RESEARCH-ARTICLE

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Research on the impact of green fiscal on carbon emissions based on the fixed effect model with panel data

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Abstract

Green fiscal policy tools are an important innovation in the modern fiscal system. A series of fiscal policies to promote green governance have been introduced one after another, which is of great significance to achieving carbon emission reduction. Based on this, this study uses 29 provinces in China from 2007 to 2021 as data samples, constructs a green fiscal indicator system, studies the mechanism of green fiscal on carbon emission reduction, and conducts heterogeneity analysis. Research shows that green fiscal significantly reduces carbon emission levels, and this result still holds after robustness testing; in the mechanism analysis, green fiscal can significantly improve energy efficiency, and the Sobel test shows that energy efficiency has a mediating effect on green fiscal carbon emission reduction; in the heterogeneity analysis, the carbon emission reduction effect of green fiscal is more significant in the central and western regions. Finally, corresponding policy recommendations are put forward to help reduce carbon emissions.

CCS Concepts

• **Social and professional topics Computing** → technology policy Government; technology policy Governmental regulations.

Keywords

Green fiscal, Carbon emissions, Energy efficiency, Fixed effect model

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1 Introduction

Since the reform and opening, China's economy has developed rapidly, while carbon emissions have also increased year by year. To actively respond to global climate change, China has successively introduced a series of green development policies. The "Opinions on Fiscal Support for Carbon Peaking and Carbon Neutrality" proposes to support the development of green fiscal, achieve green and low-carbon life and resource conservation and utilization, to support carbon peaking and carbon neutrality. Green fiscal policy tools with green taxation, energy-saving and environmental protection expenditures, ecological transfer payments, and government green procurement as the main content have become an important innovation in the modern fiscal system, and a series of fiscal policies to promote green governance have been introduced. Green fiscal can effectively stimulate the development of low-carbon energy and low-carbon industries and is of great significance to achieving carbon emission reduction.

Overviewing the existing literature, the research on the impact of green fiscal on carbon emissions can be divided into three main viewpoints. ① The development of green fiscal will inhibit the growth of carbon emissions, that is, with the development of green fiscal, carbon emissions will gradually decrease. For example,(Xu, Feng & Zhu, 2023) concluded that green fiscal helps to inhibit carbon dioxide emissions and has the effect of reducing pollution and carbon emissions(Deng, 2024). also confirmed the positive impact of green fiscal development on short-term and long-term carbon emissions. ② The development of green fiscal promotes the growth of carbon emissions. For example, the development of green fiscal will lead to a large amount of energy use to a certain extent, thereby leading to an increase in carbon emissions (Safi et al., 2021).;(Al-Mulali, Sab & Fereidouni, 2012) found that green fiscal reduces financial costs, leading to the expansion of corporate production scale, thereby bringing more resource waste and more serious pollution emissions. ③ In the short term, the development of green fiscal will promote the increase of carbon emissions; but in the long run, green fiscal will reduce carbon emissions. (Bai et al.2022) showed that the impact of green fiscal on carbon emissions in the central region showed an inverted U-shape, there is an inverted "U" curve relationship between the level of green fiscal and total carbon emissions. (Ye , Cai & Wang, 2023) conducted an empirical analysis of the impact of green fiscal in eastern, central and western China on carbon emissions. The results showed that the development of green fiscal in the eastern and central regions was negatively correlated with carbon emissions after exceeding the inflection point of the environmental Kuznets curve, while the development of green fiscal in the western region was positively correlated with carbon emissions.

According to existing research, it can be inferred that green fiscal has an impact on carbon emissions, but what the specific impact is, through what mechanism, and whether this impact is heterogeneous are important contents of this study. In view of this,

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this paper constructs a comprehensive green fiscal indicator system based on panel data of 29 provinces from 2007 to 2021, uses the entropy method to measure green finance, and uses a fixed effect model to study the impact of green finance on carbon emissions, providing reference value and empirical support for the formulation of green fiscal policies, and promoting to achieve the "dual carbon" goals.

2 Theoretical Analysis and Research Hypothesis

2.1 Green Fiscal and Carbon Emissions

Green fiscal mainly includes green fiscal revenue, green fiscal expenditure, green transfer payments, green government procurement and green fiscal management. In recent years, the impact of green fiscal revenue policy on carbon emissions has attracted the attention of scholars. There are two main views: one is the "suppression theory" and the other is the "assistance theory" . The "suppression theory" believes that my country's tax policy has effectively suppressed carbon emissions. The "assistance theory" believes that the current green fiscal revenue policy lacks a carbon tax design for carbon dioxide (Zhang and Ma ,2021), resulting in the inability of green fiscal revenue policy to effectively suppress carbon emissions. The government's green fiscal expenditure is mainly used to provide financial support to enterprises, to encourage and guide society and enterprises to move towards low carbonization. It has become a consensus that green fiscal expenditure can effectively reduce carbon emissions. The higher the green fiscal expenditure, the higher the degree of suppression of carbon emissions. Green transfer payments are also called ecological transfer payments. They achieve carbon neutrality by transferring funds for ecological and environmental governance. Green government procurement and green fiscal management require the government to integrate the concept of environmental protection into all management in daily procurement projects and management, to consider low-carbon and environmental protection in fiscal management, and to take measures such as priority procurement and prohibition of procurement in procurement to drive enterprises' production and sales activities to achieve low-carbonization.

Based on existing research, there are still some problems in the mechanism of green fiscal on carbon emissions. First, can green fiscal revenue suppress carbon emissions? According to the data of CEADs "China CO_2 Emission Inventory 1997-2021 (IPCC Sector Emissions)", in 2021, thermal power generation, ferrous metal smelting and rolling, and non-metallic mineral products accounted for about 80% of my country's carbon emissions. However, due to the low resource tax rate, as the prices of resource products continue to rise, local governments and enterprises expand production for economic goals, resulting in the phenomenon of simultaneous growth of resource taxes and carbon emissions. This further raises the research question of this paper: Can green fiscal effectively suppress carbon emissions? In recent years, against the background of rising energy prices, high-emission enterprises have further expanded production, resulting in the simultaneous growth of green fiscal data and related enterprise output, weakening the emission reduction effect of green fiscal.

Based on this, hypothesis H_1 is proposed: Green fiscal has a suppressive effect on carbon emissions.

2.2 Green Fiscal and Energy Efficiency

As a diversified fiscal tool with environmental friendliness and policy guidance, green fiscal promotes the development of green economy through a series of policy measures, such as green taxation, green subsidies, and green procurement, and plays a very important role in reducing carbon emissions. On the one hand, green fiscal effectively guarantees carbon emission reduction in terms of funds. By increasing the loan quota for high-pollution and high-emission enterprises, it promotes the optimization and upgrading of their production structure; increasing investment in green technology innovation and improving energy efficiency. On the other hand, green fiscal achieves carbon emission reduction through policies. By implementing tax reduction policies, tax reduction and policy subsidies are provided to enterprises that meet carbon emission standards; the transformation and upgrading of low-carbon and high-carbon industries are accelerated, and the use and development of alternative energy and renewable energy are promoted to achieve low-carbon and green development goals.

Green fiscal mainly improves energy efficiency through three mechanisms: First, through the low-carbon structural effect generated by the joint efforts of the central and local governments, the production factor allocation model is reshaped. Second, through the green scale effect generated by the joint efforts of the government and enterprises, it can save energy input and reduce energy redundancy and improve energy efficiency. Third, through the regulatory constraint effect of self-driving force, the trading mechanism of "low pollution - high return - low pollution" is improved to improve energy efficiency (Zhou and Lin ,2025). Improving energy efficiency is conducive to reducing energy consumption and reducing carbon emissions from the source.

Based on this, hypothesis H_2 is proposed: Green fiscal promotes carbon emission reduction by improving energy efficiency.

3 Model and Data

3.1 Model construction

To verify the effect of green fiscal on carbon emission reduction, the model is constructed as follows:

$$lnCit = \alpha 0 + \alpha 1GFit + \alpha 2Controlit + \varepsilon it \quad (1)$$

Wherein, $\ln C_{it}$ represents the carbon emissions in province i at time t; GF_{it} represents the level of green fiscal development in province i at time t. Control represents the population size (lnPSE), the proportion of the secondary industry (Strind), the proportion of the tertiary industry (Strsev) and the level of economic development (lnEDL).

To further study the mechanism of the carbon emission reduction effect of green fiscal, we refer to the suggestions of (Jiang, 2022) on the test of mediation effect and construct the mediation effect model as follows:

$$ECR = \beta 0 + \beta 1GFit + \beta 2Controlit + \varepsilon it \quad (2)$$

Wherein, ECR represents energy efficiency. According to the test rules, when conducting the mediation effect test, if the regression coefficient α_1 of model (1) and the coefficient β_1 in model (2) are both significant, it can be inferred that energy efficiency plays a

Table 1: Green fiscal indicator system

Target layer	Criterion layer	Index layer	Indicator specification	weight
Green fiscal comprehensive index	Environmental protection	Proportion of environmental protection expenditure	Environmental protection expenditure/Local fiscal general budget expenditure	0.1349929
	Technological progress	Proportion of science and technology expenditure	Science and technology expenditure/Local fiscal general budget expenditure	0.3849474
		Proportion of education expenditure	Education expenditure/Local fiscal general budget expenditure	0.0979961
	Social security and social services	Proportion of public service expenditure	General public service expenditure/Local fiscal general budget expenditure	0.2103037
		Proportion of green fiscal revenue	(Resource tax+Urban maintenance and construction tax+Urban land use tax+Vehicle and vessel usage and license plate tax+Farmland occupation tax)/Local fiscal general budget revenue	0.0369228
		Proportion of social security and employment expenditure	Social security and employment expenditure/Local fiscal general budget expenditure	0.1348371

Table 2: Variables and explanations

Variable category	Variable description	Variable abbreviation	Specific explanations
Explained variable	Carbon emissions	lnC	logarithm of carbon emissions
Core explanatory variables	green fiscal comprehensive index	GF	green fiscal comprehensive index measurement value
Control variables	logarithm of population size	lnPSE	logarithm of the total population
	logarithm of economic development level	lnEDL	logarithm of GDP per capita
	Proportion of secondary industry	Strind	Secondary industry/GDP
	Proportion of tertiary industry	Strsev	Tertiary industry/GDP
Intermediary variables	Energy efficiency	ECR	Total energy consumption/GDP

mediating role in the carbon emission reduction effect of green fiscal.

3.2 Variable description

3.2.1 Explained variable. This article refers to the practice of (Zhang, Li & Li ,2024) Carbon emissions (lnC) are taken as the explained variable.

3.2.2 Core explanatory variable. The core explanatory variable is the green fiscal comprehensive index (as shown in Table 1) .

3.2.3 Control variables. Population size, economic development level and the ratio of the secondary and tertiary industries will have an impact on green fiscal and carbon emissions.so they are used as control variables.

3.2.4 Intermediary variables. Energy efficiency was selected as the intermediary variable, and it was expressed by the energy consumption per unit GDP of each province.

3.3 Data Sources and Descriptive Statistics

This study uses data samples from 29 provinces in mainland my country (excluding the Tibet Autonomous Region and Shanghai) from 2007 to 2021 for analysis. Carbon emissions data comes from the CEADs database. Energy efficiency is calculated using the statistical yearbooks of each province. Other various indicators are calculated based on data provided by the National Bureau of Statistics. Table 3 gives the descriptive statistics of the variables.

Table 3: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
lnc	435	5.584	.802	3.218	7.65
gf	435	.343	.09	.162	.667
lnedl	435	10.637	.563	8.841	12.123
strind	435	.445	.088	.158	.615
strsev	435	.449	.094	.286	.839
lnpse	435	8.208	.753	6.314	9.448
ecr	435	.892	.51	.176	3.46

Table 4: Benchmark regression results

	(1)	(2)
	lnc	lnc
gf	-2.385***	-1.449***
	(-13.728)	(-9.247)
lnedl		0.307***
		(8.485)
strind		-0.577
		(-0.996)
strsev		-0.842
		(-1.374)
lnpse		0.613***
		(2.943)
_cons	6.402***	-1.581
	(106.097)	(-1.011)
N	435	435
R^2	0.318	0.576
F	188.445	108.921

***p<0.01, **p<0.05, *p<0.10

From column (1) in the table, we can see that when the baseline regression does not include control variables, the regression coefficient of the green fiscal comprehensive index (GF) is -2.385, and it is significant at the 1% level. Column (2) shows the baseline regression results with control variables, and the regression coefficient of the green fiscal comprehensive index (GF) is -1.449, which is still significant at the 1% level. Regardless of whether the control variables are added, the p value is significant and effective, indicating that green fiscal can significantly promote the reduction of carbon emissions.

4 Empirical analysis

4.1 Benchmark regression analysis

After the Hausman test, the regression model uses time and region fixed effects. The benchmark regression results are shown in Table 4

4.2 Robustness test

The logarithm of carbon emission intensity (lnCII) is used to replace the explained variable to test the robustness of the benchmark regression results. The results are shown in Table 5

4.3 Mechanism test

As shown in Table 6, to test the mechanism, energy utilization efficiency (ECR) is used as a mediating variable to test the green finance comprehensive index (GF).

4.4 Heterogeneity analysis

To further study the differences in the carbon emission reduction effects of green fiscal in different regions, the 29 provinces are divided into eastern, central and western regions. The eastern region includes 9 provinces: Beijing, Tianjin, Hebei, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan; the central region includes 6 provinces: Shanxi, Anhui, Jiangxi, Henan, Hubei and Hunan; the western region includes 11 provinces: Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang. The results are shown in Table 7.

The central and western regions are mainly dominated by the primary and secondary industries, and the economic development level is relatively low. The carbon emission reduction effect of green fiscal is very significant in the central and western regions. Regardless of whether the control variables are added, the regression

Table 5: Robustness test results

	(1)	(2)
	lnc	lncii
gf	-1.449***	-0.858***
	(-9.247)	(-6.270)
lnedl	0.307***	-0.607***
	(8.485)	(-19.197)
strind	-0.577	-1.124**
	(-0.996)	(-2.224)
strsev	-0.842	-0.315
	(-1.374)	(-0.589)
lnpse	0.613***	0.244
	(2.943)	(1.343)
_cons	-1.581	7.274***
	(-1.011)	(5.328)
N	435	435
R^2	0.576	0.726
F	108.921	212.640

***p<0.01, **p<0.05, *p<0.10

In Table 5, after replacing the explanatory variables in column (2), the regression coefficient of the green fiscal composite index (GF) is significantly negative, which continues to support the reliability and robustness of the research conclusions obtained in the benchmark regression.

Table 6: Intermediary inspection results

	(1)		(2)
	ecr		logc
gf	2.903***		-0.461***
	(11.972)		(-2.965)
ecr			-0.340***
			(-12.395)
_cons	-20.537***		-8.574***
	(-8.486)		(-5.930)
N	435		435
R^2	0.798		0.694
F	316.685		150.925
Sobel test		-0.674***	

***p<0.01, **p<0.05, *p<0.10

In column (1) of Table 6, the regression coefficient of the green fiscal comprehensive index is positive and significant at the 1% level, indicating that green fiscal can significantly improve energy efficiency. In column (2), the core explanatory variable green fiscal comprehensive index (GF) is significantly negative at the 1% level, and the mediating variable energy utilization efficiency (ECR) is significantly negative at the 1% level. To further clarify the effectiveness of the transmission mechanism, the Sobel test is selected to verify the significance of the transmission mechanism. The coefficient of the Sobel test result is -0.647 and is significant at the 1% level. The above results show that energy efficiency has a mediating effect in green fiscal carbon emission reduction.

coefficient of the green fiscal comprehensive index (GF) is significantly negative at the 1% level. This shows that the development of green fiscal can significantly reduce carbon emissions.

5 Conclusion

The conclusions drawn in this paper are: First, green fiscal can effectively suppress carbon emissions, and this result still holds after robustness testing; Second, from the perspective of the mechanism of action, energy efficiency has a mediating effect on green fiscal carbon emission reduction; Third, from the perspective of heterogeneity analysis, the carbon emission reduction effect of green fiscal is more significant in the central and western regions. Therefore, we should optimize green fiscal policies and improve energy efficiency. We should formulate green fiscal policies based on the development of each region. We should promote the optimization

Table 7: Heterogeneity analysis results

	East		Middle		West	
	logc	logc	logc	logc	logc	logc
gf	-0.258	-0.755**	-1.938***	-1.943***	-2.233***	-3.239***
	(-1.050)	(-2.146)	(-5.295)	(-3.719)	(-8.779)	(-15.879)
logedl	0.208***		0.881***		0.162***	
	(2.639)		(8.529)		(2.988)	
strind	4.160***		-10.577***		0.478	
	(3.296)		(-5.508)		(0.431)	
strsev	3.721***		-9.498***		-0.160	
	(3.034)		(-4.834)		(-0.144)	
logpse	0.401		-6.314***		1.543***	
	(1.201)		(-3.509)		(3.361)	
_cons	-3.555	5.912***	60.948***	6.556***	-7.977**	6.302***
	(-1.346)	(40.752)	(4.008)	(34.334)	(-2.291)	(103.936)
N	135	135	90	90	165	165
R^2	0.604	0.036	0.705	0.143	0.712	0.622
F	36.985	4.604	37.724	13.832	73.802	252.146

***p<0.01, **p<0.05, *p<0.10

In Table 7, the regression coefficient of the green fiscal comprehensive index (GF) in the eastern region is significantly negative at the 5% level without adding control variables, but the regression coefficient of the green fiscal comprehensive index (GF) is not significant when adding control variables for regression analysis. This may be due to the developed economy in the eastern region and the dominant position of the tertiary industry in the industrial structure. In addition, in the long-term development process of enterprises, they have relatively advanced production technology and equipment, and the effect of improving energy efficiency brought by the development of green fiscal has tended to saturate, and the role of green fiscal in carbon emission reduction has decreased.

and upgrading of production technology and integrate the concept of green development into enterprise development.

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