to be selected for the pilot environmental protection tax "expansion," and the traditional concept of the tax's "revenue raising" function should be appropriately revised in the assessment of VOC_S environmental protection tax collection and management, respecting the inherent regulation law of the tax and avoiding the revenue raising effect as the basis for the assessment. The assessment system should be appropriately designed in line with the VOC emission intensity of major taxpayers.

Second, the restrictive resource tax system for carbon emissions and forest resource development and utilization should be improved. The dual effects of the coal resource tax in terms of energy saving and emission reduction and tax burden fairness should be emphasized; ecological carbon sink resources such as forest grassland and marine blue carbon should be included in the scope of resource taxation; and flexible tax incentives should be implemented for different taxable resource sectors and areas.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: http://olap.epsnet.com.cn EPS global statistical data / analysis platform.

AUTHOR CONTRIBUTIONS

PF, WL, and HL contributed to conception and design of the study. HL organized the database and performed the statistical analysis. PF, WL, HL, and XW wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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