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The Impact of Tax Incentives on Carbon Intensity in Industrial Enterprises: Mediating Role of Green Technology Innovation

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Abstract: This study examines the mechanism of the two tax incentives, namely the deduction of R&D expenses and income tax incentives, on the carbon intensity of industrial enterprises. The results show that both R&D cost deduction and income tax incentives can significantly reduce carbon intensity. However, R&D cost deduction has a stronger role in reducing carbon intensity and plays a more dominant governance role, and the two have a complementary relationship in the process of reducing carbon intensity. Moreover, it shows that green technological innovation plays a part of the mediating effect in the process of the two tax incentives in reducing carbon intensity. Threshold effect analysis shows that income tax incentives have a governance effect on carbon intensity under certain conditions. When the R&D expense deduction exceeds the threshold, income tax incentives can reduce carbon intensity. R&D expense deductions exhibit a threshold effect on reducing carbon intensity, and this governance effect becomes stronger as the threshold range of income tax incentives increases. The research conclusions are highly significant for improving tax incentive policies and maximizing incentives for industrial enterprises to reduce carbon intensity. The findings provide important guidance for refining tax preferential policies and enhancing their effectiveness in encouraging industrial enterprises to lower carbon intensity.

Key words: R&D expense additional deduction; preferential income tax; carbon intensity; mediating effect; threshold effect

1 Introduction

Greening and decarbonizing the economy and society are essential for achieving high-quality development. China possesses a vast and comprehensive industrial system with substantial energy demands and high carbon emissions, pursuing a green and low-carbon high-quality development path has become an inevitable choice. China has made a solemn commitment to strive for carbon peaking by 2030 and carbon neutrality by 2060. As the world's largest developing country, China is still in the transition from high-speed development to high-quality development. Under the peak carbon emissions and carbon neutrality target framework, it needs to balance economic growth and carbon emission reduction, a task that is both urgent and arduous.

The industrial sector is characterized by high energy consumption and high carbon emissions, accounting for approximately 65% of total social energy consumption. It has a significant impact on achieving carbon peaking nationwide and has become a key area for energy conservation and carbon reduction. Industrial enterprises, as the micro-entities of economic development, are the basic organizations for achieving the macro-level the peak carbon emissions and carbon neutrality target in the industrial sector. However, enterprises invest heavily in improving energy efficiency and reducing carbon intensity upfront, but the returns are relatively low, resulting in insufficient intrinsic motivation for emission reduction. Government policy guidance is needed (Du and Li, 2020; Ma et al., 2025). To promote energy conservation and carbon reduction in industrial enterprises, the Chinese government has introduced a number of measures: In 2021, the State Council issued the "Action Plan for Carbon Peaking Before 2030", which included carbon peaking in the industrial

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sector as a key task. It proposed to establish and improve a tax policy system to promote green and low-carbon development, give full play to the role of taxation in promoting green and low-carbon development of market entities, and promote the decarbonization of industrial energy consumption and the efficient use of fossil energy. In 2022, the Ministry of Industry and Information Technology, the National Development and Reform Commission, and other six departments jointly issued the "Action Plan for Improving Industrial Energy Efficiency", which shortened the window period for industrial "carbon reduction" to three years and proposed a target of reducing energy consumption per unit of added value of industrial enterprises above designated size by 13.5% from 2020 to 2025. It also coordinated fiscal funds to promote industrial energy efficiency improvement. Carbon intensity represents the amount of carbon dioxide emissions corresponding to a unit of economic output(Cheng et al., 2018). It combines carbon emission reduction activities with economic development and is a comprehensive indicator for measuring energy utilization efficiency, technological level, and energy structure(Lee and Wang, 2022). How to reduce carbon intensity has long been a hot topic in academia. Tax incentives are an important research direction among the factors affecting corporate carbon intensity. Currently, some scholars have conducted research on the relationship between tax incentives and corporate energy conservation and carbon reduction, but no consistent conclusion has been reached. Some scholars believe that tax incentive policies can have a positive impact on reducing carbon intensity. Based on macro-perspectives, relevant research shows that public investment has a governance effect on carbon intensity, and increasing government fiscal expenditure helps to reduce carbon intensity(Xinping, 2010). Increasing tax exemption rates can significantly improve energy efficiency, emission reduction efficiency and energy conservation and emission reduction efficiency(Cai and Harrison, 2011; Liu and Mao, 2019). As a macro-control policy of the government, tax incentives can guide public funds and social capital to invest in the low-carbon field, promote low-carbon research and development, enhance the market competitiveness of low-carbon products, and accelerate the low-carbon transformation of enterprises. Specifically, direct tax incentives (such as income tax reduction and exemption, tax rate preferences, etc.) and indirect incentives (such as additional deductions, investment tax credits, accelerated depreciation, etc.) can reduce the cost of enterprises to improve energy efficiency, encourage enterprises to actively improve energy-saving technologies and reduce energy consumption(Feng and Ge, 2024; Sun and Feng, 2023). Therefore, fiscal and tax policies are indispensable in the process of low-carbon economic transformation, but at present, China's fiscal investment is still insufficient, and the incentive effect of tax incentives on green and low-carbon industries needs to be further strengthened. Some scholars have summarized the low-carbon transformation process of developed countries and believe that developed countries have focused on encouraging technological innovation, improving energy efficiency and developing new energy sources as the key points of low-carbon fiscal and tax policies, which has greatly promoted the development of low-carbon economy. The comprehensive use of administrative measures, fiscal and tax policies and market mechanisms and the realization of synergy can better promote energy conservation and emission reduction(Liu et al., 2025). Tax incentive policies and environmental supervision play a synergistic role in incentivizing enterprises to optimize production processes and implement emission reduction strategies, thereby reducing the sulfur dioxide emission intensity of enterprises(Qi et al., 2023). For example, Japan's fiscal and tax policies, such as government subsidies and tax incentives, which began in the 1970s, have effectively promoted energy transformation. Japan has increased the exemption of experimental research expenses for enterprises in the high-tech field by formulating systems such as the "Tax System for Promoting Basic Technology Development", developed world-leading energy-saving technologies and achieved predetermined emission reduction targets(Slepov et al., 2021). China needs to build a fiscal and tax policy system that supports innovation to help achieve the peak carbon emissions and carbon

neutrality target. Some research has also put forward different views on the positive impact of tax incentives. The expansion of local government fiscal expenditure will increase carbon emissions, and increasing the proportion of non-economic fiscal expenditure can effectively reduce carbon emissions(Wang and Chen, 2024). Public fiscal expenditure plays a key role in promoting industrial transformation and upgrading, but the relationship between the two is inverted U-shaped, and there is an optimal scale of public fiscal expenditure(Zhao and Yan, 2024). Tax incentives and green technology innovation of environmental protection enterprises have an inverted "U"-shaped relationship. Excessive tax incentives will inhibit green technology innovation and weaken its driving effect on green and low-carbon development and the improvement of natural resource efficiency(Xia et al., 2022; Zhao and Yan, 2024). Based on the above literature, current research on tax incentives and carbon intensity has the following limitations: (1) Existing empirical analyses of tax incentives and carbon emissions are mostly concentrated at the macro level. When exploring the transmission mechanism of technological innovation, it is difficult to distinguish the direction of technological innovation, and the direction provided for enterprises to reduce carbon through technology is not clear enough. From a micro perspective, research on the carbon intensity governance effect of tax incentives at the enterprise level is mostly carried out from the theoretical analysis level. The path of tax incentives for enterprises to govern carbon intensity lacks empirical testing based on the use of models and data, and needs further in-depth research; (2) Empirical studies on the effects of tax incentive policies mostly use the total amount of tax incentives. The analysis of the differences in the effects of different types of tax incentive policies needs to be deepened, and the guidance provided for the precise formulation of tax incentive policies is not clear enough; (3) Some of the above literature confirms the positive role of tax incentives in carbon intensity governance, but it does not analyze the interaction between different types of tax incentive policies in the process of affecting carbon intensity, and there is a lack of research on the nonlinear carbon intensity governance effect of different types of tax incentive policies. The exploration of the intensity of different types of tax incentive policies is not precise enough. Therefore, this paper uses listed industrial enterprises in China as a research sample to empirically analyze the impact of two tax incentive policies—R&D expense deduction and income tax incentives—on corporate carbon intensity, attempting to answer the following questions: Can R&D expense deduction and income tax incentives reduce corporate carbon intensity? What are the differences in their effects on carbon intensity? Are there complementary or substitutive relationships between R&D expense deduction and income tax incentives in the process of reducing carbon intensity, and what are the pathways of their influence? Furthermore, do R&D expense deduction and income tax incentives have a nonlinear threshold effect on carbon intensity governance? In the context of the peak carbon emissions and carbon neutrality goal and high-quality development, answering these questions has a significant theoretical and practical value.

Compared with existing literature, this paper's potential contributions are: First, it incorporates two representative tax incentive policies—R&D expense deduction and income tax incentives—into a unified analytical framework. It uses a panel regression model to empirically test the asymmetric impact of these policies on the carbon intensity of industrial enterprises, and to enrich the research on the carbon intensity governance effect of micro-level tax incentives. Second, this study constructs an interaction term model to explore the potential policy combination effects of R&D expense deduction and income tax incentives in the process of addressing the carbon intensity of industrial enterprises. It provides policy references for leveraging the combination of tax incentive policies to achieve carbon intensity governance. Third, from the perspective of green technology innovation, this study explores the transmission mechanism of tax incentives' effects on carbon intensity governance. By addressing the difficulty in distinguishing the direction of technological innovation in past macro and industry-level studies, it provides clearer guidance for

technology-driven carbon reduction. Fourth, using panel threshold regression modeling, this study examines the nonlinear threshold effect of R&D expense deductions and income tax incentives on enterprise carbon intensity. It clarifies the interaction between these two tax incentive policies in the carbon intensity governance process and provides a reference for maximizing their synergistic effect in reducing carbon intensity.

2 Theoretical Analysis and Research Hypotheses

2.1 The impact of tax incentives on the carbon intensity of industrial enterprises

Enterprises typically face high risks and uncertainties during the low-carbon transition process. Compared with other social responsibility activities, reducing carbon intensity is unlikely to bring welfare improvements to stakeholders in the short term, and the implementation effect is difficult to observe and verify(Miao, 2024). This results in insufficient motivation for enterprises to reduce carbon intensity. Tax incentives, as a "post-compensation" policy, are an important tool for the government to support the sustainable development of enterprises(Zhang et al., 2025), and are crucial for enhancing enterprises' enthusiasm for reducing carbon intensity. Although the guidance direction and function of R&D expense deduction and income tax incentives are different, they can both have a positive impact on enterprises' carbon intensity reduction. From the perspective of the externalities of corporate carbon intensity governance, the benefits generated by energy conservation and emission reduction under market conditions are public goods and have strong externalities (Allcott et al., 2014). As rational economic agents whose goal is profit maximization, enterprises carefully weigh the additional costs and potential benefits of reducing carbon intensity when making decisions R&D expense deduction and income tax incentives are a form of compensation for the economic losses caused by externalities (Busom et al., 2014). It reduces the cost of low-carbon transformation for enterprises and also reduces the negative impact of externalities on enterprises' enthusiasm for energy conservation and carbon reduction. From the perspective of financial pressure, even if enterprises have the willingness to undergo low-carbon transformation, they face a large amount of financial investment in reducing carbon intensity. Given limited resources, it is difficult for them to consider long-term development. They will still prioritize survival, and sufficient funds are indispensable for enterprises to save energy and reduce carbon emissions. The additional deduction of R&D expenses and income tax incentives can directly reduce the tax burden of enterprises(Fang et al., 2022; Qian et al., 2023), improve the level of free cash flow of enterprises and alleviate financial pressure, and provide financial security for enterprises' low-carbon transformation. At the same time, tax incentives help enhance enterprises' willingness to invest, have a positive impact on their operating performance(Harimurti, 2024), encourage enterprises to consider their development from a longer-term perspective(Na et al., 2021; Picas et al., 2021), improve the cost-bearing capacity of enterprises to participate in improving energy efficiency and optimizing energy structure. Furthermore, it promotes enterprises to win long-term cost savings from energy efficiency improvement through short-term cost investment, thereby forming a good government-enterprise relationship and social image to achieve long-term development. From the perspective of driving technological innovation, technological innovation is the key to developing a low-carbon economy (Li et al., 2025). Independent R&D and technology introduction have a significant promoting effect on reducing carbon intensity(Ali et al., 2023). However, due to the immaturity of technologies in low-carbon industries, more R&D investment is needed. A significant obstacle for enterprises in reducing carbon intensity stems from the high investment and risks associated with developing energy-saving and emission-reduction technologies, limiting their investment(Sovacool and Monyei, 2021; Wang et al., 2025b). R&D expense deductions and income tax incentives help subsidize the positive externalities of enterprises' low-carbon R&D activities. They reduce concerns about the risks associated with technological innovation, incentivize firms to increase R&D investment and adopt new technologies (Weidong

et al., 2022; Zhuoma et al., 2024), and promote energy structure optimization, improved energy efficiency, and lower carbon intensity.

Based on the above analysis, R&D expense deductions and income tax incentives can reduce corporate carbon intensity by mitigating externalities, alleviating financial pressure, and driving technological innovation. Therefore, this paper proposes Hypothesis 1 which is:

H1: Both R&D expense deductions and income tax incentives can significantly reduce corporate carbon intensity.

2.2 The asymmetric impact of R&D expense deduction and income tax incentives on the carbon intensity of industrial enterprises

The goals and focuses of the R&D expense deduction and income tax incentives are different. The R&D expense deduction aims to reduce the tax burden on enterprises' technological innovation and reduce the cost risk of technological innovation to enhance their enthusiasm for technological innovation (Wang et al., 2025a), while income tax incentives emphasize tax reduction after profits are generated. The two types of tax incentives show significant differences in their effects on enterprise innovation and have an asymmetric impact on enterprise carbon intensity. The core of enterprises reducing carbon intensity lies in technological innovation. Related technological innovations are characterized by long cycles, high risks, and positive externalities(Yue et al., 2023). The innovation orientation of tax incentive policies is crucial for promoting enterprises to reduce carbon intensity. The R&D expense deduction is based on a certain percentage added to the actual number of new products and new process technologies developed by enterprises to form taxable income for deduction, which has a strong orientation towards technological innovation. While alleviating the financing constraints of enterprises, the R&D expense deduction can improve innovation output and quality to a greater extent and promote transformation and upgrading(Li et al., 2023). Compared with income tax incentives, it has a more significant effect on improving enterprises' investment willingness and capital operation efficiency(Kaushik, 2023). It promotes low-carbon transformation and reduces carbon intensity by incentivizing enterprises to innovate technology and improve production processes. China's income tax incentives are mainly tax rate incentives, which are reflected in the actual income tax rate. The strength of income tax incentives depends on the size of the enterprise's taxable profit and is not directly linked to technological innovation activities. The technological innovation orientation is weaker than that of the R&D expense deduction(Lichter et al., 2025). It mainly promotes enterprises to consider long-term development and carry out technological innovation to achieve low-carbon transformation by alleviating financing constraints(Wu et al., 2024). Due to the lack of policy guidance, some enterprises may invest the funds saved by income tax incentives in short-term high-yield operating projects(Sandmo, 1974), and therefore weakening the incentive effect of income tax incentives on enterprises' technological carbon reduction. In terms of the scope of beneficiaries, the R&D expense deduction subsidizes all eligible enterprise innovation projects, which can reduce the burden on enterprises throughout the innovation process(Xiang et al., 2025) and help drive enterprises to develop new processes and technologies to achieve technological carbon reduction; income tax incentives are affected by the economic effects of enterprises. Only enterprises that make profits can benefit from them. The scope of effect is small for low-profit enterprises and has no effect on loss-making enterprises. Enterprises enjoying income tax incentives are usually in the later stage of innovation and achievement transformation. The incentive effect of income tax incentives on enterprises in other innovation stages is limited(Erosa and González, 2019), making it difficult for all enterprises that carry out technological innovation in the process of low-carbon transformation to benefit. Therefore, the direct boosting effect of income tax incentives on enterprises' R&D activities such as technological transformation during the low-carbon transformation process is not as strong as that of R&D expense deduction, and its effect on reducing carbon intensity is relatively

weak. This paper proposes the following Hypothesis 2:

H2: Compared with income tax incentives, R&D expense deduction has a stronger effect on reducing corporate carbon intensity.

2.3 Interaction between R&D expense deduction and income tax incentives on the carbon intensity of industrial enterprises

When implementing R&D expense deduction and income tax incentive policies, there may be situations where enterprises enjoy both tax incentive policies at the same time. The interaction between the two tax incentive policies in influencing carbon intensity deserves attention, as it can help avoid overestimating policy effects when focusing on a single policy alone (Guerzoni and Raiteri, 2015).

Although R&D expense deduction and income tax incentives differ in terms of applicable conditions, preferential methods, and role orientation, both tax incentive policies can essentially achieve the effect of governing corporate carbon intensity by reducing the cost of low-carbon transformation. When the policy scope overlaps, they may promote each other and play a policy effect of "1+1>2". On the one hand, R&D expense deduction helps guide enterprises to carry out low-carbon technological innovation and strengthens the role of income tax incentives in reducing carbon intensity. The additional deduction of R&D expenses helps drive enterprise technological innovation and guides enterprises to consider long-term development and truly use resources for high-quality transformation projects (Yang and Rasiah, 2025). To a certain extent, it makes up for the inadequacy of relying solely on income tax incentives to directly guide enterprise investment direction and enhances the role of income tax incentives in reducing carbon intensity. On the other hand, income tax incentives provide more sufficient cash flow for the process of reducing carbon intensity through the additional deduction of R&D expenses, which helps to enhance the policy incentive effect of the additional deduction of R&D expenses and improve the governance effect on carbon intensity. While enterprises work to improve energy efficiency and reduce carbon intensity under the additional R&D expense deduction policy, income tax incentives ease financing constraints. They further lower the costs and risks of optimizing process technology and enhancing energy efficiency. This helps to enhance the governance effect of the additional deduction of R&D expenses on enterprise carbon intensity. Based on the above analysis, this paper proposes the following hypothesis:

H3: The additional deduction of R&D expenses and income tax incentives are complementary in the process of reducing carbon intensity.

2.4 Tax incentives for industrial enterprises' carbon intensity governance mechanisms

Innovation is the primary driving force for development. Under the guidance of the concept of high-quality development, green technology innovation has become the key to balancing economic development and environmental protection, and is crucial in promoting the development of a low-carbon economy and energy conservation and emission reduction in industrial enterprises.

Based on two main reasons, this study argues that green technology innovation plays an important role in the process of R&D expense deduction and income tax incentives affecting the carbon intensity of industrial enterprises. On the one hand, green technology innovation is affected by tax incentives. Enterprises' green technology innovation is directly constrained by working capital. Tax incentives can directly or indirectly reduce the financing constraints of enterprises and enhance their enthusiasm for green technology innovation(Song et al., 2020; Wang et al., 2024). Information asymmetry leads to banks and external investors reducing their willingness to provide loans or investments to enterprises. Enterprises disclose tax incentive information in financial statements, sending a positive signal about their strong development status(Xiong et al., 2023). This attracts external investors and increases their willingness to hold more company stock. The two tax incentive policies can indirectly address enterprises' financing challenges through their "halo effect."

They reduce moral hazard in principal-agent relationships, enabling managers to focus on long-term development, improve energy efficiency, and promote green technology innovation. On the other hand, green technology innovation is the improvement and enhancement of production equipment and processes, which runs through all stages of the product life cycle. It helps to save a lot of production resources, improve the energy efficiency of enterprises, and reduce energy consumption per unit output value(Tang et al., 2018). Enterprises can improve their production processes by introducing advanced production machinery and equipment and hiring high-level scientific research personnel through green technology innovation, which helps to improve energy efficiency and thus reduce carbon intensity(Lyu et al., 2024). Green technology innovation is an effective means to reduce carbon intensity(Dong et al., 2024). Continuous green technology innovation is conducive to achieving technological progress and reducing energy consumption and carbon emissions per unit output value when producing the same products(Huang et al., 2020). It plays an important role in reducing carbon intensity. Based on the above analysis, hypothesis 4 is proposed:

H4: R&D expense deduction and income tax incentives reduce carbon intensity by incentivizing enterprises to innovate green technology.

3 Research Design

3.1 Sample selection and data sources

This paper uses A-share listed companies in China's industrial sector from 2016 to 2021 as a research sample. The classification standard for industrial enterprises follows the "Guidelines for Industry Classification of Listed Companies," by selecting listed industrial companies whose industry codes begin with 06-46 in the "National Economic Industry Classification," and by including mining, manufacturing, and gas and water production and supply. *ST and ST companies were excluded from the sample data, resulting in 14,473 annual sample observations of Chinese industrial companies. To eliminate the interference of extreme values on the research results, continuous variables were shortened by 1% using a Winsor adjustment. The data in this paper comes from the CSMAR database, WIND database, the "China Industrial Economic Statistical Yearbook," and the "China Energy Statistical Yearbook."

Considering that 2016 marked the start of the 13th Five-Year Plan, research on China’s low-carbon development strategy began. The government introduced policies such as the Comprehensive Work Plan for Energy Conservation and Emission Reduction and the Work Plan for Controlling Greenhouse Gas Emissions, along with a series of incentive measures that may have influenced corporate carbon intensity. The data on industrial energy consumption breakdowns after 2021 has not yet been disclosed; therefore, the sample period for this study is from 2016 to 2021.

3.2 Variable selection and measurement

3.2.1 Explained variable

Carbon intensity. Based on available data and enterprise-level carbon disclosure in China, and drawing on relevant research(Chapple et al., 2014; Shang et al., 2023; Yang et al., 2023), enterprise CO_2 emissions are estimated from industry-level emissions using main operating costs. Carbon intensity is measured as emissions per unit of main business revenue. The CO_2 conversion factor per ton of standard coal is 2.493. Enterprise emissions are expressed in 10,000 tons, and carbon intensity (tons/10,000 yuan) represents CO_2 emissions for every 10,000 yuan of revenue(He et al., 2023). The carbon intensity calculation formula is as follows:

$$\text{Enterprise carbon dioxide emissions}=\frac{\text{Cost of main business of the enterprise}}{\text{Industry main operating costs}}\times\text{Total energy consumption of the industry}\times\text{Carbon dioxide conversion coefficient}$$

$$\text{carbon intensity}=\frac{\text{carbon dioxide emission}\times 10^{8}}{\text{Enterprise's main business income}}$$

3.2.2 Explanatory variables

(1) Additional deduction for R&D expenses

R&D expense additional deduction (ADPRE). Drawing on relevant research on the measurement method and the assignment level of the deduction ratio for R&D expense additional deduction(Qian et al., 2023), this paper uses "research and development investment × corporate income tax rate × deduction ratio / total assets" to measure the level of enterprise R&D expense additional deduction. Based on the directory of high-tech enterprises, enterprises enjoying R&D expense additional deduction are identified. The R&D expense additional deduction ratio of enterprises in the sample from 2016 to 2017 is assigned to 50%, and the R&D expense additional deduction ratio of enterprises from 2018 to 2021 is assigned to 75%.

(2) Income tax incentives

Income tax incentives (ITPRE). Based on relevant research(Xudong, 2018), the effective income tax rate of a company is measured by subtracting the effective income tax rate from 1, where the effective income tax rate is the ratio of corporate income tax to the sum of net profit, corporate income tax and interest expense. The specific calculation formula is: Income tax incentive = 1 - Corporate income tax / (Net profit + Corporate income tax + Interest expense).

3.2.2 Mediator variables

Green technology innovation (lnEAPATENT). Based on relevant research(Lyu et al., 2024), the number of green patents of enterprises is used to reflect the level of green technology innovation of enterprises. The application of green patents means that the corresponding technical solutions have been completed and put into use, and the patent authorization and approval usually take a long time and there is a certain lag. Therefore, in the main test, the number of green patent applications of enterprises after standardization by "ln(1+number of green patent applications)" is used to measure the green technology innovation of enterprises. In the robustness test, the number of green patents granted is used to measure the green technology innovation.

3.2.3 Control variables

Based on existing academic research, this paper incorporates firm size(Zenger, 1994), debt-to-equity ratio(Nguyen and Do, 2025; Yu et al., 2025), firm age(Bian and Luo, 2025), development capability(Yu et al., 2025), profitability(Zhang and Guo, 2025), board size(Yu et al., 2025), percentage of independent directors(Gu et al., 2025), equity concentration(Zhou et al., 2025), and firm nature(Zhou et al., 2025) as control variables into the regression model. In addition, industry attributes and time factors are also included as control variables. Specific measurement methods are shown in Table 1.

Table 1 Variable Selection and Determination Methods

	Variable name	Variable definition	Measurement method
Dependent Variable	INTENSITY	Carbon Intensity	See above
Independent Variable	ADPRE	Additional deduction for R&D expenses	(Corporate income tax rate × Additional deduction rate × R&D investment) / Total assets of the enterprise
	ITPRE	Income tax incentives	Tax incentives = 1 - Corporate income tax / (Net profit + Corporate income tax + Interest expense)
Mediator Variables	lnEAPATENT	Green technology innovation	ln(1 + number of green patent applications)
Control Variables	SIZE	Enterprise size	Logarithm of total corporate assets
	LEV	Debt-to-asset ratio	Total Liabilities / Total Assets
	AGE	Company age	Take the natural logarithm after subtracting the company's founding year from the sample observation year.
	GRO	Development capabilities	Total asset growth rate
	PRPFIT	Profitability	Total profit / Operating revenue
	BSIZE	Board size	Natural logarithm of the number of board members

DRATIO	Independent Directors Percentage	Number of independent directors / Number of directors
TOP	Shareholding concentration	Shareholding ratio of the largest shareholder
STATE	Enterprise nature	State-owned enterprises take 1, non-state-owned enterprises take 0.
INDUSTRY	Industry	The dummy variable takes a value of 1 if it belongs to this industry, and a value of 0 otherwise.
YEAR	Years	A dummy variable; it takes the value 1 if the year is specified, and 0 otherwise.

3.3 Model Construction

(1) Model of the Impact of Tax Incentives on Carbon Intensity

Based on the aforementioned theoretical analysis and research hypotheses, this paper constructs the following models. Model (1) examines the individual effects of R&D expense deduction and income tax incentives on carbon intensity. Model (2) investigates the combined impact of these two tax incentive policies on carbon intensity. Model (3) builds upon Model (2) by incorporating an interaction term to analyze the interplay between the two tax incentive policies in governing carbon intensity.

$$INTENSITY_{it} = \alpha_0 + \alpha_1 ADPRE_{it} / ITPRE_{it} + \alpha_2 \sum CONTROL_{it} + \alpha_3 \sum YEAR_{it} + \alpha_4 \sum INDUSTRY_{it} + \varepsilon_{it} \quad (1)$$

$$INTENSITY_{it} = \chi_0 + \chi_1 ADPRE_{it} + \chi_2 ITPRE_{it} + \chi_3 \sum CONTROL_{it} + \chi_4 \sum YEAR_{it} + \chi_5 \sum INDUSTRY_{it} + \varepsilon_{it} \quad (2)$$

$$INTENSITY_{it} = \delta_0 + \delta_1 ADPRE_{it} \times ITPRE_{it} + \delta_2 ADPRE_{it} + \delta_3 ITPRE_{i,t} + \delta_4 \sum CONTROL_{it} + \chi_4 \sum YEAR_{it} + \delta_5 \sum INDUSTRY_{it} + \varepsilon_{it} \quad (3)$$

(2)Pathway Model of Tax Incentives' Impact on Carbon Intensity

Based on the causal mediation analysis method proposed by Imai et al(Imai et al., 2010), models (4) through (7) were further constructed upon models (1) and (2) to examine the impact pathways through which R&D expense deduction and income tax incentives reduce carbon intensity by stimulating green technological innovation in enterprises.

$$\ln EAPATENT_{it} = \beta_0 + \beta_1 ADPRE_{it} + \beta_2 \sum CONTROL_{it} + \beta_3 \sum YEAR_{it} + \beta_4 \sum INDUSTRY_{it} + \varepsilon_{it} \quad (4)$$

$$\ln EAPATENT_{it} = \varphi_0 + \varphi_1 ITPRE_{it} + \varphi_2 \sum CONTROL_{it} + \varphi_3 \sum YEAR_{it} + \varphi_4 \sum INDUSTRY_{it} + \varepsilon_{it} \quad (5)$$

$$INTENSITY_{it} = \eta_0 + \eta_1 ADPRE_{it} + \eta_2 \ln EAPATENT_{it} + \eta_3 \sum CONTROL_{it} + \eta_4 \sum YEAR_{it} + \eta_5 \sum INDUSTRY_{it} + \varepsilon_{it} \quad (6)$$

$$INTENSITY_{it} = \gamma_0 + \gamma_1 ITPRE_{it} + \gamma_2 \ln EAPATENT_{it} + \gamma_3 \sum CONTROL_{it} + \gamma_4 \sum YEAR_{it} + \gamma_5 \sum INDUSTRY_{it} + \varepsilon_{it} \quad (7)$$

Where i and t denote firm and year, respectively, ε_{it} it represents the random disturbance term, and $\sum CONTROL_{it}$ denotes the control variables.

4. Empirical Results Analysis

4.1 Descriptive Statistics

Descriptive statistics for each variable are presented in Table 2.

Table 2 Descriptive Statistics Results (Sample Observations = 14,473)

Variable Name	Mean	Standard Deviation	Minimum	Median	Maximum
INTENSITY	0.446	0.561	0.037	0.146	2.267
ADPRE	0.003	0.002	0.000	0.002	0.012
ITPRE	0.864	0.101	0.379	0.871	1.000
lnEAPATENT	0.412	0.825	0	0	3.829
SIZE	22.142	1.243	19.998	21.960	26.022
LEV	0.386	0.187	0.057	0.377	0.853
AGE	2.958	0.292	1.386	2.996	4.159
GRO	0.215	0.367	-0.263	0.107	2.148
PRPFIT	0.096	0.172	-0.811	0.095	0.532
BSIZE	2.102	0.194	1.609	2.197	2.639
DRATIO	0.377	0.054	0.333	0.364	0.571
TOP	0.336	0.142	0.091	0.313	0.723

Dumb variable	Value=1		Value=0	
STATE	Frequency	Percentage (%)	Frequency	Percentage (%)
	10,403	28.121%	4,070	71.879%

Table 2 presents the descriptive statistics for the variables used in this study. As shown in Table 2, the standard deviation of corporate carbon intensity is 0.561, with minimum and maximum values of 0.037 and 2.267, respectively, indicating significant variation in carbon intensity across different industrial enterprises. The mean R&D expense deduction is 0.003 with a standard deviation of 0.002, indicating limited policy intensity for this incentive and relatively small differences in policy benefits among sample enterprises. The maximum and minimum values for income tax incentives are 1 and 0.379, respectively, with a mean and median of 0.864 and 0.871. Overall, industrial enterprises enjoy relatively high-income tax incentives.

4.2 Dynamic Analysis Based on Kernel Density Estimation

To further clarify the dynamic characteristics of R&D expense additional deduction and income tax incentives for industrial enterprises, this study selected six annual cross-sections from 2016 to 2021. Using kernel density estimation based on kernel functions, kernel density curves were plotted for R&D expense additional deduction and income tax incentives of Chinese industrial enterprises, as shown in Figure 2a and Figure 2b:

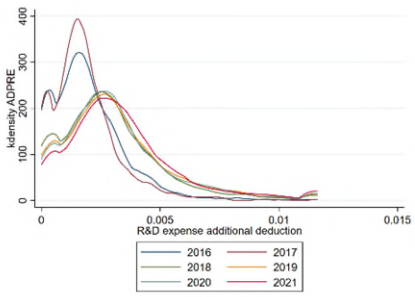


Figure 2a: Trend in the Deduction of Additional R&D Expenses for Industrial Enterprises

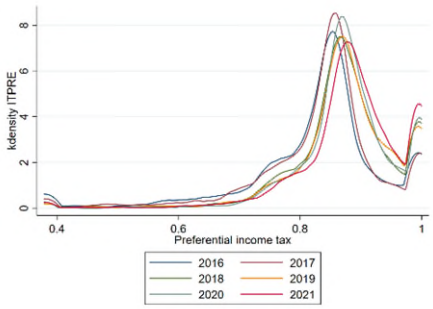


Figure 2b: Trend in Industrial Enterprise Income Tax Preferential Densities

Figure 2a and Figure 2b respectively illustrate the dynamic evolution of R&D expense additional deduction and income tax incentives for Chinese industrial enterprises from 2016 to 2021. The horizontal axis of Figure 2a represents R&D expense additional deduction, while the vertical axis denotes kernel density. The kernel density distribution curve exhibits an overall rightward shift, visually reflecting the increasing scale of R&D expense additional deduction enjoyed by Chinese industrial enterprises. The kernel density distribution curve also shows a transition from a peaked shape to a broadened peak shape, indicating a widening disparity in the scale of R&D expense additional deduction among different industrial enterprises. The kernel density distribution curve in Figure 2b shifts progressively to the right each year, indicating that the income tax benefits enjoyed by Chinese industrial enterprises increase annually. The relatively minor variation in curve width reveals that the disparity in income tax benefits among different industrial enterprises remains relatively stable.

4.3 Model Regression Results

First, we estimated Models (1) to (3) of the tax incentive carbon intensity impact model. The regression results are shown in Table 3:

Table 3: Testing the Carbon Intensity Mitigation Effects of Tax Incentives

VARIABLES	Model (1)		Model (2)		Model (3)
	INTENSITY	INTENSITY	INTENSITY	Standardized Coefficient	INTENSITY
ADPRE	-44.152***		-43.538***	-0.170	-10.470
	(2.011)		(2.043)		(15.537)
ITPRE		-0.217***	-0.099**	-0.018	-0.015
		(0.047)	(0.047)		(0.065)
ADPRE×ITPRE			0.034***		-37.045**
			(0.005)		(16.893)
SIZE	0.034***	0.034***	-0.019	0.075	0.034***
	(0.005)	(0.005)	(0.031)		(0.005)
LEV	-0.021	-0.005	0.074***	-0.006	-0.018
	(0.031)	(0.032)	(0.015)		(0.031)
AGE	0.075***	0.097***	-0.022*	0.038	0.074***
	(0.015)	(0.015)	(0.012)		(0.015)
GRO	-0.023*	-0.020	-0.180***	-0.014	-0.022*
	(0.012)	(0.013)	(0.028)		(0.012)
PRPFIT	-0.172***	-0.168***	0.006	-0.055	-0.182***
	(0.028)	(0.029)	(0.031)		(0.028)
BSIZE	0.007	0.011	-0.338***	0.002	0.007
	(0.031)	(0.032)	(0.109)		(0.031)
DRATIO	-0.336***	-0.325***	0.079**	-0.032	-0.334***
	(0.109)	(0.110)	(0.032)		(0.109)
TOP	0.082**	0.072**	0.118***	0.020	0.079**
	(0.032)	(0.033)	(0.012)		(0.032)
STATE	0.118***	0.130***	-43.538***	0.095	0.119***
	(0.012)	(0.012)	(2.043)		(0.012)
CONSTANT	-0.243*	-0.167	-0.099**		-0.220
	(0.137)	(0.147)	(0.047)		(0.150)
YEAR	YES	YES	YES		YES
INDUSTRY	YES	YES	YES		YES
Observations	14,473	14,473	14,473		14,473
R^2	0.101	0.078	0.102		0.102

Note: The values in parentheses represent robust standard errors. The same applies below.

As shown in the first column of Model (1) in Table 4, the coefficient for R&D expense additional deduction is -44.152 and passes the 1% statistical significance test, indicating that overall, R&D expense additional deduction significantly reduces the carbon intensity of industrial enterprises. Column 2 of Model (1) reveals the policy effect of income tax incentives. The regression coefficient for income tax incentives is -0.217 and is statistically significant at the 10% level, indicating that income tax incentives have a positive impact on carbon intensity management in industrial enterprises, thus validating H1. When R&D expense additional deduction and income tax incentives are implemented concurrently, Model (2) shows that both policies retain significant negative coefficients, reaffirming H1. The standardized coefficient for R&D expense additional deduction is 9.4 times that of income tax incentives, and the regression coefficient for R&D expense additional deduction exhibits higher statistical significance than income tax incentives. This indicates an asymmetric impact of the two tax incentives on carbon intensity, with R&D tax credits demonstrating stronger policy effects in reducing carbon intensity, thus validating H2. Further incorporating the interaction term between the two tax incentives into the regression analysis, Model

(3) shows an interaction coefficient of -37.045, significant at the 5% level. This demonstrates that the R&D expense additional deduction and income tax incentive exhibit a complementary relationship in reducing carbon intensity, validating H3. Summarizing the regression results in Table 3, both R&D expense additional deduction and income tax incentives significantly reduce carbon intensity on average. The R&D expense additional deduction policy demonstrates stronger effects, while both tax incentives exhibit complementary synergistic effects in lowering carbon intensity.

The results of mediating path tests for Models (4) to (7) are presented in Table 4:

Table 4: Testing Tax Incentive Pathways for Carbon Intensity Mitigation

	Model (4)	Model (5)	Model (6)	Model (7)
VARIABLES	lnEAPATENT	lnEAPATENT	INTENSITY	INTENSITY
ADPRE	62.357***		-42.550***	
	(3.805)		(2.051)	
ITPRE		0.714***		-0.188***
		(0.065)		(0.047)
lnEAPATENT			-0.026***	-0.041***
			(0.006)	(0.006)
SIZE	0.162***	0.165***	0.039***	0.041***
	(0.008)	(0.009)	(0.005)	(0.005)
LEV	0.379***	0.347***	-0.012	0.009
	(0.043)	(0.043)	(0.032)	(0.032)
AGE	-0.217***	-0.243***	0.069***	0.087***
	(0.025)	(0.024)	(0.015)	(0.015)
GRO	0.027	0.018	-0.022*	-0.019
	(0.018)	(0.018)	(0.012)	(0.013)
PRPFIT	0.113***	0.142***	-0.169***	-0.162***
	(0.040)	(0.040)	(0.028)	(0.029)
BSIZE	0.125**	0.123**	0.010	0.016
	(0.049)	(0.049)	(0.031)	(0.032)
DRATIO	0.411**	0.409**	-0.325***	-0.309***
	(0.166)	(0.167)	(0.109)	(0.111)
TOP	-0.086*	-0.059	0.080**	0.069**
	(0.049)	(0.049)	(0.032)	(0.033)
STATE	0.068***	0.052***	0.120***	0.132***
	(0.017)	(0.017)	(0.012)	(0.012)
Constant	-3.480***	-3.990***	-0.332**	-0.330**
	(0.232)	(0.248)	(0.136)	(0.146)
YEAR	YES	YES	YES	YES
INDUSTRY	YES	YES	YES	YES
Observations	14,473	14,473	14,473	14,473
R^2	0.111	0.095	0.103	0.081

In Models (4) and (5), the regression coefficients for R&D expense deductions and income tax incentives were significantly positive at the 1% level. Models (6) and (7) tested the mediating effect, revealing that both tax incentive policies and green technological innovation were significant at the 1% level. Green technological innovation mediated the process by which tax incentives reduced corporate carbon intensity, validating Hypothesis 4. Tax incentives enable enterprises to accumulate greater cash flow, correct externalities arising from green R&D investments, and incentivize green technological innovation. Enterprises enhance energy utilization efficiency and reduce carbon intensity by lowering carbon emissions per unit of output through green technological innovations such as expanding R&D scale, hiring high-level R&D personnel, improving production processes, and optimizing energy structures.

4.5 Robustness Test

(1) Endogeneity Test

This paper employs a two-stage least squares approach to control for potential endogeneity issues between R&D expense additional deduction, income tax incentives, and carbon intensity, as well as between R&D expense additional deduction, income tax incentives, and green technological innovation. Due to space limitations, the detailed regression results for the control variables in the robustness test are provided in the appendix.

Following the instrumental variable selection approach in relevant fiscal incentive policy studies(Lin and Xie, 2023), this paper selects the average R&D tax credit (AVERAGE1) of all enterprises in the same city and industry except the firm itself as the instrumental variable for the firm's R&D tax credit. The average income tax incentive (AVERAGE2) of all enterprises in the same city and industry except the firm itself serves as the instrumental variable for the firm's income tax incentive. These variables were chosen as instruments because the fiscal decentralization system grants local governments discretion over tax incentives for enterprises within their jurisdiction, and local government finances are highly correlated with regional economic development levels. Given significant differences in industry-specific characteristics and varying tax systems across sectors, enterprises within the same city and industry typically receive positively correlated R&D tax credits and income tax incentives. Furthermore, the R&D tax credits and income tax incentives received by other enterprises bear no direct relationship to the firm's own green technological innovation and carbon intensity, satisfying the exogeneity condition for instrumental variables. This paper further validates the feasibility of this instrumental variable selection through model verification, with regression results presented in Table 5.

Table 5 Instrument Variables Test

VARIABLES	Research and Development Expense Deduction and Carbon Intensity INTENSITY	Income Tax Incentives and Carbon Intensity INTENSITY	Research and Development Expense Deduction and Green Technology Innovation lnEAPATENT	Income Tax Incentives and Green Technology Innovation lnEAPATENT
ADPRE	-126.763***		138.997***	
	(6.146)		(8.747)	
ITPRE		-2.353***		3.475***
		(0.301)		(0.433)
YEAR/ INDUSTRY	YES	YES	YES	YES
Cragg-Donald Wald F-statistic [Threshold]	2386.083 [16.38]	410.089 [16.38]	2386.083 [16.38]	410.089 [16.38]
Anderson canonical correlation LR Statistic (P value)	2050.568***	399.272***	2050.568***	399.272***
Observations	14,473	14,473	14,473	14,473

Since the number of instrumental variables equals that of endogenous variables, the model is perfectly identified. The Anderson LM statistic was used to test for non-identifiability, verifying whether instrumental variables correlate with explanatory variables. The Anderson LM statistic P-values in the non-identifiability test were all 0.0000, rejecting the null hypothesis. The rank condition holds, and the non-identifiability test is passed. In the weak instrument identification test, the Cragg-Donald Wald F-statistic significantly exceeds the 10% critical value from the Stock-Yogo test (indicated in parentheses), confirming the absence of weak instrumentation issues. The selection of instrumental variables is thus reasonable. The signs and significance levels of the model coefficients have changed, demonstrating the robustness of the results.

(2) Modify the measurement approach for certain core variables

To further enhance the credibility of the empirical research in this paper and reduce result bias caused by measurement errors in variables, the original regression model was re-examined by altering the measurement method for the core variable. Based on the classification of high-carbon emission industries by China's National Development and Reform Commission, if a company operates in the power generation, petrochemical, chemical, building materials, steel, non-ferrous metals, papermaking, or domestic civil aviation sectors, its carbon intensity is considered high and thus assigned a value of 1; otherwise, it is assigned a value of 0. To replace the carbon intensity variable measurement in the above models, considering that carbon intensity (INTENSITY') is a discrete variable, the Probit model was adopted for analysis in each model to more accurately determine its impact. The replacement for the mediator measurement is the enterprise green patent application count (lnEGPATENT), standardized via "ln(1 + green patent authorization count)". The regression results after replacing the core variable measurement method are shown in Table 6:

Table 6: Testing the Carbon Intensity Mitigation Effects of Tax Incentives Using Alternative Variable Measurement Approaches

VARIABLES	(1)	(2)	(3)		(4)
	INTENSITY'	INTENSITY'	INTENSITY'	Standardized Coefficient	INTENSITY'
ADPRE	-116.215***		-114.433***	-0.138	36.916
	(7.307)		(7.366)		(54.482)
ITPRE		-0.537***	-0.273**	-0.018	0.082
		(0.119)	(0.121)		(0.182)
ADPRE×ITPRE					-172.402***
					(61.774)
YEAR/INDUSTRY	YES	YES	YES		YES
Observations	14,473	14,473	14,473		14,473
R^2	0.115	0.097	0.115		0.144

According to Table 5, the regression coefficients and significance of each model did not change after the core explanatory variables were replaced, confirming the robustness of the original conclusions. Robustness tests for the mediating effect paths are presented in Table 7:

Table 7: Testing Carbon Intensity Mitigation Pathways Using Alternative Measures of Tax Incentives

VARIABLES	(1) lnEGPATENT	(2) lnEGPATENT	(3) INTENSITY'	(4) INTENSITY'
ADPRE	45.910***		-111.856***	
	(3.217)		(7.337)	
ITPRE		0.548***		-0.467***
		(0.058)		(0.120)
lnEGPATENT			-0.093***	-0.125***
			(0.017)	(0.017)
YEAR/ INDUSTRY	YES	YES	YES	YES
Observations	14,473	14,473	14,473	14,473

According to Table 7, after switching to the variable measurement approach, both tax incentive policies exhibit positive and statistically significant coefficients at the 1% level with green technology innovation. The regression coefficients for both tax incentive policies, green technology innovation, and carbon intensity are significant at the 1% level. The mediating effect of green technology innovation remains valid, consistent with the main test results. This further validates H4, confirming the robustness of the original conclusion.

5 Testing the Nonlinear Threshold Effect of Corporate Carbon Intensity Management under Tax Incentives*

*Due to the requirement for strongly balanced panel data in threshold panel models, the threshold effect analysis

The policy synergistic effects of R&D expense additional deduction and income tax incentives on carbon intensity governance exist, with the strongly policy-directed R&D expense additional deduction playing a more significant role in reducing carbon intensity. However, does a higher level of R&D expense additional deduction necessarily enhance the carbon intensity mitigation effect of income tax incentives? Are there conditions under which income tax incentives exert their carbon intensity mitigation effect? To explore potential nonlinear relationships, subsequent analysis focuses on the R&D expense additional deduction policy. Both R&D expense additional deduction and income tax incentives are selected as threshold variables to identify whether these two tax incentive policies exhibit threshold effects on corporate carbon intensity mitigation. Following Hansen's methodology [64], we internally partitioned the data based on its inherent characteristics to examine differences in the contribution of the two tax incentives to carbon intensity governance across distinct R&D tax credit threshold intervals. Due to space constraints, regression results incorporating control variables are presented in the appendix.

To avoid bias from artificially dividing R&D tax credit thresholds, intervals were inherently defined based on the data's characteristics to examine differences in the contribution of these two tax incentives to carbon intensity governance across varying R&D tax credit threshold ranges. Following Hansen's methodology [64], the following threshold effect model was constructed:

$$INTENSITY_{it} = \phi_0 + \phi_1 ITPRE_{i,t} * I(ADPRE_{i,t} \le \gamma_1) + \phi_2 ITPRE_{i,t} * I(\gamma_1 < ADPRE_{i,t} \le \gamma_2) + \ldots + \phi_{n+1} ITPRE_{i,t} * I(ADPRE_{i,t} > \gamma_n) + \phi_{n+2} \sum CONTROL_{it} + \phi_{n+3} \sum YEAR_t + \phi_{n+4} \sum INDUSTRY_{it} + \mu_{it} + \varepsilon_{it} \quad (8)$$

$$INTENSITY_{it} = \eta_0 + \eta_1 ADPRE_{i,t} * I(ITPRE_{i,t} \le \theta_1) + \eta_2 ADPRE_{i,t} * I(\theta_1 < ITPRE_{i,t} \le \theta_2) + \ldots + \eta_{n+1} ADPRE_{i,t} * I(ITPRE_{i,t} > \theta_n) + \eta_{n+2} \sum CONTROL_{it} + \eta_{n+3} \sum YEAR_t + \eta_{n+4} \sum INDUSTRY_{it} + \mu_{it} + \varepsilon_{it} \quad (9)$$

Where, I(▪) denotes an indicator function that takes the value 1 if the inequality in parentheses holds, and 0 otherwise; γ_1, γ_2, …, γ_n and θ_1, …, θ_n are the threshold values to be estimated for ADPRE_(i,t), respectively. The meanings of other variables remain consistent with the preceding text. First, we test for the existence of threshold effects, confirming the number of existing thresholds along with their corresponding F-values and P-values. The results are presented in Table 9:

Table 9: Threshold Effect Test Results (Observations = 10,338)

Explanatory variable	Threshold Setting	F- Vaile	P- Vaile	Threshold			Conclusion
				1%	5%	10%	
Income Tax Incentives	Single threshold	33.996***	0.000	9.057	4.95	3.464	Passed inspection
	Double threshold	61.994***	0.000	7.525	4.367	2.822	Passed inspection
Additional Deduction for R&D Expenses	Single threshold	7.813***	0.010	8.535	4.425	2.898	Passed inspection
	Double threshold	14.530***	0.000	7.427	4.037	2.484	Passed inspection

Note: Both the p-value and critical value were obtained through bootstrap sampling with 300 iterations.

The threshold effect test results in Table 9 indicate that both the single threshold and dual threshold effect tests are statistically significant at the 1% level. Further testing of each threshold value and its significance is shown in Table 10.

section balanced the previously observed data. This yielded 1,723 balanced panel observations for industrial enterprises during the sample period. The number of regression observations incorporating lagged explanatory variables was 1,723 × 6 = 10,338.

Table 10 Threshold Estimates and Confidence Intervals

		Threshold Estimate	95% confidence interval
Income tax incentives as the explanatory variable R&D expense additional deduction as the threshold variable	Threshold value γ_1	0.005	[0.458，0.999]
	Threshold value γ_{11}	0.002	[0.413，0.999]
	Threshold value γ_{12}	0.005	[0.413，0.999]
Using R&D expense additional deduction as the explanatory variable Income tax incentives as the threshold variable	Threshold value θ_1	0.892	[0.025，0.245]
	Threshold value θ_{11}	0.915	[0.150，0.215]
	Threshold value θ_{12}	0.830	[0.051，0.095]

Each threshold value has a 95% confidence interval that does not include zero, indicating that all threshold values are at a significant level. When income tax incentives serve as the explanatory variable, the single threshold is 0.005, and the dual thresholds are 0.002 and 0.005. When R&D expense additional deduction serves as the explanatory variable, the single threshold is 0.892, and the dual thresholds are 0.915 and 0.830. This study employs single-threshold and dual-threshold models to examine the threshold effects of R&D expense additional deduction. The model analyzing the impact of tax incentives on carbon intensity, with R&D expense additional deduction as the threshold variable, will be analyzed based on both single-threshold and dual-threshold approaches. The constructed likelihood ratio statistic (LR value) and the maximum likelihood ratio function plot corresponding to the threshold value are used to test the validity of the threshold estimates. The single-threshold and dual-threshold maximum likelihood ratio function plots, with income tax incentives as the explanatory variable and R&D expense additional deduction as the threshold variable, are shown in Figures 3a to 3b.



Figure 3a: Single-Threshold Likelihood Ratio Plot for Explanatory Variable ITPRE



Figure 3b: Single-Threshold Likelihood Ratio Plot for Explanatory Variable ADPRE

The likelihood ratio function plots generated using Figures 3a and 3b provide an intuitive visualization of the single threshold estimate and its construction process. The threshold estimates represent the ADPRE values when the LR value is 0. The 95% confidence intervals for each threshold estimate correspond to the critical value of 7.35 under an LR value significance level below 5% (indicated by the red dashed line in Figures 3a and 3b). The LR values associated with these threshold estimates all fall below 7.35, consistent with the true value. Panel threshold effect regression was conducted using Models (8) and (9), with results presented in Table 11.

Table 11 Threshold Effect Regression Results

Threshold Type	Threshold Range	Variable	Coefficient	Standard Error
Using income tax incentives as the explanatory variable and R&D expense additional deduction as the threshold variable				
Single threshold	ADPRE≤0.005	ITPRE_1	-0.045	(0.039)
	ADPRE>0.005	ITPRE_2	-0.177***	(0.042)
Double threshold	ADPRE≤0.002	ITPRE_1	0.026	(0.040)
	0.002<ADPRE≤0.005	ITPRE_2	-0.065*	(0.039)
	ADPRE>0.005	ITPRE_3	-0.188***	(0.042)
Using R&D expense additional deduction as the explanatory variable and income tax incentives as the threshold variable				
Single threshold	ITPRE≤0.892	ADPRE_1	-19.183***	(3.035)
	ITPRE>0.892	ADPRE_2	-26.250***	(2.917)
Double threshold	ITPRE≤0.830	ADPRE_1	-12.740***	(3.921)
	0.830< ITPRE≤0.915	ADPRE_2	-20.495***	(3.029)
	ITPRE>0.915	ADPRE_3	-28.887***	(3.080)
		CONTROL	YES	
		FIRM/ YEAR/ INDUSTRY	YES	

Combining model (8) with the regression results in Table 11, different threshold ranges for R&D expense additional deduction affect the carbon intensity mitigation effect of income tax incentives. Under a single threshold, when R&D expense additional deduction falls below the threshold value (θ1=0.005), the regression coefficient for income tax incentives is negative but not significant, indicating that the carbon intensity mitigation effect of income tax incentives is difficult to achieve. When R&D tax credits are greater than or equal to the threshold (θ_1=0.005), the regression coefficient for income tax incentives is -0.177 and significant at the 1% level, demonstrating a carbon intensity mitigation effect. Under the dual threshold approach: When R&D expense additional deduction is less than or equal to the first threshold (θ_{11}=0.002), the income tax incentive regression coefficient is positive but not significant, making it difficult to achieve carbon intensity management effects; As the R&D expense additional deduction increases, when it exceeds the first threshold (θ_{11}=0.002) but remains below the second threshold (θ_{12}=0.005), the income tax incentive regression coefficient turns negative and is significant at the 10% level; When R&D expense additional deduction reaches higher levels exceeding the second threshold (θ_{12}=0.005), the income tax incentive coefficient is -0.188 and significant at the 1% level. Both the absolute value and significance of the coefficient further increase, indicating that income tax incentives can most significantly reduce carbon intensity at this stage. Based on the above regression results, when the R&D expense additional deduction falls below the threshold value, the income tax incentive struggles to exert its carbon intensity mitigation effect. Only when the additional deduction level exceeds the threshold value can the income tax incentive significantly reduce carbon intensity. The underlying reason aligns with the theoretical analysis and Hypothesis 3 in this study: When the R&D tax credit level is low, the lack of technological innovation guidance limits its effectiveness in driving corporate technological decarbonization and long-term development focus. Some enterprises may invest the tax savings into projects with short capital recovery cycles and immediate economic benefits, undermining the carbon intensity mitigation potential of the tax incentive. As the R&D tax credit threshold is raised beyond a certain level, its innovation-driving effect on enterprises intensifies. This approach encourages companies to engage in long-term strategic planning, allocating resources to high-quality development initiatives such as creating new processes and technologies or improving energy efficiency. As a result, income tax incentives can only effectively drive corporate low-carbon transformation under scenarios with substantial R&D tax credits. These credits help reduce externalities linked to the low-carbon transition and ease financing constraints, thereby supporting better carbon intensity management.

When using R&D expense additional deduction as the explanatory variable and income tax

incentives as the threshold variable, R&D expense additional deduction exerts a significant regulatory effect on carbon intensity under various income tax incentive conditions. Under a single threshold, when income tax incentives are less than or equal to the threshold value (γ_1=0.892), the regression coefficient for R&D expense additional deduction is -19.183 and is statistically significant at the 1% level; When income tax incentives exceed the threshold (γ_1=0.892), the regression coefficient for R&D tax credits is -26.250 and significant at the 1% level, yielding a carbon intensity mitigation effect 1.368 times greater than that observed in the first threshold interval. Under the dual threshold, when R&D expense additional deduction is less than or equal to the first income tax incentive threshold (γ_{11}=0.830), the regression coefficient for R&D expense additional deduction is -12.740 and significant at the 1% level; As the R&D expense additional deduction level increases beyond the first threshold (γ_{11}=0.830) and remains below the second threshold (γ_{12}=0.915), the regression coefficient for R&D expense additional deduction is -20.495 and statistically significant at the 1% level, with a stronger carbon intensity mitigation effect compared to the previous threshold range; When the R&D tax credit exceeds the second threshold (γ_{12}=0.915), the regression coefficient is -28.887 and statistically significant at the 1% level, achieving the maximum carbon intensity mitigation effect. Summarizing the above findings reveals: The carbon intensity mitigation effect generated by R&D tax credits does not require income tax incentives as a prerequisite; that is, R&D tax credits can significantly reduce industrial enterprises' carbon intensity across different income tax incentive threshold ranges. The carbon intensity mitigation utility of R&D expense additional deduction exhibits a non-linear growth pattern as the income tax incentive threshold increases. Specifically, when income tax incentives are at higher levels, R&D expense additional deduction maximizes its carbon intensity mitigation effect. As the level of R&D expense additional deduction increases, its effect on reducing carbon intensity also intensifies. Even at low-income tax incentive thresholds, R&D expense additional deductions can still drive corporate low-carbon transformation through innovation-driven effects. They enhance corporate motivation for management system innovation and green technology innovation to reduce carbon intensity, thereby achieving the intended policy effects. When corporate income tax incentives reach higher thresholds, companies that also benefit from additional R&D deductions can preserve more cash flow. They reduce the marginal cost of R&D investments during the low-carbon transition and diversify transition risks. This strengthens market competitiveness, sends positive signals to external stakeholders, and improves the chances of attracting capital market support. The effect of R&D deductions grows as both policies become more intense, demonstrating strong carbon intensity management capabilities. Based on the above analysis, income tax incentives only achieve carbon intensity reduction effects when R&D expenditures exceed a certain threshold. Maintaining R&D expense additional deduction levels above this threshold is a prerequisite for realizing the carbon intensity governance effects of tax incentives. The R&D expense additional deduction plays a primary role in reducing carbon intensity, consistent with the asymmetric carbon intensity governance effects observed in the theoretical analysis and research assumptions for both tax incentive policies. Maximizing the governance efficacy of these policies on carbon intensity occurs when both tax incentives operate at relatively strong levels.

6 Conclusions and Implications

This study uses listed industrial companies in China from 2016 to 2021 as its sample. It empirically examines the asymmetric effects of two tax incentives—additional R&D deductions and corporate income tax incentives—on carbon intensity. It also explores how these incentives interact to influence carbon intensity and shape governance pathways. Furthermore, the study identifies the conditions under which these incentives affect carbon intensity. Hansen's threshold effect model is applied to analyze their nonlinear relationship with carbon intensity. The findings reveal: First, both

R&D expense additional deduction and income tax incentives contribute to reducing industrial enterprises' carbon intensity, though their effects exhibit asymmetry, with R&D expense additional deduction demonstrating stronger carbon intensity reduction. Second, these incentives generally exert synergistic effects in lowering carbon intensity, exhibiting a complementary relationship. Third, they reduce carbon intensity by incentivizing enterprises to pursue green technological innovation. Fourth, both R&D tax credits and income tax incentives exhibit threshold effects on corporate carbon intensity: Under low R&D tax credit levels, income tax incentives struggle to achieve their intended policy effects. As R&D tax credits increase, their carbon intensity mitigation impact on enterprises strengthens. When R&D tax credits are low, there is insufficient guidance for enterprises to engage in long-term activities like technological R&D. Some enterprises may instead invest income tax incentive funds into operational projects with short capital recovery cycles and immediate economic benefits, making it difficult to realize the policy effects of income tax incentives. When the R&D expense additional deduction threshold is raised above the threshold value, it helps guide enterprises toward long-term strategic decisions, drives R&D for new technologies to enhance energy efficiency, and incentivizes low-carbon transformation and carbon intensity reduction under the income tax incentive framework. Conversely, within different income tax incentive threshold ranges, the R&D expense additional deduction consistently demonstrates significant carbon intensity management effects, exhibiting a non-linear growth pattern in policy effectiveness as the income tax incentive threshold increases. When income tax incentives operate within higher threshold ranges, enterprises supported by both income tax incentives and R&D expense additional deductions can conserve greater cash flow, reduce the marginal cost of R&D investment during low-carbon transition, and mitigate transition risks. R&D expense additional deductions can thus maximize their role in lowering carbon intensity.

The findings of this study offer the following implications for national and local governments seeking to incentivize enterprises to reduce carbon intensity through tax incentives under the dual carbon goals: First, considering the asymmetric governance effects of R&D expense additional deduction and income tax incentives on industrial enterprises' carbon intensity, governments should enhance the intensity of R&D expense additional deduction policies. They should prioritize the governance impact of R&D expense additional deduction on carbon intensity, forming a policy combination centered on R&D expense additional deduction with income tax incentives as a supplement. This approach leverages the synergistic effects of both tax incentives in governing industrial enterprises' carbon intensity. Second, when designing tax incentive policies, governments should recognize the pivotal role of incentivizing green technological innovation in reducing industrial carbon intensity. They should strengthen tax support for companies engaged in green technological innovation and low-carbon transformation. This will guide firms toward green and low-carbon production through innovation. It will also encourage greater corporate investment in the green transition. For instance, tax reductions could be strengthened for projects directly related to product manufacturing and energy utilization — such as process improvements, workflow optimization, and equipment upgrades for energy conservation and emissions reduction — to incentivize enterprises to drive energy savings and carbon reduction through green technological innovation. Industrial enterprises should prioritize long-term sustainable development and broaden societal benefits. They need to actively respond to government initiatives for low-carbon transition. Companies should seize the opportunities offered by tax incentives and recognize the critical role of green technological innovation. Finally, threshold effect analysis shows that the carbon intensity reduction from additional R&D deductions grows as the threshold range increases. Importantly, income tax incentives only deliver carbon intensity benefits when R&D deductions exceed the threshold value. Governments should recognize this threshold effect, work to raise enterprises' R&D deductions above the threshold, and then strengthen income tax incentives. This approach

maximizes the combined impact of both tax policies on carbon intensity management.

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- Consent to Participate

Informed consent was obtained from all individual participants included in the study. Participants were informed of the purpose, procedures, and potential risks of the research, and their participation was entirely voluntary. All participants provided written/oral consent prior to their inclusion in the study, and they were assured of their right to withdraw from the study at any time without penalty.

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I used or generated research data in this study. The data for this study is sourced from CSMAR, and these data are authorized for use in support of the results of this study. They can be obtained from the corresponding authors upon reasonable request.

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