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Tax pressure, farmland management, and agricultural carbon abatement: Empirical evidence from tax-and-fees reform in rural China

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Agriculture is the second largest source of carbon emissions in the world. To achieve the strategic goals of "carbon peaking" and "carbon neutrality", how to effectively control agricultural carbon emissions has become a focus of the Chinese government. As China's most critical agricultural policy in the early 21st century, assessing the impact of rural tax-and-fees reform (RTFR) on agricultural carbon emissions has vital theoretical and practical implications. Based on panel data of 31 Chinese provinces from 2000 to 2019, this paper constructs a continuous difference-in-differences (CDID) model to identify the effects of RTFR on agricultural carbon emissions, and further tests the mechanisms and heterogeneity of the reform to achieve agricultural carbon emission reduction. The results demonstrate that the reform can effectively reduce the agricultural carbon intensity and improve agricultural carbon efficiency, with the effects of −6.35% and 6.14%, respectively. Moreover, the dynamic effect test shows that the impact of RTFR on agricultural carbon intensity and carbon efficiency is persistent. Furthermore, the mechanism analysis indicates that RTFR achieves the improvement of agricultural operation efficiency and the reduction of agricultural carbon emissions through the expansion of land operation area, the increase of productive investment in agriculture, and the special transfer payment from the central government. However, the impact of RTFR on local government revenue is not conducive to realizing the reform's carbon reduction effect. The heterogeneity analysis illustrates that the reform policy effects differ in natural climatic conditions, topographical conditions, and crop cultivation structure. The RTFR mostly has a significant negative impact on the carbon emissions generated from material inputs and agricultural production. Therefore, to address the climate change crisis and improve the environmental efficiency of agricultural production, it is necessary to both reduce peasants' tax burden and implement institutional construction efforts, to further promote the transformation of agricultural production to a low-carbon model.

KEYWORDS

rural tax-and-fees reform, agricultural carbon abatement, farmland management, continuous difference-in-differences model, tax pressure

1 Introduction

Since the 1980s, the massive emission of greenhouse gases represented by carbon dioxide has led to a significant acceleration of the global warming trend, and the resulting environmental problems have caused a momentous negative impact on the normal operation of human society, and it has become the consensus of the international community to curb greenhouse gas emissions (Jia et al., 2021; Wang et al., 2021; Wang et al., 2022). Evidence shows that agricultural greenhouse gas emissions account for about 25% of global emissions, ranking second only to energy emissions (Yang et al., 2022). In China, agricultural greenhouse gas emissions account for about 15% of the total national emissions, and are the main source of greenhouse gas emissions (Cui et al., 2021; Kong et al., 2022). Therefore, in the context of Chinese society's efforts to achieve "carbon peaking" and "carbon neutrality", it is of great strategic importance to investigate the influencing factors and pathways of agricultural carbon abatement.

To achieve agricultural carbon emission reduction, it is necessary to innovate agricultural development models and enhance the efficiency and level of agricultural production (Jia et al., 2021; Guo et al., 2022; Huang et al., 2022; Xu et al., 2022; Yu et al., 2022). From the international experience, the more successful agricultural modernization models are broadly divided into two kinds. One is the large-scale land management agricultural production model represented by the United States, and the other is the technology-intensive agricultural production model represented by the Netherlands and Israel (Cabral et al., 2022; Chen et al., 2022; Liu and Wang, 2022). Because of the huge geographical differences and uneven population distribution in China, both agricultural modernization models are possible in regions with different comparative advantages (Han and Lin, 2021; Huang and Xiong, 2022). In terms of large-scale operation, a reasonable concentration of land is extremely important. Through the transfer of land, the concentration of land from general farmers to farmers with high productivity and the development of moderate scale operation can effectively improve production efficiency and realize the modernization of agricultural production methods (Carauta et al., 2021; Li et al., 2022). In terms of technologized operation, in addition to continuous innovation in agricultural technology, it is more important that farmers have the capital and ability to apply new technologies to the actual production process, improve new technologies such as mechanical, biological, and environmental protection that are actually used in agricultural production, and complete the technological transformation of agricultural production methods (Chen, 2020; Norton and Alwang, 2020; Zhang et al., 2022).

However, to complete the transformation of agricultural production in large-scale and technology, all cannot be without the corresponding capital investment (Liu et al., 2019; Fei et al., 2021). Generally, China has many people and little land, which is a typical agricultural production mode of the small-scale peasant economy (Liu and Zhuang, 2000). The small-scale peasant economy is the most widely distributed agricultural production mode in East Asia, with many characteristics such as decentralized operation on small plots of land; low productivity level; insufficient specialization and division of labor; low economic returns; and inferior risk resistance (Munroe, 2001; Lahiff and Kay, 2007; Akram-Lodhi and Kay, 2010; Zhang, 2012; Falkowski, 2018). Therefore, the crucial to achieving the modernization and transformation of traditional Chinese agriculture is to address the plight of insufficient agricultural capital and low returns for farmers. For a long time, Chinese farmers not only need to face the difficulties of low agricultural returns, but also have to bear an excessive land burden (Xu et al., 2020). Land burden mainly refers to a series of tax and fee pressures, including agricultural tax, agricultural special tax, and rural public expenditure. Under the heavy pressure of land burden, the comparative return of agricultural operation is low, the contradiction of increasing production without increasing farmers' income is prominent, and land transfer is difficult (Rymanov, 2017; Gurel, 2019). In some regions, farmers who have transferred their land are not only unable to receive their rightful land rent, but even have to pay unreasonable land transfer management fees. Under such conditions, the double constraints of land burden and agricultural income have suppressed the rational concentration of land and restricted the reasonable investment in agricultural reproduction, which has seriously prevented the modernization and transformation of Chinese agriculture.

Against this background, to maintain social stability, solve the problem of the excessive burden on farmers, and promote the modernization of agriculture and rural areas, the Chinese government gradually implemented the rural tax-and-fees reform (RTFR) in the early 21st century (Li and Sicular, 2014; Wang, 2019). By the end of 2005, the agricultural tax, which had lasted for more than 2,000 years in Chinese society, was officially suspended, marking a fundamental change in the relationship between urban and rural areas as well as agricultural production in China (Chen, 2009). By the end of 2006, the reform directly alleviated the tax-and-fees' burden on farmers by about 160 billion Yuan, with a per-capita reduction of about 170 Yuan. Therefore, the RTFR objective reduces the pressure on farmers' land and helps increase agricultural income (Tao and Qin, 2007; Liu et al., 2012; Wang and Shen, 2014). Under the realistic requirement of constructing a low-carbon society, does the RTFR help reduce agricultural carbon emissions? Further, can the impact of RTFR on carbon emissions be realized through the effective utilization of land? In addition, considering the economic and geographical conditions of China, how do the carbon abatement effects of the reform vary in different geographical regions? These are a series of questions that need to be assessed scientifically.

The existing literature demonstrates that government policy intervention is effective in achieving agricultural carbon abatement (Huang et al., 2022; Li and Li, 2022; Yang et al., 2022). Regarding traditional fiscal and monetary policies, rural support-oriented fiscal policies can lead to agricultural emission reduction by promoting agricultural technological progress, increasing farmers' investment capacity, and improving cultivated land quality (Lin and Huang, 2021; Mamun et al., 2021). The Chinese government's policy to develop digital and green finance can also decrease agricultural carbon emissions by guiding farmers' entrepreneurship and agricultural technology innovation (Chang, 2022; Guo et al., 2022; Xu et al., 2022). As for environmental regulation policies, administrative regulation imposed by the central government on local governments and government officials is also conducive to agricultural carbon abatement by stimulating technological innovation inputs and agronomic investments by local governments (Liu et al., 2022). It has also been argued in the literature that enhanced remote regulation of agricultural tractor use by the government is also contributive to improving agricultural production efficiency to achieve carbon curbs (Hou et al., 2022). In addition, carbon trading policies are also considered as an effective measure to achieve carbon mitigation in agriculture (Wu et al., 2022). Carbon trading policies can control agricultural carbon emissions by affecting the technical efficiency of agricultural enterprises, agricultural production efficiency, and consumer preferences (Hua et al., 2022; Yu et al., 2022). In terms of land use policies, long-term rational land planning formulated by local governments is conducive to minimizing the leakage of agricultural carbon emissions through agricultural intensification (Pan et al., 2020). Meanwhile, some scholars argue that carbon emission reduction plans based on market incentives may make policy makers' emission reduction goals deviate from farmers' production goals, which in turn is detrimental to the government's commitment to reduce land use change and agricultural GHG emissions (Carriquiry et al., 2020; Carauta et al., 2021).

In addition, the existing literature provides an extensive discussion on the effects of agriculture-related tax policies. Bawa and Williamson (2020) evaluate the impact of the U.S. *Tax Cuts and Jobs Act* (TCJA) on income distribution. They find that the TCJA reduces the tax system's progressivity and has a higher revenue-raising effect on middle- and high-income farm households. By assessing the tax system in Serbia, Milosevic et al. (2020) find that an agricultural tax system based on organic production and tax incentives is conducive to achieving higher levels of sustainable agricultural production. Moreover, Buchholz and Musshoff (2021) find that pesticide taxation in Germany induces farmers to adjust their planting and farming strategies and thus achieve green agriculture. Meanwhile, a study conducted in Denmark came to a similar conclusion that pesticide taxation could promote green technological innovation in agricultural products (Pedersen et al., 2020). Besides, Moberg et al. (2021) argue that the imposition of food excise taxes in Sweden can reduce ecological pollution from agricultural production by restricting the expansion of agricultural land. In China, Shen et al. (2021) find that the progressivity of China's tax system has increased after the abolition of agricultural taxes, dramatically improving rural residents' social welfare. However, it is also observed that the abolition of agricultural taxes objectively exacerbated the fiscal pressure on local governments, causing them to turn to distort energy prices to cover fiscal deficits and further worsen energy efficiency (Jiang et al., 2022). Simultaneously caught in the fiscal pressure, local governments intensified their Value Added Tax (VAT) collection efforts after the agricultural tax abolishment, which in turn increases the operating costs of Small and medium-sized enterprises (SMEs) and private firms and negatively affects the welfare effects of workers (Li et al., 2021). Furthermore, Xu et al. (2020) compare the impact of soil N_2O emissions on agricultural green total factor productivity (AGTFP) before and after agricultural tax reform and find that the impact of soil N_2O emissions on AGTFP is more pronounced after 2006.

The above literature suggests that the current research results on the impact of public policies on agricultural carbon emissions and the effects of tax reform policies are relatively abundant, which helps to correctly understand the basic status, influencing factors, and mechanisms of agricultural carbon emissions, and also provides a solid theoretical foundation for the further development of agricultural carbon abatement mechanisms and institutional arrangements. However, even so, there are still shortcomings in the existing studies, which are mainly reflected in two aspects: first, most of the discussions in the current literature focus on the impact of agriculture-related tax policies on agricultural emissions in developed countries, and there is a lack of analysis on developing countries. Actually, developed countries have fully completed the industrialization and modernization transition, and the amount of agriculture-related tax revenues accounts for a relatively low proportion of the total tax revenue. In contrast, in developing or underdeveloped countries, the industrialization and modernization transition is still a work in progress, and the impact of agricultural tax revenues on the overall national fiscal revenues is conversely larger. Thus, the absence of existing literature on the abatement effect of agricultural tax policies in developing countries is not conducive to an in-depth insight into how developing countries can direct the greening of agriculture and rural development through fiscal policy reforms. Second, when discussing the effects of agriculture-related tax policies, the existing literature mainly analyzes the impact of tax policies on income distribution, enterprise behavior, farm household behavior, and energy efficiency. These studies lack a detailed discussion of agricultural tax reform effects' on agricultural environmental governance, which ignores the direct policy objectives of agricultural tax reform and is not beneficial to conclude the lessons learned from agricultural tax reform on agricultural and rural environmental governance.

To compensate for the gaps in the existing literature, we construct a quasi-natural experiment with the RTFR implemented by the Chinese government in 2005 to evaluate the impact of RTFR on agricultural carbon emissions, by using a difference-in-differences with a continuous treatment (CDID) approach based on panel data of 31 provincial administrative regions in China from 2000 to 2019. Compared with the previous studies, the possible contributions of this paper include: first, based on the policy practice in China, we use the CDID method to assess the impact of RTFR on agricultural carbon emissions for the first time, which increases the reliability of the conclusions and addresses the gap in the existing literature regarding the impact of agricultural tax policy reform on agricultural environmental pollution in developing countries. Second, we discuss in detail the mechanism behind the effect of RTFR on agricultural carbon abatement in two dimensions: the subject of taxation (farmers) and the object of taxation (governments). This contributes to a deeper understanding of how tax system reform affects the behavior of farmers and governments, and thus provides lessons for developing countries to improve their agricultural carbon abatement mechanisms and institutional arrangements. Third, we provide a relatively comprehensive and systematic measurement framework for agricultural carbon emissions. The framework systematically evaluates China's agricultural carbon emissions from three aspects: agricultural material inputs, agricultural cultivation, and crop growth. Compared with the lack of carbon emission measurement in tillage and crop growth (Guo et al., 2022; Li et al., 2022; Yang et al., 2022), our framework can reflect the actual situation of agricultural carbon emissions in China more objectively and comprehensively.

The remainder of this paper is organized as follows: Section 2 presents the institutional background and theoretical framework; Section 3 is the methodology, which focuses on this paper's framework for measuring agricultural carbon emissions and the identification of causal relationships; Section 4 presents the main results, and shows the estimation results of robustness tests after reporting the benchmark regressions; Section 5 is the mechanism identification; Section 6 is the heterogeneity analysis; and Section 7 is the study conclusions, policy implications, and limitations.

2 Institutional background and theoretical framework

2.1 Institutional background

The RTFR launched by the Chinese government at the beginning of the 21st century is another major historical event following the 1978 system of responsibility for the joint production of Chinese rural families. The reform completely terminates the exploitation of peasants in China's traditional agricultural society, and accomplishes a historic institutional change unprecedented in more than 2,000 years. Launched in 2000 and finally completed by the end of 2005, the reform can be roughly divided into two stages according to the process of reform.

The period from 2000 to 2003 was the first phase of the RTFR (the rural fees reform phase), and the primary policy objective of this phase was to regulate the agricultural fees system and curb the rural fundamental government from charging peasants indiscriminately. In March 2000, the RTFR is first piloted in Anhui province. From 2001 to March 2003, the reform is gradually extended to Jiangsu, Shanghai, Zhejiang, Hebei Inner Mongolia, Jilin, Heilongjiang, Jiangxi, Shandong, Henan, Hubei, Hunan, Sichuan, Chongqing, Guizhou, Shaanxi, Gansu, Qinghai, Ningxia, and other 18 provincial administrative regions. The main contents of this phase include: (1) Abolishing public expenditure charges of countryside governments; abolishing rural education and other agricultural-related managerial fees and government funds; and abolishing the slaughter tax. (2) Adjusting the agricultural tax and agricultural special tax, and setting the upper limit of the agricultural tax rate at 7%. (3) Reforming the collection methods of the three public expenditure charges in rural communities, and gradually abolishing the labor accumulation employment and compulsory employment institutions for public affairs. Overall, the RTFR in this phase regulates the phenomenon of unreasonable fees and charges in rural China, leading to a significant decrease in the burden on peasants.

From 2004 to the end of 2005, the second phase of the RTFR, that is, the agricultural tax reform phase, the principal policy objectives of this phase are to gradually reduce the agricultural tax rate until the final abolishment, and to establish the corresponding supporting measures in the post-agricultural tax era. The major reform measures in this phase include: (1) In January 2004, the central government formally aborts the agricultural special tax except for the tobacco leaf tax at the national level. In March 2004, Heilongjiang and Jilin provinces took the lead in abolishing the agricultural tax. Meanwhile, the agricultural tax rate was reduced by three percentage points in 11 grain-producing provinces (districts), including Hebei, Inner Mongolia, Liaoning, Shandong, Jiangsu, Jiangxi, Anhui, Henan, Hubei, Hunan, and Sichuan; the agricultural tax rate is reduced by one percentage point in

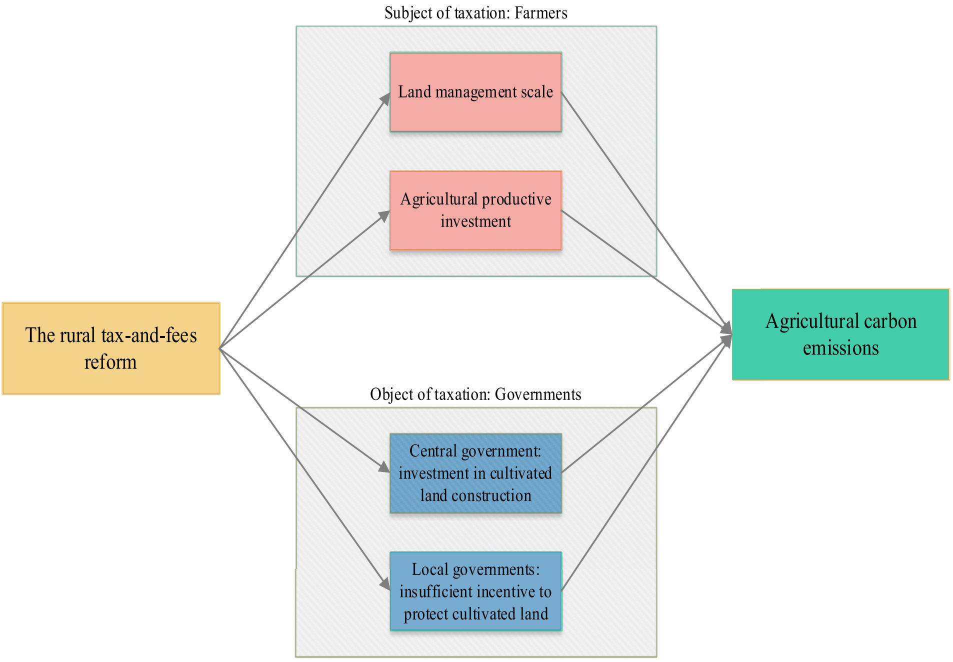


FIGURE 1
Framework for analyzing the agricultural carbon abatement effect of the RTFR in China.

the remaining provinces. By the beginning of 2005, agricultural taxes are completely abolished in all provinces except for a few counties in Hebei, Shandong, and Yunnan, where agricultural taxes are still levied at a lower rate. On 29 December 2005, the central government announced that the agricultural tax would be officially abolished as of 1 January 2006, which means that the agricultural tax, which has existed in China's rural areas for more than 2,000 years, has completely bid farewell to the historical stage, and China's rural areas have ceremoniously entered the post-tax era. (2) In terms of supporting measures: In March 2004, the central government introduced direct production subsidies for grain farmers in 13 major grain-producing regions, and seed subsidies and agricultural machinery purchase subsidies for peasants in other regions. In 2005, the central government launched a nationwide policy of "two reductions and three subsidies", which directly increased farmers' income by about 45 billion yuan at the end of 2005. At the same time, since 2004, the central government has arranged special transfer payments for RTFR, mainly for farmland improvement and rural public infrastructure construction, which amounted to 52.4 billion yuan in that year, making up for the shortfall in fiscal expenditures of grassroots governments after the reform. On 1 January 2006, *the Regulations of the People's Republic of China on Agricultural Taxes*, which had been in effect since 1958, were officially abolished, and the 6-year rural tax reform is finally completed.

2.2 Theoretical framework

Generally speaking, the tax issue involves two aspects: the object of taxation, which is the taxpayer, is responsible for paying taxes, and the subject of taxation, which is usually the government, is responsible for collecting taxes (Hines and Keen, 2021; Hotak and Kaneko, 2022). Therefore, when studying the mechanism behind the effect of tax reform policy, we need to analyze both the object of taxation (farmers) and the subject of taxation (government). To visualize our analysis, Figure 1 gives the theoretical framework of this paper.

2.2.1 The subject of taxation: Farmers

Under the reality of China's small-scale peasant economy, the inputs of production factors such as land, labor, and cultivated materials are highly fragmented in rural areas. Moderate scale management of agricultural land can obtain scale revenue through the expansion of land production scale, which can solve the problem of land fragmentation, to a certain extent, and promote the scale management of cultivated land (Liu et al., 2018). Meanwhile, it is also conducive to the large-scale use of agricultural machinery, pesticides, and fertilizers, reducing the waste caused by decentralized inputs, promoting agricultural intensification, and thus reducing pollution emissions and improving agricultural operation efficiency (Diao et al., 2018). Moreover, under market economy conditions, the free transfer of land will induce farmers with lower marginal land output to rent out their land to farmers with higher marginal output, which can improve the productivity of farmers in general, and thus achieve more agricultural output with the given factor inputs and realize energy saving and emission reduction (Liu et al., 2019; Chambers and Pieralli, 2020; Li et al., 2021). However, the orderly transfer of land is a prerequisite for the realization of large-scale management (Adamopoulos and Restuccia, 2020). Before the reform of rural tax-and-fees, farmers face burdens from both agricultural taxes and various non-tax forms of fees. In some areas, agricultural taxes are increased at various levels, and taxes are often apportioned according to the area of farmland, which makes the problem of increasing production without increasing income prominent. Under the heavy burden of taxes and fees, the comparative revenue of agriculture is low, and the long-term lack of investment in agriculture hinders the normal transfer of farmland and is not conducive to the expansion of operation scale. In addition, the impact of transaction cost, as a non-productive cost, on agricultural land transfer deserves attention (Gao et al., 2019). In the process of land transfer, the supply and demand sides need to conduct multiple rounds of negotiation on the burden of agricultural taxes and fees, which increases the transaction cost of land transfer and thus discourages the expansion of the land operation scale. Thus, after the rural taxes and fees reform, the burden of peasants is reduced, the transaction cost of farmland transfer is lowered, and the revenue of agricultural operation is relatively higher, which can increase the effective demand for farmland transfer, and then expand the scale of farmland operation, improve the efficiency of agricultural production, and reduce carbon emission. Accordingly, we propose hypothesis 1.

H_1: Rural tax reform can achieve improvement in agricultural carbon emission performance by expanding the scale of farmland management.

Compared with traditional agriculture, modern agriculture can enhance agricultural production efficiency through the development of agricultural mechanization, the widespread application of pesticides and fertilizers, and the adoption of new cultivation techniques (Conradie et al., 2009; Guanziroli et al., 2013; McArthur and McCord, 2017). Empirically, traditional agriculture production cannot be achieved without labor input, while the sustainable development of modern agriculture depends on agricultural investment and the advancement of agricultural production technology (Chen, 2020; Mano et al., 2020). For agricultural investment, productive investment of peasant households can increase agricultural production efficiency and improve carbon emission performance by enhancing soil conservation, leveling arable land, and utilization of new technologies and production tools, thereby achieving more agricultural products output with given production inputs (Liu et al., 2020; Norton and Alwang, 2020). However, farmers' productive investments are often influenced by factors such as returns on agricultural products, government policies, financial market conditions, and land institutions (Zhang and Fan, 2004; Kallas et al., 2012; Lecoutere and Jassogne, 2019; Czubak et al., 2021). Before the RTFR, the burden of taxes and fees, such as agricultural taxes, rural public expenditure fees, and compulsory labor, prevented the improvement of cultivated returns and discouraged farmers from accumulating wealth, which in turn inhibited the growth of productive investment. Meanwhile, before the reform, taxes and fees collection by grassroots governments is more subjective. Due to the pressure of fiscal expenditure, grassroots governments usually mix formal taxes and fees with miscellaneous fees and charges, resulting in strong policy uncertainty and poor predictability. Thus, under the pressure of highly uncertain taxes and fees, peasants are exposed to the risk of tax fluctuations and have to reduce their agricultural investments in order to secure their basic productive livelihood and tax needs, which in turn discourages the development of productive efficiency. After the rural reform, the tax burden disappears, and unreasonable taxes and fees are abolished. Under this condition, agricultural revenues increase and policy uncertainty decreases, which helps to strengthen farmers' perception of security and increase expected revenues, thus stimulating their agricultural investment and hence increasing their agricultural productivity. In summary, we propose hypothesis 2.

H_2: RTFR can improve agricultural carbon performance by increasing agricultural productive investment.

2.2.2 The object of taxation: Governments

After the RTFR, the central government proceeded to establish a set of supporting reform measures corresponding to the reform. A series of reform initiatives increased transfer payments to counties and townships in financially difficult and impoverished areas, and increased support for infrastructure construction and social development while safeguarding the expenditures required by grassroots governments to perform their functions. Concerning the construction and protection of cultivatable land, the central government arranges special funds for the construction of farmland water conservancy, which improves the agricultural irrigation conditions in rural China. Meanwhile, through a series of institutional arrangements, the central government also implements fertile land projects and farmland standardization construction projects, and increases efforts to reclaim and organize land, improving the quality of arable land in rural China. Considering that irrigation and cultivation activities are essential sources of agricultural carbon emissions in China (Guo et al., 2022; Li et al., 2022; Yang et al., 2022), the treated arable land is more scientifically and rationally equipped with irrigation facilities and has a higher degree of cultivation standardization. As a result, the energy consumed for irrigation and tillage used to produce a unit area of crops is saved, which improves the efficiency of agricultural operations and contributes to the improvement of agricultural carbon performance (Kirmikil and Arici, 2013; Hong et al., 2019; Yuan et al., 2022). For this reason, we propose hypothesis 3.

H_3: After the RTFR, the central government's investment in agricultural cultivation governance can optimize the layout of field roads, irrigation facilities, and cultivated land, which in turn promotes cultivated operation efficiency and contributes to the enhancement of agricultural carbon performance.

As the direct beneficiaries of agricultural taxes, the behavior of local governments deserves special attention; after the 1994 tax-sharing reform, China's taxes were divided into three categories: central taxes, local taxes, and shared taxes. The implementation of the tax-sharing system causes fiscal revenues to be tilted toward the central government and the share of local revenues to decline, but local governments still need to bear a large amount of public goods expenditures, leading to an increase in the gap between local government revenues and expenditures and an urgent need to find new sources of revenues to make up for the gap (Zhang, 2018; Ding et al., 2019). In addition, the lack of clear property rights of rural land leads to the absence of agricultural land owners, the deficiency of collective economic organizations, and the lack of land contracting rights of farmers, which puts rural land in a disadvantaged position compared to urban land on property rights (Hong and Sun, 2020; Wang and Tan, 2020). Therefore, under the fiscal decentralization system, local governments are more inclined to expropriate peasant collective land in the urban periphery to cover the financial gap (Xu, 2019). By character, agricultural tax is a local tax and shared tax, and is a crucial source of financial revenue for the grassroots government. After the abolition of agricultural tax, the tax revenue of local governments is significantly reduced. In the absence of tax incentives, it intensifies the tendency of local governments to expropriate agricultural land on the outskirts of cities in exchange for fiscal revenue (Li et al., 2010; Zeuthen, 2018). Under the constraints of *The Land Management Law of the People's Republic of China*, the Chinese government implements a compensation system for the occupation of arable land. That is, the amount of arable land occupied by construction is to be supplemented by an equivalent amount and quality of arable land. However, in the process of rapid industrialization and urbanization, the preservation of arable land is increasingly regarded as a heavy political and financial burden by local governments. The problem of substandard compensation land for occupied arable land is widespread, which affects the quality of China's arable land to a certain extent (Zhong et al., 2017; Yang et al., 2018; Shao et al., 2020). Thus, on arable land with relatively worse quality, peasants will adopt intensive farming methods and invest more fertilizers, farm materials, and cultivating labor to increase agricultural output per unit area, which objectively exacerbates agricultural carbon emissions and is not conducive to the improvement of agricultural carbon performance. Accordingly, this paper proposes hypothesis 4.

H_4: After the RTFR, the incentive of local governments to protect cultivated land decreases, which affects the quality of arable land in China and is detrimental to the improvement of agricultural carbon performance.

3 Methodology

3.1 The measurement of agricultural carbon emissions

Based on the whole process of agricultural production, this paper measures China's agricultural carbon emissions from three aspects: agriculture material input, agricultural production, and crop growth, by drawing on relevant studies (Zhang et al., 2019; Cui et al., 2021; Liu et al., 2021). The specific measurement framework is shown in Figure 2.

In terms of agricultural material inputs, we specifically investigate the carbon emissions generated by pesticides, fertilizers, agricultural films, and agricultural diesel fuel during the production process of this product and its subsequent application, and the corresponding agricultural carbon emission factors refer to the literature of Liu et al. (2021) and Zhang et al. (2019). For agricultural production, we examine the carbon emissions from cultivation and irrigation activities. Agricultural cultivation disrupts the carbon fixation function of the soil, and organic carbon in the soil is lost to the air, resulting in carbon emissions. The irrigation process indirectly consumes fossil fuels such as oil, which also contributes to carbon emissions. The carbon emissions from these two agricultural production activities are derived from the study by Yang et al. (2022). Finally, there are methane and nitrous oxide emissions induced by the crop growth process. We calculate the carbon emissions formed during the growth of the four major staple grains (rice, wheat, corn, and soybean) in China, with specific carbon emission factors derived from the research of Tian et al. (2014) and Xiong et al. (2016). Based on this measurement framework, we calculate the agricultural carbon emissions of each provincial administrative region in China by employing the following equation.

$$AC_{it} = \sum AC_{it}^{c} = \sum T_{it}^{c} \times \delta^{c} \tag{1}$$

Where AC_{it} denotes the total agricultural carbon emissions in period t of region i, and AC_{it}^{c} denotes the agricultural carbon emissions generated by carbon sources of category c in period t of region i. T_{it}^{c} and δ^{c} denote the actual quantities of each type of carbon sources consumed and their corresponding carbon emission coefficients, respectively. To facilitate analysis and comparison, we convert the greenhouse gases produced by each carbon source into standard carbon dioxide uniformly in the actual calculation process.

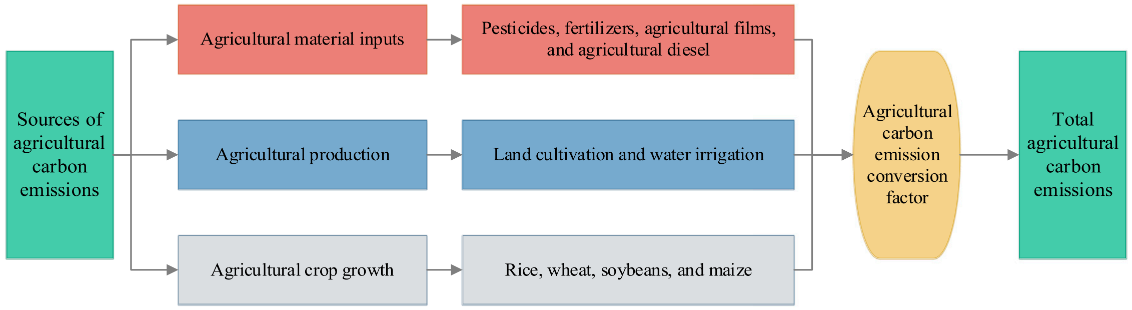


FIGURE 2
Measurement framework of agricultural carbon emissions in China.

3.2 Model setting

The difference-in-differences (DID) model is a classic approach to assess policy effects (Wu et al., 2021). The general idea is to consider an exogenous policy shock as a quasi-natural experiment and to divide the sample into treatment and control groups. Then, an economic variable to be analyzed is selected, and two sets of variables are obtained by making the first difference for that economic variable according to the time before and after the policy implementation, and the first difference eliminates individual heterogeneity. Next, a second difference is made between the two sets of variables to eliminate the effect of time variation on the estimation results, and finally, the net effect of policy implementation is obtained (Wang et al., 2022). However, because RTFR is a policy reform conducted at a national level, each individual is subject to policy intervention. Thus, to identify the impact of RTFR on the agricultural carbon performance, drawing on Chen (2017) and Perego (2019), we use the CDID model by dividing the "relative treatment group" and the "relative control group" to estimate the results, and the model is set up as follows.

$$ACP_{it} = \alpha_0 + \alpha_1 \, Incentive_i \times Post + \gamma \, Control_{it} + year_t + province_i + \varepsilon_{it} \quad (2)$$

where i and t denote provinces and years. ACP_{it} is the agricultural carbon performance of province i in year t, measured by agricultural carbon intensity and agricultural carbon efficiency. $Incentive_i$ is the treatment intensity variable that divides the relative treatment group and the relative control group, which measures the magnitude of the impact from the policy shock on each province. $Post$ is the time dummy variable of the reform, which is assigned to one when the sample is in the year of the RTFR and subsequent years (i.e., 2005–2019). The term $Incentive_i \times Post$ is the treatment effect variable of the policy shock, reflecting the impact of RTFR on agricultural carbon performance, and its coefficient α_1 is the estimated parameter of the policy effect that we focus on. $Control_{it}$ is a set of control variables affecting agricultural carbon emissions; $year_t$ is the time fixed effect; $province_i$ is the provincial fixed effect; and ε_{it} is the random error term.

3.3 Variables and data

3.3.1 Dependent variables

Referring to the existing literature (Zhang et al., 2019; Wu et al., 2020; Liu et al., 2021; Guo et al., 2022), we select agricultural carbon intensity (ACI_{it}) and agricultural carbon efficiency (ACE_{it}) as proxy variables for agricultural carbon performance in China. Agricultural carbon intensity (ACI_{it}) represents CO_2 emissions per 10,000 Yuan of agricultural GDP, expressed using the total agricultural carbon emissions of each region divided by the agricultural GDP of that region. Agricultural carbon efficiency (ACE_{it}) is calculated employing the Super-SBM model that includes non-expected outputs (Wu et al., 2021). Specifically, we calculated agricultural carbon efficiency for each region in China, 2000–2019, by substituting labor, land, agricultural machinery, and fertilizer application as input variables, gross agricultural product as the expected output, and total agricultural carbon emissions as non-expected output in the Super-SBM model.

3.3.2 Independent variable

In the difference-in-differences model, the sample needs to be divided into treatment and control groups based on whether they are subject to policy intervention. However, in the RTFR, all provinces have been affected by policy shocks, and it is impossible to divide the "complete treatment group" and "complete control group". For this reason, we draw on the analytical idea of existing studies (Chen, 2017; Perego, 2019; Jiang et al., 2022), and construct a CDID model to divide the "relative treatment group" and "relative control group" for policy assessment by using the output value of agriculture, forestry, animal husbandry, and fishery industries in 2004 as a proxy variable to measure the intensity of exogenous shocks to RTFR. The reason for using the 2004 agricultural, forestry, animal husbandry, and fishery output value as the basis for classification is that, first, the fees reform in 2000–2003 has already affected the agricultural output value in 2004, and therefore, using the 2004 output value as the criteria for measurement reflects the policy effect after the complete abolition of the agricultural tax in 2005, rather than the previous effect caused by the fees reform. Second, because agricultural production is constrained by natural conditions, the impact of economic factors on agricultural production is relatively minor, and the prices of agricultural products generally remain stable in the long run under the policy guidance of the Chinese government (Yu, 2014; Yang et al., 2017; Nigatu and Adjemian, 2020). Thus, expressing the treatment variables in terms of the 2004 agricultural output level can avoid the two-way causality of the treatment variables after the reform, and also avoid the endogeneity of agricultural taxation and economic characteristics variables. On this basis, we standardize the total output value of agriculture, forestry, animal husbandry, and fishery in 2004 to obtain the agricultural output intensity of each province ($Incentive_i$), and multiply the agricultural output intensity with the dummy variable ($Post$), indicating the policy time to perform CDID regression. The specific formula of agricultural output intensity is as follows:

$$Incentive_i = \frac{Agriculture_i}{\overline{Agriculture}} \tag{3}$$

Where $Agriculture_i$ represents the total agricultural, forestry, animal husbandry, and fishery output value of province$i$ in 2004, $\overline{Agriculture}$ is the mean value of agricultural output value of all provinces in 2004, and $Incentive_i$ denotes the intensity of agricultural output value by province i in 2004. The independent variable ($Incentive_i \times Post$) is constructed by interacting the agricultural output value intensity ($Incentive_i$) with the time variable of policy occurrence ($Post$) to analyze the impact of agricultural tax reform.

3.3.3 Control variables

Taking reference from previous studies (Xiong et al., 2016; Zhang et al., 2019; Liu et al., 2021), we select the indicators related to economic and social development and agricultural production for each region as the control variables in this paper. The specific variables include regional gross domestic product, the proportion of secondary industry, the proportion of tertiary industry, the intensity of financial support to agriculture, crop cultivation area, agricultural mechanization level per unit area, fertilizer application intensity, disaster rate, and farmers' per capita disposable income.

The data used in this paper are mainly from *the China Statistical Yearbook*, *the China Rural Statistical Yearbook*, *the China Financial Yearbook,* and the provincial database from the National Bureau of Statistics, as well as the statistical yearbooks and statistical bulletins of each province. The specifics and descriptive statistics of each variable are reported in Table 1.

4 Results

4.1 Baseline regression

Table 2 reports the regression results of Eq. 2. In column (1), which includes only individual and time fixed effects, the coefficient of $Incentive_i \times Post$ is significantly negative at the 5% statistical level, indicating that the RTFR produces a significant carbon emission reduction effect, significantly reducing the agricultural carbon intensity. After adding control variables in column (2), the coefficient of$Incentive_i \times Post$ is still significantly negative at -0.0625, indicating that for every 1% higher ratio of agricultural output value to mean agricultural output value in a province before the reform, its agricultural carbon intensity is significantly reduced by 0.0625% after the RTFR in 2005. Meanwhile, as observed in column (3), the coefficient of $Incentive_i \times Post$ is significantly positive at the 1% statistical level, demonstrating that the RTFR significantly improves agricultural carbon efficiency and can perform the function of saving agricultural energy consumption. After adding control variables in column (4), the coefficient of $Incentive_i \times Post$ is still significantly positive at 0.0614, indicating that for every 1% higher ratio of agricultural output value to an average agricultural output value in a province before the reform, its agricultural carbon efficiency can be significantly higher by 0.0614% after the RTFR. Therefore, the baseline regression results initially verify the carbon reduction effect of the RTFR.

4.2 Parallel trend test and dynamics effects analysis

The prerequisite to enabling the validity of DID model estimation results is to satisfy the parallel trend assumption. That is, the dependent variables in the treatment and control groups have a common trend of change before the RTFR. To check the efficiency of the conclusions in this paper and to analyze the differences in the carbon reduction effects of RTFR at different time points, a dynamic effects analysis is conducted in this paper (Chunxiang et al., 2022), with the following model settings.

$$ACP_{it} = \beta_0 + \sum_{t=2001}^{2019} \beta_t \times Incentive_i \times Time_t + \gamma Control_{it} + year_t + province_i + \varepsilon_{it} \tag{4}$$

TABLE 1 Descriptive statistics.

Variables	Definition	Obs	Mean	Std. Dev	Min	Max
ACI_{it}	Logarithm of agricultural carbon intensity	620	9.3965	0.8539	7.0978	11.5801
ACE_{it}	Agricultural carbon efficiency	620	0.3579	0.2295	0.0675	1.1335
$Incentive_i \times Post$	The rural tax-and-fees reform	620	0.7727	0.7755	0.0000	2.8064
$lngdp_{it}$	Logarithm of gross domestic product	620	9.0440	1.2673	4.7689	11.7310
$is2_{it}$	Share of secondary industry value added in GDP	620	0.4196	0.0834	0.1597	0.6196
$is3_{it}$	Share of tertiary sector added value in GDP	620	0.4614	0.0911	0.2965	0.8373
ifa_{it}	Share of expenditure on agricultural and forestry services in government financial expenditure	620	0.1046	0.0426	0.0048	0.3137
$lnarea_{it}$	Logarithm of crop cultivation area	620	8.0895	1.1832	4.4836	9.6164
am_{it}	Total power of agricultural machinery divided by crop cultivation area	620	0.6005	0.3503	0.1317	2.6979
af_{it}	Fertilizer application divided by crop cultivation area	620	0.0341	0.0131	0.0088	0.0799
$adis_{it}$	Disaster area divided by crop cultivation area	620	0.2221	0.1602	0.0000	0.9359
$lnincome_{it}$	Logarithm of per capita disposable income of peasants	620	8.7761	0.7714	7.1929	10.5589

TABLE 2 Baseline regression results.

Variables	ACI		ACE	
	(1)	(2)	(3)	(4)
$Incentive_i \times Post$	−0.0635**	−0.0625***	0.0615***	0.0614***
	(0.0276)	(0.0231)	(0.0118)	(0.00734)
Control variables	NO	YES	NO	YES
Year fixed effect	YES	YES	YES	YES
Region fixed effect	YES	YES	YES	YES
cons	10.21***	8.694***	0.211***	3.141***
	(0.0405)	(1.322)	(0.0192)	(0.479)
N	620	620	620	620
R^2	0.952	0.966	0.886	0.938

Notes: Standard errors in parentheses, ***, **, * imply statistical significance at the 1%, 5% and 10% level, respectively.

Where $Incentive_i$ is the treatment intensity indicator and $Time_t$ denotes the point-in-time dummy variable, which takes the value of 1 in the current year and 0 in other cases. Since the first year of the sample (i.e., 2000) is used as the base period in this paper, β_t denotes the estimated coefficient for the years 2001–2019. The other variables in the equation are the same as in Eq. 2. Figure 3 shows the estimation results of dynamic effects. The circles in the figure are the point estimates, the dashed lines are the 95% confidence intervals, and Figures 3A,B are the results of the dynamic effect tests for agricultural carbon intensity and agricultural carbon efficiency, respectively. The results show that β_t is not significant from 2001 to 2005 and satisfies the parallel trend assumption, which means that the evolutionary trend of agricultural carbon performance in the relative treatment and relative control groups remains the same before the RTFR. Meanwhile, Figure 3A continues to decline in the years after the implementation of the reform, and the significance level continues to increase, indicating that the carbon reduction effect of RTFR is persistent. In addition, Figure 3B continues to rise in the years after the implementation of the reform, indicating that the efficiency of RTFR in improving agricultural carbon emissions is also persistent.

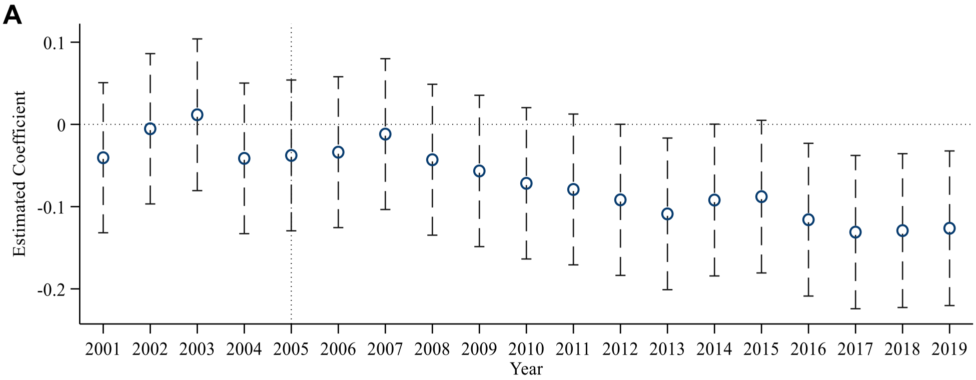
4.3 Robustness checks

4.3.1 Placebo test

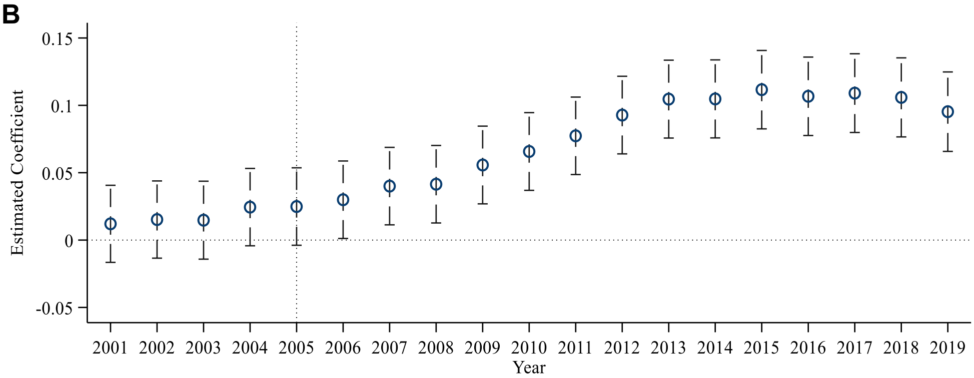
To further test whether the estimation results in this paper are affected by other unobservable factors or omitted variables, this paper refers to the idea of Cai et al. (2016) to randomly select the treatment group for a placebo test. Specifically, the province and the time when the reform started were randomly selected from the sample, and the multiplication of the two items was followed by the regression in Eq. 2, and the above operation is repeated 1,000 times. Figure 4 reports the results based on a placebo test for random selection in the context of agricultural carbon intensity and agricultural carbon efficiency as dependent variables, respectively. We observe that the coefficients of the multiplication terms are mostly concentrated around 0 and symmetrically distributed, indicating that the improvement in agricultural carbon efficiency is due to the RTFR and not due to other unobservable chance factors, and no important explanatory variables are omitted in Eq. 2.

4.3.2 Endogenous treatment

Considering the endogeneity problem from reverse causality may produce biased estimation results. Hence, we further use the two-stage least squares (2SLS) method with the help of instrumental variables (IV) for robustness checking. Drawing on Nunn and Qian's (2014) approach, we use the tobacco



The dynamic effects of agricultural tax reform on agricultural carbon intensity



The dynamic effects of agricultural tax reform on agricultural carbon efficiency

FIGURE 3
Dynamic effects analysis.

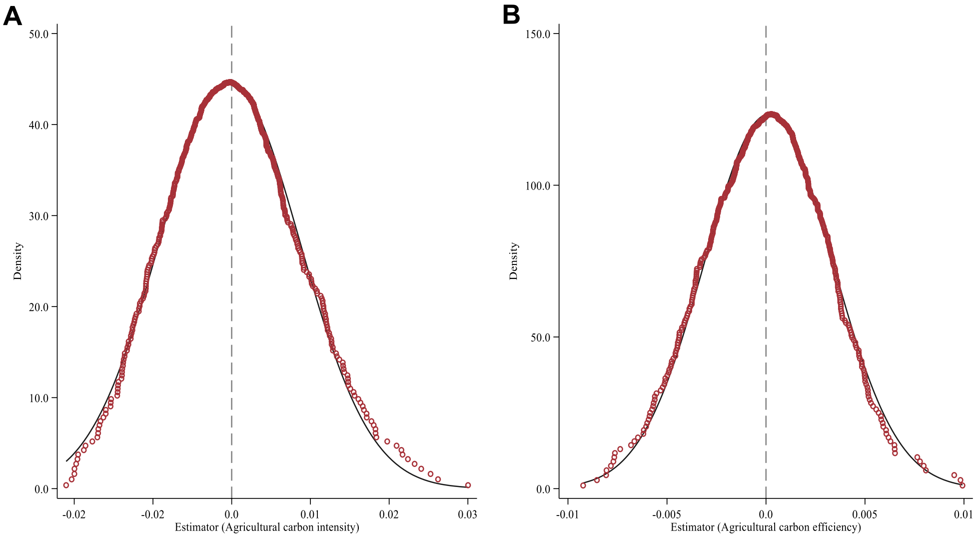


FIGURE 4
Placebo test results.

TABLE 3 Robustness tests I.

Variables	**2SLS**		**SEM**		**SAR**	
	ACI	**ACE**	**ACI**	**ACE**	**ACI**	**ACE**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
$Incentive_i \times Post$	−0.0529***	0.0554***	−0.0923***	0.0636***	−0.0390*	0.0594***
	(0.0105)	(0.0096)	(0.0216)	(0.0088)	(0.0204)	(0.0070)
Control variables	YES	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES	YES
Region fixed effect	YES	YES	YES	YES	YES	YES
Spatial ρ					0.303***	0.0869**
					(0.0626)	(0.0426)
KP rk LM test	291.401	291.401				
LM p-value	(0.0000)	(0.0000)				
KP rk Wald F	15.355	15.355				
cons	15.89***	1.252***	0.670***	0.483***	0.154***	0.0524***
	(0.938)	(0.207)	(0.097)	(0.947)	(0.00448)	(0.00153)
N	620	620	620	620	620	620
R^2 (*log-l*)	0.461	0.815	227.37	805.85	266.11	901.01

Notes: Standard errors in parentheses, ***, **, * imply statistical significance at the 1%, 5% and 10% level, respectively.

cultivation area in each province for 1999 as the IV for the RTFR, obtain the fitted value of the agricultural output intensity variable through the first stage in 2SLS, and regress this fitted value on the interaction term after the policy occurs as the independent variable of CDID to test the robustness of the estimated results for the abolition of agricultural tax in this paper.

The reason for selecting the tobacco cultivation area in each province for 1999 as the IV of agricultural output intensity is as follows. (1) The larger the tobacco cultivation area in a province in 1999, the smaller the impact of the agricultural tax abolition policy implemented by the central government on local government revenues (the 2005 rural tax reform did not abolish the tobacco cultivation tax), and the smaller the impact of the agricultural tax reform on local agricultural production, thus satisfying the correlation condition. (2) Since the area sown to tobacco does not account for a large proportion of the agricultural area in most provinces, and the existing literature does not include tobacco cultivation in the measurement system when calculating agricultural carbon emissions, the tobacco cultivation area is not relevant to the agricultural carbon emissions discussed in the vast majority of the literature and satisfies the exclusivity condition. Based on this, we believe that it is reasonable to choose the tobacco cultivation area by the province in 1999 as the IV for agricultural output intensity.

The estimated results of 2SLS are reported in columns (1) and (2) of Table 3. We find that the estimation results are still significant, and although there are changes compared to the results of the baseline regression, they are still in line with expectations. The results of the IV regression still show that there are still significant carbon-reducing effects of abolishing agricultural taxes, indicating that the results of the baseline regression are robust. Meanwhile, the KP rk LM test rejects the null hypothesis, implying that the IV chosen in this paper is reasonable, and the KP rk Wald F-statistic value is greater than 10, suggesting that there are no weak instrumental variables, which also confirms the reasonability of the IV in this paper.

4.3.3 Spatial spillover effect analysis

Another prerequisite for obtaining valid estimation results by using the DID model is to satisfy the Stable Unit Treatment Value Assumption (SUTVA), but it is often infringed because of the existence spatial spillover effect (Delgado and Florax, 2015; Su et al., 2021). Existing studies show that agricultural carbon emissions have a strong spatial spillover effect, and agricultural production affects not only the agricultural carbon emissions in the region, but also those in the neighboring regions (Wu et al., 2019; Wu et al., 2021; Jia et al., 2022; Li and Li, 2022). Thus, any study that does not consider the spatial spillover effect may lead to an inappropriate evaluation of the policy effect (Zhang and Wu, 2022). Accordingly, we draw on Zhang and

TABLE 4 Robustness tests II.

Variables	Replacement treatment intensity index					
	ACI	ACE	ACI	ACE	ACI	ACE
	(1)	(2)	(3)	(4)	(5)	(6)
50% quantile	−0.149***	0.0876***				
	(0.0324)	(0.00977)				
75% quantile			−0.0564*	0.0677***		
			(0.0318)	(0.0102)		
Food output intensity					−0.162***	0.138***
					(0.0517)	(0.0150)
Control variables	YES	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES	YES
Region fixed effect	YES	YES	YES	YES	YES	YES
cons	9.476***	2.862***	8.654***	3.093***	8.781***	3.130***
	(1.329)	(0.493)	(1.372)	(0.502)	(1.316)	(0.473)
N	620	620	620	620	620	620
R^2	0.967	0.938	0.966	0.933	0.966	0.940

Notes: Standard errors in parentheses, ***, **, * imply statistical significance at the 1%, 5% and 10% level, respectively.

Wu's (2022) research method and use a spatial difference-in-differences (SDID) model for robustness testing. Since the spatial correlation of agricultural carbon emissions may be captured by the error term and the auto regressive term relying on the variables (Wu et al., 2021), we use the SDID model based on the spatial error model (SEM) and the spatial auto regressive model (SAR) for robustness testing to overcome the estimation bias arising from ignoring the spatial spillover effect. The estimation results of the SDID model are reported in columns (3) to (6) of Table 3. The estimation results show that under different forms of spatial econometric model settings, the estimation results are still significant, and although there are variations, they are still consistent with the basic conclusions. Consequently, the fundamental findings of this paper still hold after controlling for spatial spillover effects.

4.3.4 Replacement intensity variables

In the baseline regression section, we construct an indicator of agricultural output intensity based on the agricultural output value of each province in 2004, and multiply the agricultural output intensity and the time dummy variable indicating the occurrence of the policy as the independent variable in CDID model. In this section, we adopt two ways to change the independent variable in Eq. 2 and conduct robustness checks. First, the dummy variable $Treat_{it}$ is used to measure whether the provinces are affected by the RTFR, replacing the intensity variable. Specifically, we define the samples with agricultural output above the median and 75% quantile in 2004 as the treatment group, respectively, and take the value of $Treat_{it}$ as 1 and 0 *vice versa*. $Treat_{it}$ is multiplied with the policy time dummy variable ($Post$) as the independent variable ($Treat_{it} \times Post$) of the CDID model. Second, food production in 2004 is employed as the intensity of agricultural output variable ($Food_{it}$), and the interaction term of food output intensity with the policy time dummy variable is used as the CDID independent variable ($Food_{it} \times Post$) for robustness testing. The results are presented in Table 4. Columns (1) to (6) of Table 4 show that the effects of RTFR on agricultural carbon intensity and agricultural carbon efficiency are similar with the baseline regression results after replacing the intensity variable, further indicating that the results in this paper about the effects of RTFR on agricultural carbon emissions are robust.

4.4 Contemporaneous policies interference

4.4.1 Major food production area program

In 2003, the Chinese government began to implement the major food production areas (MFA) policy and designate 13 major food production areas nationwide to promote food production and ensure national food security. The logic of the

TABLE 5 Excluding contemporaneous policy interference.

Variables	**Excluding contemporaneous policy interference**					
	ACI	**ACE**	**ACI**	**ACE**	**ACI**	**ACE**
	(1)	**(2)**	**(5)**	**(6)**	**(7)**	**(8)**
$Incentive_i \times Post$	−0.0808***	0.0543***	−0.0522**	0.0457***	−0.0584**	0.0357***
	(0.0263)	(0.00782)	(0.0248)	(0.00768)	(0.0273)	(0.00794)
Major food production	0.0685	0.0270**			0.0742	0.0205
area program	(0.0461)	(0.0125)			(0.0455)	(0.0125)
Comprehensive agricultural			−0.0376	0.0580***	−0.0202	0.0501***
development program			(0.0335)	(0.0103)	(0.0348)	(0.0105)
Control variables	YES	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES	YES
Region fixed effect	YES	YES	YES	YES	YES	YES
cons	8.896***	3.221***	8.473***	3.483***	7.360***	4.020***
	(1.338)	(0.472)	(1.323)	(0.470)	(1.370)	(0.478)
N	620	620	620	620	620	620
R^2	0.966	0.939	0.966	0.943	0.967	0.945

Notes: Standard errors in parentheses, ***, **, * imply statistical significance at the 1%, 5% and 10% level, respectively.

MFA program's impact on agricultural carbon emissions is that the MFA program can improve the scale and intensification of agricultural production through the specialized cultivation of large field crops, ameliorate the original scattered operation of small farmers, realize the large-scale application of pesticides, chemical fertilizers, and agricultural machinery, and promote the efficiency of tillage and irrigation, thus achieving the agricultural carbon emission abatement. To exclude the interference of the carbon reduction effect of the MFA project in the baseline regression results, a dummy variable indicating the MFA policy (the policy dummy variable takes the value of 1 for provinces belonging to the major food producing area and after the establishment of the MFA program, and 0 for the other cases) is added to Eq. 2 as a control variable for robustness check. The results in columns (1) and (2) of Table 5 show that the estimated coefficients of rural tax reform change slightly relative to the baseline regression results after controlling for the MFA program, but are still significant at the 5% level, indicating that the MFA program does not influence the conclusions over the same period.

4.4.2 Comprehensive agricultural development program

In 2011, the Chinese government began to implement the comprehensive agricultural development (CAD) program nationwide, aiming to ensure the quality of farmland and improve crop yields through scientific planning of farmland and construction of farmland infrastructure. On the one hand, the implementation of the CAD program can improve the agricultural scale operation efficiency by optimizing the input of agricultural labor, arable land, and agricultural materials, thus promoting the transformation of farmland into a whole and continuous operation, hence improving the agricultural operation efficiency. On the other hand, the CAD program can help improve land fertility and quality, increase agricultural production with the same agrarian material inputs, further improve cultivated scale management efficiency, and complete the agricultural carbon emission reduction. To exclude the influence of CAD program on the research conclusions, we multiply the investment amount of CAD program in each province as the intensity variable with the policy time dummy variable of the beginning CAD program, and introduce the regression in Eq. 2 again to test the reliability of the estimated results. The results are presented in columns (3) and (4) of Table 5. It can be seen that the estimated coefficients of RTFR are still significant, so the conclusions of this paper are not influenced by the CAD program.

Moreover, we also introduce the policy variables indicating the MFA program and the CAD program simultaneously into Eq. 2 for the regression. The results are presented in columns (5) and (6) of Table 5. We find that the estimated coefficients of RTFR are still significant. Thus, the conclusions of this paper are still very robust after controlling for policy interferences.

5 Mechanism analysis

The empirical results in the previous section show that the implementation of RTFR has a significant abatement effect on

TABLE 6 Mechanism identification: farmer's perspective.

	Agricultural productive investment			Cultivated land operating area		
	API	**ACI**	**ACE**	**CLOA**	**ACI**	**ACE**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
$Incentive_i \times Post$	0.0750***	−0.0315*	0.0443***	0.0455***	−0.0275*	0.0437***
	(0.0207)	(0.0168)	(0.00436)	(0.0142)	(0.0152)	(0.00440)
Agricultural productive investment		−0.110**	0.0779***			
		(0.0476)	(0.0222)			
Cultivated land operating area					−0.271***	0.116***
					(0.0761)	(0.0328)
Control variables	YES	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES	YES
Region fixed effect	YES	YES	YES	YES	YES	YES
cons	−2.632	5.719***	3.470***	−9.635***	3.399**	2.556***
	(2.386)	(1.236)	(0.464)	(1.593)	(1.365)	(0.487)
N	372	372	372	372	372	372
R^2	0.958	0.985	0.977	0.987	0.985	0.977

Notes: Standard errors in parentheses, ***, **, * imply statistical significance at the 1%, 5% and 10% level, respectively.

agricultural carbon emissions. In the theoretical analysis section, we conclude that the carbon abatement effect of the reform can be realized through large-scale management, productive investment in agriculture, and financial support from the central government. However, the impact of tax-and-fees reform on local government revenues may reduce the importance of local governments on arable land protection, which in turn affects the carbon reduction effectiveness of the reform. Therefore, after confirming the reduction effect of RTFR on agricultural carbon emissions by using Eq. 2, to explore the transmission effect of the above potential mechanism, we further draw on the test approach proposed by Baron and Kenny (1986), to construct Eqs 5, 6 to perform a stepwise test for whether the mechanism holds (Wu et al., 2021) and to verify the validity of the theoretical hypothesis in this paper.

$$M_{it} = \alpha_0 + \alpha_1 \, Incentive_i \times Post + \gamma \, Control_{it} + year_t + province_i + \varepsilon_{it} \tag{5}$$

$$ACP_{it} = \varphi_0 + \varphi_1 \, Incentive_i \times Post + \lambda \, M_{it} + \theta \, Control_{it} + year_t + province_i + \varepsilon_{it} \tag{6}$$

where M_{it} is the mechanism variables, combined with the availability of provincial-level data, we select, the average cultivated land area operated by farm households, the average annual amount of productive fixed investment in agriculture by farm households, the total amount of rural land management transfer payments from the central government, and the local government cultivated land occupation tax, as proxy variables for the cultivated land area operated by farm households, productive investment by farm households, central government financial support, and local government cultivated land protection efforts, respectively. It should be noted that after 2012, the government no longer publishes data on the average cultivated land area operated by farm households and the average annual amount of productive fixed investment in agriculture by farm households, so the data used in the regression analysis at the farm household level covers the period 2000–2011. In contrast, the Chinese government only published data for the period 2001–2016 for the total amount of rural land management transfer payments from the central government. Therefore, for the analysis at the central government level, the time span of the data is 2001–2016. Moreover, the cultivated land occupation tax is a tax levied on individuals who occupy cultivated land to build houses or engage in non-agricultural construction, which is collected and managed by local governments. Therefore, we argue that the cultivated land occupation tax can be used as a reverse proxy indicator of the local government's cultivated land protection effort, and the higher the amount of cultivated land protection tax, the weaker the local government's cultivated land protection effort. The meanings of the remaining variables in Eqs 5, 6 are consistent with Eq. 2 and are omitted here. Tables 6, 7 report the estimation results at the farmer level and the government level, respectively.

TABLE 7 Mechanism identification: administration perspective.

	Land governance input			Cultivated land occupation tax		
	LGI	ACI	ACE	CLOT	ACI	ACE
	(1)	(2)	(3)	(4)	(5)	(6)
$Incentive_i \times Post$	0.138***	−0.0541	0.0559***	0.572***	−0.0621***	0.0604***
	(0.0514)	(0.0334)	(0.0100)	(0.0540)	(0.0216)	(0.00733)
Land governance input		−0.0869***	0.0187***			
		(0.0234)	(0.00701)			
Cultivated land occupation tax					0.0311**	−0.0177***
					(0.0142)	(0.00437)
Control variables	YES	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES	YES
Region fixed effect	YES	YES	YES	YES	YES	YES
cons	7.918**	10.03***	2.855***	−35.41***	10.11***	2.335***
	(3.527)	(1.575)	(0.475)	(2.832)	(1.398)	(0.526)
N	465	465	465	620	620	620
R^2	0.885	0.974	0.951	0.927	0.967	0.940

Notes: Standard errors in parentheses, ***, **, * imply statistical significance at the 1%, 5% and 10% level, respectively.

Columns (1) and (4) of Table 6 show the estimated results from the impact of RTFR on the farmers' productive investment and the farmers' cultivated operating area, respectively. The results show that the coefficient estimates of $Incentive_i \times Post$ are 0.0750 and 0.0455, respectively, and pass the significance test at the 1% statistical level. This indicates that, under the taxpayer (farm household) perspective, the abolition of agricultural tax significantly increases the productive investment and cultivated operating area of farm households. This paper then tests the impact of productive investment in agriculture and the area of farmland operated by farm households on agricultural carbon performance. The estimation results in (2)–(3) and (5)–(6) of Table 6 show that the coefficient estimates of each mechanism variable pass the significance test at the 5% (or 1%) statistical level. This indicates that RTFR promotes agricultural carbon performance through agricultural productive investment and farmland transfer, and $\mathbf{H_1}$ and $\mathbf{H_2}$ are validated.

Table 7, columns (1) and (4) show the estimates of the effects for RTFR on central government land management inputs and local government cultivated land protection efforts, respectively. The results show that the coefficient estimates of $Incentive_i \times Post$ are 0.135 and 0.572, respectively, and pass the significance test at the 1% statistical level. This indicates that under the tax collector (government) dimension, the abolition of agricultural tax significantly increases the amount of central government transfer payments for land governance, but also weakens the local government's incentive to protect arable land. We then test the impact of central government and local government behavior on agricultural carbon performance. The estimation results in (2)–(3) and (5)–(6) of Table 7 show that the coefficient estimates of each mechanism variable pass the significance test at the 5% (or 1%) statistical level. This indicates that RTFR promotes the improvement of agricultural carbon performance through central government transfer payments, and $\mathbf{H_3}$ is verified. At the same time, the weakening of land protection by local governments is also detrimental to the enhancement of agricultural carbon performance, as verified by $\mathbf{H_4}$. From the estimated coefficients, the estimated coefficients of central government land governance inputs on agricultural carbon emission intensity and agricultural carbon performance are −0.0869 and 0.0187, respectively, while those of local governments are 0.0311 and −0.0177, respectively; therefore, the central government plays a more influential role in the carbon abatement effect of government actions on RTFR.

6 Heterogeneity analysis

To verify the possible heterogeneity in the carbon reduction effect of RTFR in terms of crop type, geographic location, and

TABLE 8 Heterogeneity analysis I.

	Food production differences		**North-south differences**		**Topographical differences**	
	ACI	**ACE**	**ACI**	**ACE**	**ACI**	**ACE**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
$Incentive_i \times Post \times Mfpa_{it}$	−0.0139	0.0459***				
	(0.0163)	(0.00523)				
$Incentive_i \times Post \times \mathrm{South}_{it}$			−0.0871***	0.0471***		
			(0.0214)	(0.00688)		
$Incentive_i \times Post \times Plain_{it}$					−0.00923	0.0424***
					(0.0160)	(0.00518)
Control variables	YES	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES	YES
Region fixed effect	YES	YES	YES	YES	YES	YES
cons	8.251***	3.561***	9.106***	3.118***	8.278***	3.427***
	(1.326)	(0.464)	(1.325)	(0.499)	(1.321)	(0.463)
N	620	620	620	620	620	620
R^2	0.966	0.936	0.966	0.934	0.966	0.935

Notes: Standard errors in parentheses, ***, **, * imply statistical significance at the 1%, 5%, and 10% level, respectively. The major food-producing regions include Heilongjiang, Henan, Shandong, Sichuan, Jiangsu, Hebei, Jilin, Anhui, Hunan, Hubei, Inner Mongolia, Jiangxi, and Liaoning. The southern region includes Jiangsu, Yunnan, Guizhou, Sichuan, Anhui, Hunan, Hubei, Jiangxi, Guangdong, Guangxi, Fujian, Shanghai, Zhejiang, and Hainan. Plain areas include Liaoning, Jilin, Heilongjiang, Beijing, Tianjin, Hebei, Shandong, Henan, Jiangsu, Anhui, Hunan, Hubei, Jiangxi, Zhejiang, and Shanghai.

topographic conditions, we construct a continuous difference-in-difference-differences (CDDD) model for examination. The model is set up as follows.

$$ACP_{it} = \alpha_0 + \alpha_1 Incentive_i \times Post \times H_i + \alpha_2 Incentive_i \times Post + \alpha_3 H_i + \gamma Control_{it} + year_t + province_i + \varepsilon_{it} \tag{7}$$

Where H_i is a grouping dummy variable indicating regional differences; we perform heterogeneity analysis by using whether a province is a major food production area (if so, H_i takes the value of 1, and 0 in reverse, the same below is omitted), whether it is located in the southern region, and whether it is a plain region, respectively. Table 8 reports the specific results of the heterogeneity check.

The results in columns (1) and (2) of Table 8 show that the estimated coefficients of the $Incentive_i \times Post \times Mfpa_{it}$ term have a significant improvement effect on agricultural carbon efficiency, but not on agricultural carbon intensity. It indicates that the carbon abatement effect of RTFR is only significantly different between major food-producing areas and non-major food-producing areas for agricultural carbon efficiency, and the difference is not significant for agricultural carbon intensity. This indicates that the tax-and-fees reform can significantly improve the efficiency of agricultural operations in the major food-producing areas. However, considering the long-term low comparative returns of food products, the synergistic governance effect of tax-and-fees reform on carbon reduction and income increase is not satisfactory in the major production areas.

The estimation results in columns (3) and (4) of Table 8 show that the estimated coefficients of $Incentive_i \times Post \times \mathrm{South}_{it}$, in terms of both agricultural carbon intensity and agricultural carbon efficiency, are significant, indicating that the RTFR has a more significant carbon reduction effect on the southern region compared to the northern region. We believe that the possible explanations are, first, the southern region is more densely population, and the fragmentation of land operation is more serious. Therefore, the impact on smallholder operation in the southern provinces by the increase of land transfer and productive investment after the tax reform is greater, which is more likely to improve the efficiency of agricultural operation and achieve carbon reduction in the southern region. Second, the cultivation structure of the southern region is distinct compared with the northern region, with rice cultivation dominating the southern region and wheat and soybean cultivation dominating the northern region. Compared with wheat cultivation, rice cultivation is more dependent on intensive cultivation and more investment in human and material resources. Therefore,

TABLE 9 Heterogeneity analysis II.

	Carbon emissions from various production segments of agriculture		
	Agricultural production	**Agricultural inputs**	**Crop cultivation**
	(1)	**(2)**	**(3)**
$Incentive_i \times Post$	−0.0414**	−0.0654***	0.0218
	(0.0163)	(0.00703)	(0.0518)
Control variables	YES	YES	YES
Year fixed effect	YES	YES	YES
Region fixed effect	YES	YES	YES
cons	4.106***	3.952***	8.235***
	(0.984)	(0.409)	(0.954)
N	620	620	620
R^2	0.988	0.998	0.996

Notes: Standard errors in parentheses, ***, **, * imply statistical significance at the 1%, 5% and 10% level, respectively.

the increased cultivated operation efficiency due to tax reform can play a more significant role in agricultural carbon reduction for the south.

In terms of topographic conditions, the estimation results in columns (5) and (6) of Table 8 show that the coefficients of the $Incentive_i \times Post \times Plain_{it}$ term produce a significant improvement effect on agricultural carbon efficiency, but the effect on agricultural carbon intensity is not significant. It indicates that the carbon reduction effect of RTFR is only significantly different between plain provinces and non-plain provinces for agricultural carbon efficiency, and the difference is not significant for agricultural carbon intensity. We suggest that the possible reasons for the above differences are that cultivated production in the plain provinces is mostly based on the cultivation of field crops, which are more likely to produce carbon emissions because they require more labor and machinery in the agricultural production process than other commercial crops, and because the economic returns of field crops (grain) are lower than those of commercial crops grown in mountainous areas; therefore, the reform is not effective in governing the agricultural carbon intensity for the plain provinces. However, because the topographical conditions in the plains make it easier to achieve large-scale utilization of tillage, irrigation, fertilizer, and agricultural machinery, the increased efficiency of agricultural operations due to tax-and-fees reform can play a more significant role in optimizing agricultural carbon efficiency for the plain provinces.

This paper also examines the possible heterogeneity of agricultural carbon emission sources. Based on the previous process of measuring agricultural carbon emissions, clearly, agricultural carbon emissions originate from three main sources: agricultural production, material inputs, and crop growth. In view of this, we further explore the impact of reform implementation on the agricultural carbon emissions generated from these three emission sources. The heterogeneity results are shown in Table 9. Among them, the RTFR has a significant inhibitory effect on agricultural carbon emissions from both agricultural production and material inputs. And the effects on carbon emissions from crop growth were not significant. Thus, the carbon abatement effect of RTFR is mainly realized through affecting agricultural production and material inputs, and has no significant effect on crop growth.

7 Conclusion

In the context of Chinese society's efforts to achieve the strategic goals of "carbon peaking" and "carbon neutrality", it is significant to investigate the driving mechanisms and optimization strategies of agricultural carbon emission abatement. On the above basis, this paper treats the RTFR completed in 2005 as a quasi-natural experiment and examines the causal effects, potential mechanisms, and possible heterogeneity of the reform on agricultural carbon performance by employing a continuous difference-in-differences (CDID) model. The following conclusions are drawn.

First, the implementation of RTFR has a significant improvement on agricultural carbon performance, resulting in an average reduction of 6.35% in agricultural carbon intensity and an increase of 6.14% in agricultural carbon efficiency. Meanwhile, the results of the parallel trend test and dynamic effect analysis by event study method not only support the baseline findings but also indicate that the carbon reduction effect of tax and fee reform is persistent. Moreover, after conducting a series of robustness checks such as the placebo test, instrumental variables method, spatial effects analysis, replacing independent variables, and excluding other policy interferences, it is found that the carbon reduction effect of the reform on agriculture still holds. Second, the mechanism analysis indicates that the expansion of farmers' arable land operation area, the increase in agricultural productive investment, and the rise of central government land governance transfer scale take the role of the channel in the process of agricultural carbon abatement effect of the tax-and-fees reform. However, the decline of local governments' arable land protection is not conducive to the realization of the reform's carbon reduction effect. Third, heterogeneity analysis demonstrates that RTFR can produce greater carbon abatement effects in southern regions, and can produce more significant policy effects on agricultural carbon efficiency in the major food-producing regions and plain areas. Meanwhile, the agricultural carbon reduction effect of reform implementation is mainly reflected in two aspects: reducing carbon emissions from agricultural production and agricultural materials.

From the above conclusions, this paper draws the following policy implications: First, agricultural tax is a common tax in developing countries, and the reduction of farmers' tax burden is an important channel for agricultural carbon emission reduction. The agricultural tax abolition reduces farmers' burden, promotes the transfer of agricultural land and productive agricultural investments, improves the agricultural operation efficiency, and provides a guarantee for the long-term and stable improvement of agricultural carbon performance. Countries around the world should take into account their national conditions, effectively reduce farmers' burdens, strive to improve agricultural operation efficiency, and realize agricultural modernization. Second, the impact of the RTFR is heterogeneous in different regions, and countries around the world should formulate appropriate policies according to the climate, ecological environment, topographic conditions, and planting structure of each country when formulating agricultural policies, to avoid the negative consequences arising from unreasonable policy design. Third, the promotion effect of RTFR on agricultural carbon performance is mainly realized through mechanisms such as land transfer and inputs of production materials, so it is necessary to optimize the rural land system and guarantee farmers' legitimate rights and interests to land, so that those who have constant production will have constant ownership. Fourth, the government is the primary driving force of the tax reform, and governments must have a clean and effective organizational system to complete the reform, dare to benefit the people, and take social responsibility. While maintaining social equity, it also promotes the further improvement of production efficiency. Therefore, in response to the climate change crisis, national governments should continuously optimize the organizational structure and improve organizational efficiency, to establish the institutional foundation for promoting rural agricultural modernization and achieving green and sustainable agriculture.

Lastly, there are some weaknesses in this study that deserve further improvement. First, in terms of data scale, this paper only investigates the impact of RTFR on agricultural carbon emissions at the provincial level, and does not analyze the impact of RTFR on agricultural carbon emissions at the municipal level and the county level. In fact, counties are the most important administrative units for agricultural production in China, and numerous agricultural activities are accomplished within the county. Therefore, in our future study, we will focus on the county level to identify the more elaborate policy effects of RTFR. Second, in terms of mechanism identification, it must be acknowledged that micro-individual data are more applicable to the investigation of land operation scale and agricultural inputs. However, due to the problem of data availability, micro mechanisms are not discussed in this paper. Thus, in the subsequent analytical study, we will conduct a series of field surveys to collect a batch of micro data to further enrich the study of the effect of RTFR on micro individuals.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

Conceptualization, XZ; methodology, XZ; software, XZ and CW; validation, XZ and TL; formal analysis, XZ and CW; data curation, XZ, CW, and XL; writing—original draft preparation, XZ and XL; writing—review and editing, JW and XL; visualization, XZ, XL, and CW; supervision, CW and XL.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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