

Research on the Impact of Carbon Emission Trading on the Utilization Efficiency of Resource and Environmental Factors from the Perspective of New Quality Productivity

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Abstract. Using panel data of 30 provinces in China from 2004 to 2023, this paper adopts the multi-period difference-in-differences method to verify the impact and functioning mechanism of the carbon emission trading pilot policy on the utilization efficiency of resource and environmental factors. The findings are as follows: First, carbon emission trading significantly improves the utilization efficiency of resource and environmental factors. Second, mechanism analysis shows that the policy exerts its effects by activating the fostering factors of new quality productivity. Third, heterogeneity analysis indicates that the policy effect of comprehensive pilots is stronger than that of industrial pilots, and the policy effect of provinces and municipalities where national-level urban agglomerations are located is significantly higher than that of non-urban agglomeration areas. The results of this study suggest that in the process of improving the construction of the national carbon market, we should expand the scope of industry coverage and strengthen the institutional synergy advantage of urban agglomerations, so as to realize the systematic improvement of the utilization efficiency of resource and environmental factors under carbon constraints.

Keywords: Carbon Emission Trading, Utilization Efficiency of Resource and Environmental Factors, New Quality Productivity, Multi-period Difference-in-Differences

1. Introduction

Against the backdrop of global warming and tightening resource constraints, developing a low-carbon economy and realizing efficient resource utilization is an effective path for high-quality economic development. As a late-developing major country, China is simultaneously under the dual pressure of high-carbon dependence in stock and the pain of incremental transformation, and has a long way to go in emission reduction. The current situation of increasingly scarce resources and limited environmental carrying capacity in China further increases the difficulty of emission reduction. In 2025, the State Council issued the *Opinions on Improving the Market-oriented Allocation System of Resource and Environmental Factors*, further pointing out the importance of improving the utilization efficiency of resource and environmental factors. Realizing the coordinated advancement of economic development, environmental protection and effective resource utilization is the only way for green economic development. General Secretary Xi Jinping pointed out that

"new quality productivity is inherently green productivity", which reveals the path to resolve the deep-seated contradiction among environmental protection, economic development and resource constraints. Traditional productivity relies on the large-scale input of resource factors, and its expansion logic will inevitably lead to the overdraft of environmental capacity and the exhaustion of resource supply. Only by promoting the fundamental leap of productivity form and transforming to innovation-driven, green and low-carbon new quality productivity can we break the shackles of "growth-consumption-pollution" and collaboratively realize carbon emission reduction, economic efficiency improvement and resource conservation.

As a systematic policy that affects enterprise behavior and regional environment, the effect evaluation of carbon emission trading needs to take into account the overall situation of resource utilization. Under the dual background of continuous improvement of the ecological civilization system and the in-depth advancement of the "dual carbon" strategy, a more theoretically profound proposition needs to be answered: Can market-oriented means realize the fundamental improvement of the utilization efficiency of resource and environmental factors by leveraging the systematic improvement of new quality productivity? The proposal of this proposition pushes the core issue of green governance innovation from "how to constrain emissions" to the deeper dimension of "how to stimulate leaps". If carbon emission trading can only achieve emission reduction but cannot improve resource efficiency, its policy effectiveness will be limited to the single dimension of environmental governance; if it can nurture new quality productivity and thus improve the utilization efficiency of resource and environmental factors, it will become an institutional engine for reshaping the driving force of economic growth. Taking the carbon emission trading pilot as a quasi-natural experiment, this paper uses a multi-period difference-in-differences model to systematically evaluate its policy effect, functioning mechanism and heterogeneous characteristics on the utilization efficiency of resource and environmental factors, so as to provide theoretical support and empirical evidence for improving the operation mechanism of the carbon market and promoting the coordinated development of carbon emission reduction and resource efficiency improvement.

2. Literature review

Since China approved the carbon emission trading pilot work in 2011, the academic circle has carried out continuous research in this field, and has accumulated more than ten years of exploration so far. The research content has gradually expanded from the preliminary evaluation of the emission reduction effect of the trading mechanism [1-4] to the discussion of its impact on factor allocation efficiency [5, 6]. The research industries have gradually extended from high energy-consuming fields such as electric power and iron and steel [7] to broader sectors such as manufacturing, construction and service industries [8, 9]. At present, how to systematically evaluate the impact of carbon trading on the utilization efficiency of resource and environmental factors and reveal its mechanism in optimizing factor allocation and improving green total factor productivity has become one of the important topics in the research of green and low-carbon development.

There is a rich accumulation of relevant literature on the utilization efficiency of resource and environmental factors, and research perspectives and methods are gradually diversifying. In terms of research content, existing literature mainly focuses on several aspects: the measurement and analysis of single-factor efficiency, research on green total factor productivity, and synthetic analysis of single-factor indices. Some studies focus on single factors, such as land resource utilization efficiency, water resource utilization efficiency and energy utilization efficiency, and discuss their applications in agricultural production, industrial development and urban construction from different perspectives respectively [10-13]. Some scholars pay attention to green total factor productivity,

incorporate environmental pollution and energy consumption into the total factor productivity analysis framework, and investigate production efficiency after considering undesirable outputs [14, 15]. Some scholars try to incorporate land resources, water resources and energy into a unified evaluation framework, and use the index synthesis method to measure the utilization efficiency of resources and environment [16].

Scholars have carried out in-depth discussions on the impact of carbon emission trading policies from different levels, which can be mainly divided into two dimensions: macro effects and micro effects. At the macro level, scholars focus on the impact of carbon emission trading on regional total carbon emissions [17], green total factor productivity [18], etc., and examine its policy effect in promoting overall low-carbon transformation. At the micro level, research focuses on the effect of carbon emission trading on enterprise behavior and performance, including its impact on enterprise technological innovation [19], green technology adoption [20], total factor productivity [21], enterprise operating performance and competitiveness [22], etc., aiming to reveal the transmission mechanism and incentive effect of the policy at the micro subject level.

To sum up, although existing studies have revealed the multi-dimensional impacts of carbon emission trading, they have rarely examined it under the overall framework of the comprehensive utilization efficiency of resource and environmental factors. As a systematic policy that affects enterprise behavior and regional environment, the effect evaluation of carbon emission trading needs to take into account the overall situation of resource utilization, so as to comprehensively measure the possible trade-offs among factors in policy implementation, avoid sacrificing other resources due to the single pursuit of emission reduction targets, and thus more systematically reveal the net effect of carbon emission trading on the comprehensive utilization efficiency of resources and environment. Taking the carbon emission trading policy formally implemented in China in 2013 as the research object, this paper constructs a multi-period difference-in-differences model and uses provincial panel data to investigate its impact on the utilization efficiency of resource and environmental factors. This paper answers the following questions: Can carbon emission trading improve the utilization efficiency of resource and environmental factors? What is the mechanism of this effect? And how does the effect vary across different regions?

3. Theoretical basis and research hypotheses

3.1. Impact of carbon emission trading on the utilization efficiency of resource and environment

The carbon emission trading policy is an institutional innovation for the government to use market mechanisms to promote low-carbon development. By clarifying the property right attribute of carbon emissions, it internalizes the external cost of carbon emissions, guides resource factors to flow to green and efficient fields, and realizes the coordinated development of economic growth and ecological environment protection. First, the carbon emission trading policy sets carbon emission quotas for enterprises included in the emission control scope, forms a total amount constraint, and allows enterprises to buy and sell quotas in the market according to their own emission reduction costs. This prompts enterprises with low emission reduction costs to have the motivation to reduce emissions through technological improvement and sell excess quotas for profit, while enterprises with high emission reduction costs need to purchase quotas, thereby motivating enterprises to optimize the factor input structure [23] and promoting the overall improvement of resource utilization efficiency. Second, the carbon emission trading policy guides the direction of resource allocation through price signals. The price of carbon emission quotas reflects the marginal cost of

carbon emission reduction. To reduce carbon compliance costs, enterprises will actively adjust production methods, reduce high-carbon energy consumption, promote the agglomeration of production factors such as capital, talents and technology to green and low-carbon fields, and improve the utilization efficiency of resource and environmental factors. In addition, the carbon trading mechanism endows emission reduction behavior with direct economic returns. The carbon emission quotas saved by enterprises through improving the utilization efficiency of resources and environment can be realized in value in the market, thus forming a positive incentive cycle, accelerating the elimination of high energy-consuming and low-efficiency production methods, and promoting the evolution of resource and environmental factors to a more efficient allocation state across the whole society [24]. Accordingly, research hypothesis H1 is proposed.

H1: Carbon emission trading improves the utilization efficiency of resource and environmental factors.

3.2. Influence mechanism of carbon emission trading on improving the utilization efficiency of resource and environmental factors

3.2.1. Industrial structure upgrading mechanism

The optimization and upgrading of industrial structure plays a key role in promoting the transformation of the economic system from scale expansion to quality and efficiency improvement, and is an important way to enhance regional sustainable development capacity. The Petty-Clark theorem holds that with economic development and the improvement of per capita income level, production factors will transfer from the primary industry to the secondary industry with higher added value, and then to the tertiary industry. Carbon emission trading increases the compliance cost of high-carbon emission industries, making low-carbon industries, clean technology industries and service industries and other high value-added, low-emission sectors gain relative income advantages under cost constraints. Production factors transfer from high-carbon industries to low-carbon and efficient industries, promoting the industrial structure of pilot areas to evolve towards low-carbon, service-oriented and high-end directions, and realizing the rationalization and advancement of industrial structure [25], thus improving the economic output efficiency per unit of resource and environmental factors. The pollution haven hypothesis holds that under the condition of regional differences in the intensity of environmental regulation, high-pollution and high-energy-consuming industries transfer from areas with strict environmental regulation to areas with loose regulation, and the latter become the "pollution havens" of the former. For high-carbon emission industries with low carbon efficiency and high emission reduction costs, the rising compliance cost under the carbon trading mechanism makes them lose their comparative advantage in pilot areas. These industries are forced to withdraw from the local market or transfer to areas not yet included in the carbon trading system or with low carbon price levels, freeing up development space for efficient low-carbon industries [26], thus optimizing the regional resource allocation structure and improving the output efficiency of resource and environmental factors. Accordingly, hypothesis H2 is proposed.

H2: Carbon emission trading improves the utilization efficiency of resource and environmental factors by promoting industrial structure upgrading.

3.2.2. Green innovation mechanism

The carbon emission trading mechanism endows carbon emissions with clear costs, and economic incentives enable high-emission enterprises to re-examine their production technology paths under

the framework of profit maximization. The cost pressure transmitted by carbon price constitutes a key motivation for enterprises to carry out green technology research and development. To avoid paying high carbon quota purchase fees or bearing administrative fines caused by excess emissions, enterprises will increase investment in energy-saving technologies, clean energy substitution, production process improvement and end-of-pipe treatment facilities. This cost-driven endogenous innovation behavior promotes enterprises to gradually realize low-carbon transformation on the production side: on the one hand, improving the energy structure and increasing the proportion of renewable energy or low-emission energy; on the other hand, optimizing production processes and reducing resource input and emission output per unit output. In the long run, the carbon trading mechanism does not simply put pressure on enterprises, but makes the low-carbon technology path more economically attractive by changing the relative price system, and promotes its low-carbon transformation on the production side [27]. At the same time, the carbon emission trading mechanism also strengthens the diffusion effect of green innovation through information dissemination and inter-organizational collaboration. Enterprises with high emission reduction efficiency often take the lead in mastering advanced low-carbon technologies and management experience, and the technical standards, operation procedures and production modes formed in their emission reduction practices will form a demonstration effect among competitors in the same industry or upstream and downstream supply chain enterprises. Through channels such as industry associations, technology exchange platforms and supply chain cooperation, relevant knowledge can be spilled over and replicated, thereby reducing the trial-and-error cost of other enterprises in exploring green technologies. In addition, to reduce the overall compliance cost in the entire industrial chain or region, enterprises may carry out cooperative behaviors such as joint research and development, joint construction of emission reduction infrastructure, and sharing of emission data and governance experience. This collaborative innovation mechanism further accelerates the dissemination speed and technology iteration cycle of green technologies [28]. Green technology innovation effectively improves the utilization efficiency of resource and environmental factors by optimizing production processes, improving energy utilization efficiency, promoting waste recycling and reducing resource consumption per unit output. Accordingly, hypothesis H3 is proposed.

H3: Carbon emission trading improves the utilization efficiency of resource and environmental factors by stimulating enterprise green innovation.

3.2.3. Resource allocation efficiency mechanism

On the one hand, the carbon trading mechanism forms a selective incentive and constraint mechanism of "rewarding the excellent and punishing the inferior" at the enterprise level. Specifically, the market price of carbon quotas reflects the marginal cost of emission reduction of the whole society. For enterprises with low carbon reduction costs and low carbon emission intensity, their actual carbon emissions are often lower than the quotas allocated by the government, and they can obtain additional benefits by selling excess carbon quotas, so as to further expand the scale of low-carbon production and increase investment in clean technologies and efficient equipment. This process promotes the agglomeration of production factors such as capital and talents to these enterprises with high emission reduction efficiency, forming a positive cycle. At the same time, enterprises with high carbon emission intensity and high emission reduction costs face rising compliance pressure: they either invest funds in technological transformation to reduce carbon emissions, or buy expensive quotas in the carbon market, resulting in a significant increase in production and operation costs. Under the pressure of market competition, these high-emission and low-efficiency enterprises will gradually shrink their production scale or even withdraw from the

local market. This dynamic selection process of "survival of the fittest" constantly reshapes the micro subject structure and factor allocation pattern within the industry, promotes the continuous flow of resource and environmental factors from low-efficiency fields to high-efficiency fields, and improves the overall factor utilization efficiency [29]. On the other hand, the resource reallocation effect brought by the carbon trading mechanism is also reflected in the optimal integration at the regional level. Due to significant differences in industrial structure, energy endowment, technical level and marginal emission reduction cost among different regions, a unified carbon trading market provides an institutional channel for cross-regional emission reduction division of labor and factor flow. Through cross-regional carbon quota trading, carbon emission rights flow from regions with high marginal emission reduction costs to regions with low marginal emission reduction costs. This process not only reduces the overall emission reduction cost from the perspective of the whole society and improves the economic efficiency of emission reduction, but also encourages all regions to optimize the factor input structure according to their own comparative advantages. For example, the central and western regions with low emission reduction costs can make full use of local renewable energy and ecological resources, and obtain funds to support green projects by selling carbon quotas; while the eastern developed regions with high emission reduction costs can control the total emission while maintaining economic growth by purchasing quotas, and concentrate more resources on high-tech, high value-added low-carbon industries. This inter-regional specialized division of labor and collaborative emission reduction effectively improve the coordination of resource allocation and the overall utilization efficiency of resource and environmental factors nationwide. Accordingly, hypothesis H4 is proposed.

H4: Carbon emission trading improves the utilization efficiency of resource and environmental factors by enhancing resource allocation efficiency.

The logical framework of this paper can be sorted out as shown in the following figure:

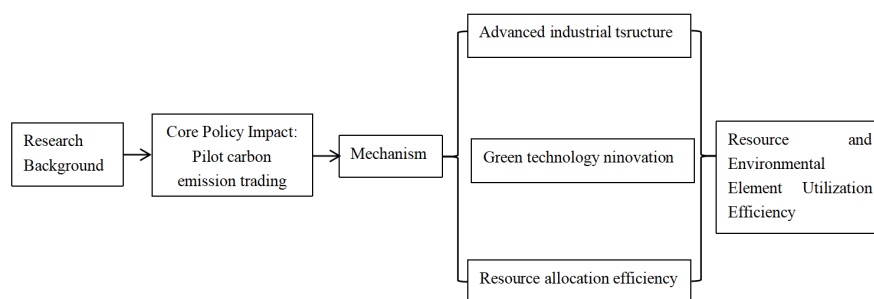


Figure 1. Research framework

4. Research design

4.1. Model setting

4.1.1. Multi-period difference-in-differences model

To identify the impact of carbon emission trading on the utilization efficiency of resource and environmental factors, this paper takes the launch of three batches of carbon emission trading pilots in 2013, 2014 and 2016 as quasi-natural experiments. The 6 provinces and municipalities included in the carbon emission trading pilots are taken as the treatment group, and the rest regions are taken as the control group. A multi-period difference-in-differences model is selected to empirically test

the difference in the changes of the utilization efficiency of resource and environmental factors in each region before and after the pilot.

$$Eff_{it} = \alpha_0 + \alpha_1 DID_{it} + \alpha_2 Controls_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

Where Eff_{it} represents the utilization efficiency of resource and environmental factors of province i in year t ; DID_{it} indicates whether province i is included in the carbon emission trading pilot and launches the carbon emission trading market in year t , and β is the policy impact coefficient of carbon emission trading; $Controls_{it}$ is the provincial-level control variable; μ_i is the province fixed effect, λ_t is the year fixed effect; ε_{it} is the random disturbance term.

4.1.2. Parallel trend test

To exclude the influence of other factors on the validity of the multi-period difference-in-differences model, this paper further tests the rationality of the parallel trend. The specific model is as follows:

$$Eff_{it} = \alpha_0 + \sum_{n \geq -6}^6 \alpha_{1n} DID_{it}^n + \alpha_2 Controls_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

Where DID_{it}^n is the policy variable of relative year generated with the pilot year as the reference. For provinces included in the pilot, $DID_{it}^n = 1$, and for regions not included, it is always 0. The year before the pilot implementation is set as the event base year, β_n is the regression coefficient relative to the base year, and other variables are defined consistently with the benchmark model.

4.1.3. Mediating effect model

To further test the mechanism of carbon emission trading on the utilization efficiency of resource and environmental factors, this paper refers to the practice of Wen Zhonglin et al. [30] and constructs a three-step mediating effect model on the basis of model (1):

$$M_{it} = \beta_0 + \beta_1 DID_{it} + \beta_2 Controls_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

$$Eff_{it} = \gamma_0 + \gamma_1 DID_{it} + \gamma_2 M_{it} + \gamma_3 Controls_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (4)$$

Where M_{it} represents the three mediating variables selected in this paper. The first step of the three-step method tests the impact of carbon emission trading policy on the utilization efficiency of resource and environmental factors, which has been verified in equation (1) and reflected by coefficient α_1 ; the second step tests the impact of carbon emission trading on the mediating variables, which is tested in equation (3) and reflected by coefficient β_1 ; the third step incorporates both policy shocks and mediating variables to test the impact of mediating variables on the utilization efficiency of resource and environmental factors, which is reflected by coefficient γ_2 . If

α_1 , β_1 and γ_2 are all significant, the three mediating effects of industrial structure optimization, green technology innovation and resource allocation efficiency exist.

4.2. Variable selection and definition

4.2.1. Explained variable

The utilization efficiency of resource and environmental factors is measured by the super-efficiency SBM model for 30 provinces in China from 2004 to 2023. This model overcomes the problem of ignoring slack variables in the traditional DEA model, and introduces a super-efficiency mechanism to further distinguish and rank effective decision-making units. In addition, the non-radial and non-oriented structural features can be compatible with the treatment of undesirable outputs, so as to more accurately depict the dynamic change process of the utilization efficiency of resource and environmental factors. Among them, input indicators select labor, capital, energy, water resources and land resources. Labor input is measured by the number of employees in each province; capital input refers to the calculation method of Shan Haojie [31] and is measured by the perpetual inventory method; energy input refers to the research of Wei Chu et al. [32] and is measured by energy consumption; water resource input refers to the research of Ding Xuhui et al. [33] and is measured by the total regional water consumption; land resource input refers to the research of Bian Zhiqiang et al. [34] and is measured by the area of construction land. The expected output indicator is the actual GDP with 2000 as the base period; undesirable outputs select industrial wastewater discharge, industrial sulfur dioxide discharge, industrial smoke and dust discharge and regional carbon emissions.

4.2.2. Core explanatory variable

The core explanatory variable is the interaction term DID matching region and time. DID=1 after a province establishes the pilot, otherwise DID=0. In 2013, carbon emission trading pilots were launched in Beijing, Shanghai, Tianjin, Shenzhen and Guangdong. Since Shenzhen is under the jurisdiction of Guangdong Province, this paper incorporates Shenzhen into Guangdong Province for consideration. In 2014, pilots in Hubei and Chongqing were launched; in 2016, the pilot in Fujian was launched. Since Sichuan is dominated by CCER trading, Sichuan is not included as a pilot area in the analysis of this paper.

4.2.3. Mediating variables

This paper selects industrial structure advancement (Is), regional green innovation level (Gti) and resource allocation efficiency (Res) as mediating variables. Industrial structure advancement is measured by the ratio of the added value of the tertiary industry to that of the secondary industry; regional green innovation is measured by the data of application and authorization of green patent technology innovation inventions and utility patents; resource allocation efficiency refers to the research of Li Qingyuan and Zhang Yinsainan [35], and is measured by the distortion degree of factor markets in each province using the production function method.

4.2.4. Control variables (selection factors)

Considering the impact of other factors on policy effects, referring to existing literature [36, 37], regional environmental regulation intensity (Er), economic development level (Lnpgdp),

industrialization level (Ind), human capital level (Edu) and foreign direct investment level (Inv) are selected. Among them, the intensity of regional environmental regulation is measured by the proportion of the actual completed investment in industrial pollution control in the industrial added value; the level of economic development is measured by per capita GDP; the level of industrialization is measured by the proportion of industrial added value in the total regional output value; the level of human capital is measured by the ratio of the number of students in ordinary institutions of higher learning to the total population at the end of the year; the level of foreign direct investment is measured by the ratio of foreign direct investment to regional GDP.

Table 1. Variable indicators and meanings

Category	Variable Name	Variable Symbol
Explained Variable	Utilization Efficiency of Resource and Environmental Factors	Eff
Core Explanatory Variable	Carbon Emission Trading Pilot	DID
	Green Technology Innovation Level	Gti
Mediating Variables	Industrial Structure Advancement Level	Is
	Resource Allocation Efficiency	Res
	Environmental Regulation Intensity	Er
Control Variables	Economic Development Level	Lnpdp
	Industrialization Level	Ind
	Human Capital Level	Edu
	Foreign Direct Investment Level	Inv

4.2.5. Descriptive statistics

The research data of this paper come from provincial statistical yearbooks, *China Environmental Statistical Yearbook*, *China Urban Statistical Yearbook* and EDGAR database, and a few missing data are filled by linear interpolation method. Finally, this paper obtains panel data of 30 provinces (autonomous regions and municipalities directly under the Central Government) from 2004 to 2023, with a total of 600 valid observations. The descriptive statistics of all variables are shown in Table 2. The explained variable, the utilization efficiency of resource and environmental factors, is at a medium level, and the standard deviation has moderate variability. All other variables have no obvious outliers and can be used for subsequent analysis.

Table 2. Descriptive statistics

Variable Symbol	Obs	Mean	SD	Min	Median	Max
Eff	600	0.373	0.217	0.094	0.311	1.234
DID	600	0.120	0.325	0.000	0.000	1.000
Er	600	0.004	0.004	0.000	0.003	0.031
Lnpdp	600	10.539	0.733	8.367	10.627	12.286
Ind	600	0.351	0.086	0.100	0.353	0.574
Edu	600	8.998	1.053	6.378	8.934	12.681
Inv	600	0.023	0.021	0.000	0.018	0.121
Is	600	1.114	0.652	0.527	0.974	5.690

Table 2. (continued)

Gti	600	6.551	1.676	0.693	6.655	10.662
Res	600	0.420	0.145	0.030	0.421	0.778

5. Empirical results

5.1. Benchmark regression results

The multi-period difference-in-differences model is used to evaluate the impact of carbon emission trading on the utilization efficiency of resource and environmental factors. Column (1) shows that when control variables are not included, the DID coefficient is 0.3608, which is significant at the 1% level, indicating that carbon emission trading significantly improves the utilization efficiency of resource and environmental factors. Column (2) adds control variables, and the DID coefficient drops to 0.3556, which is still significant at the 1% level. The goodness of fit of the model is 0.541 and 0.572 respectively, which is good, confirming the positive promoting effect of carbon emission trading policy on the utilization efficiency of resource and environmental factors, which is consistent with the theoretical analysis. By incorporating environmental factors into the market pricing system, carbon emission trading promotes their transformation from free occupation to paid use, thereby internalizing environmental costs in the decision-making of micro subjects. This mechanism forces enterprises to optimize factor allocation and improve clean technology level, while restraining the extensive consumption of resources, and promotes the coordinated improvement of resource utilization efficiency and ecological environment benefits.

Table 3. Benchmark regression results

	(1)	(2)
	Eff	Eff
DID	0.3608*** (24.1445)	0.3556*** (23.8437)
Er		1.1889 (0.8916)
Lnpgdp		-0.0367 (-0.9708)
Ind		0.1221 (1.0455)
Edu		0.0291 (1.3829)
Inv		-1.4653*** (-5.8423)
_cons	0.3956*** (27.7858)	0.4938 (1.4845)
Individual Fixed Effect	Yes	Yes
Time Fixed Effect	Yes	Yes
N	600	600

Table 3. (continued)

R^2	0.541	0.572
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Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, t-statistics in parentheses

5.2. Robustness tests

To ensure the validity of the benchmark regression results, this paper conducts robustness tests from the perspectives of parallel trend test, placebo test, PSM-DID, lagged explanatory variable, shortened research window period and replaced explained variable.

5.2.1. Parallel trend test

The parallel trend assumption is the premise for the validity of multi-period difference-in-differences model estimation. It is required that there is no significant difference between the control group and the treatment group before policy implementation, and there is a systematic difference between the two after policy implementation. Taking the year before policy implementation as the base period, test the trend change of carbon emission trading policy from 6 years before to 6 years after. As shown in Figure 1, before the policy implementation, the regression results of each period are not significant, indicating that there is no significant difference in the utilization efficiency of resource and environmental factors between the treatment group and the control group. The coefficients of each period after policy implementation are significantly positive, indicating that the utilization efficiency of resource and environmental factors in carbon emission trading pilots has been significantly improved compared with the control group, and the parallel trend test is passed.

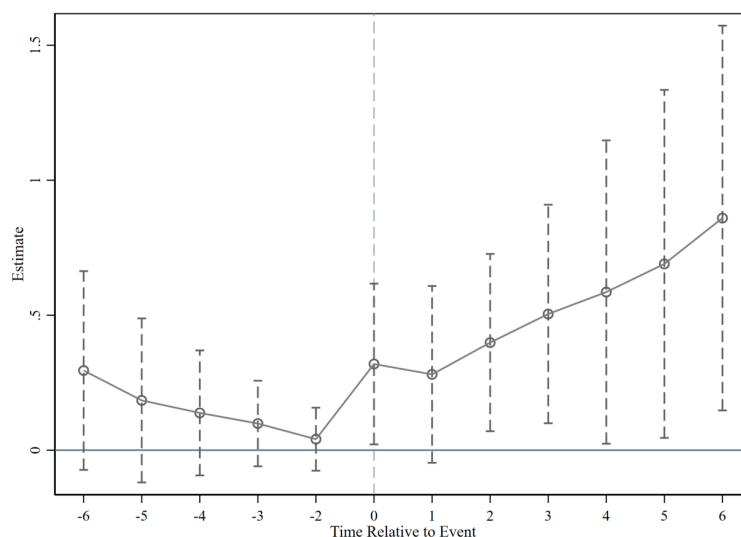


Figure 2. Parallel trend test

5.2.2. Placebo test

The random sampling method is adopted for the placebo test. 6 regions are randomly selected to construct dummy variables, and 500 repeated regression analyses are carried out on the utilization efficiency of resource and environmental factors. As shown in Figure 2, the horizontal axis represents the regression coefficient of random variables, and its distribution satisfies a normal

distribution centered on 0. The significance level corresponding to the vertical axis shows that the vast majority of p-values exceed the critical value of 0.1, indicating that the randomly generated treatment group has no significant impact on the utilization efficiency of resource and environmental factors, and there is no specification error in the model. The placebo test shows that the promoting effect of carbon emission trading on the utilization efficiency of resource and environmental factors is not caused by random factors, and the estimation results are reliable.

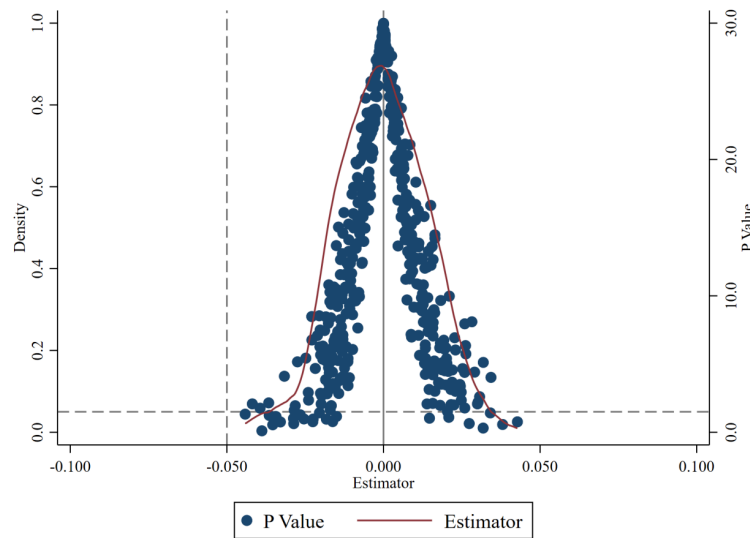


Figure 3. Placebo test

5.2.3. Multi-time point PSM-DID test

To eliminate sample selection error and endogeneity problems, the method of multi-period difference-in-differences and propensity score matching is used for robustness test. The control variables are set as matching variables, and the period-by-period matching method is used to match the samples year by year, and the matched data are estimated by the multi-period difference-in-differences model. As shown in Table 4, the direction of the difference-in-differences variable is consistent with the benchmark regression result, and it passes the significance test, indicating that the benchmark regression result is robust.

Table 4. PSM-DID test

	Eff
DID	0.3625*** (24.4945)
Er	1.9277 (1.2420)
Lnpgdp	-0.0677 (-1.6279)
Ind	0.0509 (0.4333)
Edu	0.0048

Table 4. (continued)

	(0.2275)
Inv	-0.0950
	(-0.3088)
_cons	0.9710***
	(2.6798)
Individual Fixed Effect	Yes
Time Fixed Effect	Yes
N	532
R ²	0.592

Note: *** p<0.01, ** p<0.05, * p<0.1, t-statistics in parentheses

5.2.4. Other robustness tests

A variety of methods are used to further test the stability of the model. The results are shown in Table 5. Column (1) considers the policy time lag, lags the explanatory variable by one period for regression, and the DID coefficient is still significant at the 1% level; column (2) replaces the explained variable with green total factor productivity, and the DID coefficient is still significant at the 1% level; column (3) considers the interference of long-term factors on the research results, shortens the research window period to 2010-2023, and the result is still significant at the 1% level. Through a series of robustness tests mentioned above, the reliability of the research results of this paper is confirmed.

Table 5. Robustness tests

	(1)	(2)	(3)
	Eff	Gtfp	Eff
L.DID	0.3145*** (18.8465)		
DID		0.2932*** (18.8442)	0.3154*** (16.0103)
Er	-0.5794 (-0.3728)	1.6111 (1.1579)	0.8625 (0.4644)
Lnpgdp	-0.0726 (-1.6202)	-0.1540*** (-3.8988)	-0.0808 (-1.1694)
Ind	0.1578 (1.1565)	0.1698 (1.3935)	0.1304 (0.7518)
Edu	0.0210 (0.8417)	0.0377* (1.7160)	0.0680** (2.3276)
Inv	-1.4582*** (-5.1988)	0.0738 (0.2822)	-1.4353*** (-4.9973)
_cons	0.8890** (2.2718)	1.4542*** (4.1896)	0.5567 (0.7859)

Table 5. (continued)

Individual Fixed Effect	Yes	Yes	Yes
Time Fixed Effect	Yes	Yes	Yes
N	570	600	420
R ²	0.480	0.466	0.482

Note: *** p<0.01, ** p<0.05, * p<0.1, t-statistics in parentheses

5.3. Influence mechanism test

This paper adopts the three-step method to test the mediating effect, discusses the internal mechanism of carbon emission trading on the utilization efficiency of resource and environmental factors, and focuses on testing three potential mediating paths: industrial structure advancement (Is), green technology innovation (Gti) and resource allocation efficiency (Res). The results are shown in Table 6.

5.3.1. Industrial structure advancement mechanism

Column (1) shows that the regression coefficient of the implementation of carbon emission trading policy on industrial structure advancement is 0.5078, which is significant at the 1% level, indicating that carbon emission trading promotes the flow of production factors from high-emission, low-value-added industrial sectors to low-emission, high-tech-intensive sectors by internalizing the external cost of carbon emissions and relying on price mechanism and quota constraints, thereby improving the level of industrial structure; column (2) further shows that the coefficient of industrial structure optimization on the utilization efficiency of resource and environmental factors is 0.1134 and significant, indicating that industrial structure improvement promotes resource and environmental factors to flow from traditional sectors with low marginal output to emerging sectors with higher ecological efficiency, thus realizing the "structural dividend" of resources and environment at the macro level, and finally reflecting as the Pareto improvement of the utilization efficiency of resource and environmental factors.

5.3.2. Green innovation mechanism

Column (3) shows that the regression coefficient of carbon emission trading on green technology innovation is 0.4985 and significant, indicating that carbon price constraints increase the marginal production cost of high-emission enterprises, forcing enterprises to seek breakthroughs in low-carbon production processes and end-of-pipe treatment technologies to reduce compliance costs; column (4) further shows that the regression coefficient of green technology innovation on the utilization efficiency of resource and environmental factors is 0.1205 and significant, indicating that green technologies reduce resource consumption and pollution emission intensity per unit output and improve the marginal output efficiency of resource and environmental factors by improving production processes, developing clean energy and promoting recycling technologies.

5.3.3. Resource allocation efficiency mechanism

Column (5) shows that the regression coefficient of carbon emission trading policy on resource allocation efficiency is 0.0844 and significant, indicating that carbon emission trading realizes the

improvement of resource allocation efficiency by internalizing the external cost of carbon emissions into market signals and guiding production factors to flow from high-carbon and low-efficiency sectors to low-carbon and high-efficiency sectors with the help of price mechanism; column (6) further shows that the regression coefficient of resource allocation efficiency on the utilization efficiency of resource and environmental factors is 0.0208 and significant, indicating that the optimization of resource allocation efficiency realizes the equalization of marginal output and the correction of allocation distortion of resource and environmental factors under the general equilibrium framework by guiding production factors to agglomerate to economic activities with low energy consumption, low emission and high added value, and realizes the Pareto improvement of the utilization efficiency of resource and environmental factors.

The contribution degrees of the three channels present gradient characteristics. Among them, the mediating effect of industrial structure advancement accounts for 16.19%, green technology innovation accounts for 16.89%, and resource allocation efficiency accounts for 0.49%. This structural difference reflects that in the transmission of carbon emission trading policy, technological innovation and structural upgrading are the core driving forces, while the improvement of resource allocation efficiency is indirect and lagging. The green technology innovation path has the highest proportion, which stems from the fact that carbon trading internalizes the external cost of carbon emissions through price signals and directly forces enterprises to carry out low-carbon technology research and development and process transformation, so the effect is the most significant [38]. The industrial structure advancement path accounts for slightly less, because carbon trading promotes the transfer of capital and labor to low-carbon high-end industries through factor substitution and market screening mechanisms. This process depends on the perfection of the factor market and enterprise exit barriers, and the transmission speed is slightly slower than technological innovation, but it is still a core path [39]. The low proportion of the resource allocation efficiency path does not mean that this path is unimportant, but reflects its underlying supporting attribute and measurement limitations in the transmission chain. On the one hand, the improvement of resource allocation efficiency is more realized indirectly through technological innovation and structural upgrading. Green technology changes the relative price of factors, and industrial advancement reshapes the flow direction of factors. The combined effect of the two is reflected in the improvement of overall allocation efficiency. Therefore, this path has the characteristics of second-order transmission, and the direct effect is absorbed by the first two paths. On the other hand, the improvement of resource allocation efficiency often requires a long period of institutional running-in and market improvement, and is vulnerable to structural factors such as financial frictions and factor market distortions, making it difficult for independent contributions to appear in the short term [40].

Table 6. Mediating mechanism test

	(1)	(2)	(3)	(4)	(5)	(6)
	Is	Eff	Gti	Eff	Res	Eff
DID	0.5078*** (9.7291)	0.2980*** (20.0767)	0.4985*** (3.8193)	0.3531*** (23.3660)	0.0844*** (8.2468)	0.3573*** (22.5746)
Is		0.1134*** (10.0919)				
Gti				0.1205* (2.0292)		
Res						0.1208**

Table 6. (continued)

						(0.3325)
Er	9.8425**	0.0723	-11.1455	1.2450	-0.3236	1.1822
	(2.1088)	(0.0588)	(-0.9549)	(0.9330)	(-0.3537)	(0.8857)
Lnpgdp	-0.8112***	0.0553	0.8459**	-0.0410	-0.1568***	-0.0400
	(-6.1230)	(1.5380)	(2.5533)	(-1.0770)	(-6.0374)	(-1.0224)
Ind	-1.4055***	0.2816***	5.5090***	0.0944	0.1356*	0.1249
	(-3.4380)	(2.5964)	(5.3886)	(0.7873)	(1.6927)	(1.0660)
Edu	0.2980***	-0.0047	-0.1458	0.0298	0.0191	0.0295
	(4.0496)	(-0.2416)	(-0.7921)	(1.4171)	(1.3263)	(1.3984)
Inv	0.2069	-1.4888***	4.6853**	-1.4889***	0.1693	-1.4618***
	(0.2357)	(-6.4615)	(2.1341)	(-5.9121)	(0.9837)	(-5.8184)
_cons	6.5759***	-0.2522	-4.3324	0.5156	1.7559***	0.5303
	(5.6479)	(-0.8023)	(-1.4880)	(1.5471)	(7.6945)	(1.5128)
Individual Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
N	600	600	600	600	600	600
R ²	0.465	0.640	0.767	0.573	0.637	0.572

Note: *** p<0.01, ** p<0.05, * p<0.1, t-statistics in parentheses

5.4. Heterogeneity analysis

This paper adjusts the emission reduction effect of carbon trading policy from two key situational dimensions: institutional design and spatial organization. In terms of pilot types, comprehensive pilots cover multiple industries and rely on cross-industry marginal emission reduction cost differences to realize optimal quota allocation, while industrial pilots focus on a single industry and their emission reduction paths are highly concentrated on process and energy efficiency improvement. There are structural differences between the two in market scale, industry linkage and carbon leakage risk. This heterogeneity can identify the regulating effect of industry coverage width on policy effects. In terms of regional types, national-level urban agglomerations have high-density economic connections, factor flow efficiency and collaborative governance capacity. Carbon trading policies may amplify emission reduction dividends through inter-regional technology diffusion and infrastructure sharing, while non-urban agglomeration areas are limited by loose spatial structure and weak institutional support, and policy effects are more localized. Therefore, testing these two types of heterogeneity helps to avoid estimation bias in the average treatment effect of policies, reveals the effect of carbon emission reduction effects under the conditions of institutional design and spatial organization, and provides empirical evidence for the refined design of the national carbon market and regional differentiated emission reduction strategies.

Table 7 shows that different types of carbon emission trading pilots have different impacts on the utilization efficiency of resource and environmental factors. The comprehensive column is comprehensive pilots and the control group, and the industrial column is industrial pilots and the control group. Industrial pilots refer to carbon markets that mainly cover local high-energy-consuming industrial enterprises, while comprehensive pilots refer to carbon markets that include

more diverse industries, such as service industry, construction industry or transportation industry. It can be seen from Table 7 that the marginal contribution of comprehensive pilots is 0.4895, which is higher, while that of industrial pilots is lower. The reason may be that the diversity of industrial structure in comprehensive pilots gives birth to cross-industry factor allocation dividends, while industrial pilots are limited by industry homogeneity and the convergence of marginal emission reduction costs, making it difficult to fully release the allocation efficiency of the market mechanism. Specifically, comprehensive pilots cover various industries such as service industry and industry. There are significant differences in marginal emission reduction costs among different industries. The emission reduction cost of the service industry is relatively low, while that of the industrial sector is high. This cost heterogeneity enables emission reduction responsibilities to automatically flow to the subjects with the lowest cost through market signals, so as to realize Pareto improvement of resource and environmental factors among wider economic sectors. Its coefficient is the largest, which also confirms the transformation logic of "structural diversity precedes technological homogeneity", that is, the difference in industrial structure itself is an important source driving the improvement of factor allocation efficiency. In contrast, the main bodies of industrial pilots are concentrated in high energy-consuming industries such as electric power, iron and steel and cement. Enterprises have highly similar production processes, energy consumption intensity and emission reduction paths, and similar marginal emission reduction costs. Therefore, carbon trading is more reflected in quota adjustment among homogeneous enterprises, and it is difficult to produce cross-industry factor reallocation effects, and its marginal contribution to the overall utilization efficiency of resource and environmental factors is relatively limited [41].

Table 7. Heterogeneity of pilot types

	(1)	(2)
	Comprehensive Type	Industrial Type
	Eff	Eff
DID	0.4859*** (32.2796)	0.2840*** (18.1544)
Er	0.0235 (0.0264)	0.4076 (0.3571)
Lnpgdp	0.0786*** (2.8246)	0.0524 (1.4536)
Ind	0.0515 (0.6664)	0.0738 (0.7342)
Edu	0.0174 (1.1946)	0.0123 (0.6459)
Inv	-1.8106*** (-9.5313)	-1.0972*** (-4.2774)
_cons	-0.4552* (-1.8594)	-0.2041 (-0.6612)
Individual Fixed Effect	Yes	Yes
Time Fixed Effect	Yes	Yes
N	520	540

Table 7. (continued)

R^2	0.734	0.479
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Note: *** p<0.01, ** p<0.05, * p<0.1, t-statistics in parentheses

Table 8 verifies the heterogeneity of carbon emission trading on the utilization efficiency of resource and environmental factors between provinces in national-level urban agglomerations and non-national-level urban agglomerations. Among them, national-level urban agglomerations are provinces and municipalities included in the Beijing-Tianjin-Hebei, Yangtze River Delta and Pearl River Delta, and non-national-level urban agglomerations are other provinces and municipalities. Table 8 shows that the marginal effect of national-level urban agglomerations is 0.4570, which is larger, while the marginal effect of non-national-level urban agglomerations is smaller. This heterogeneity may stem from the institutional advantages of national-level urban agglomerations in industrial coordination, policy integration and market integration. Through regional linkage mechanisms, national-level urban agglomerations break administrative barriers, realize cross-regional flow and optimal allocation of factors, and their larger coefficient confirms the spatial law that agglomeration effect amplifies policy dividends. Although non-national-level urban agglomerations have followed up at the pilot policy level, they are still constrained by weak industrial foundation, administrative division and insufficient marketization, and the policy transmission efficiency is limited [42].

Table 8. Regional heterogeneity

	(1)	(2)
	National-level Urban Agglomerations	Non-national-level Urban Agglomerations
	Eff	Eff
did	0.4570*** (12.4807)	0.2502*** (14.1589)
Er	14.2955** (2.3373)	1.0839 (0.9291)
Lnpgdp	-0.1658 (-1.2835)	0.1213*** (2.9538)
Ind	0.4964 (1.1709)	0.0424 (0.4124)
Edu	0.0719 (1.3292)	0.0051 (0.2486)
Inv	-3.0438*** (-6.7384)	-0.1793 (-0.5750)
_cons	1.4208	-0.8115**

Table 8. (continued)

	(1.2956)	(-2.3067)
Individual Fixed Effect	Yes	Yes
Time Fixed Effect	Yes	Yes
N	160	440
R ²	0.764	0.434

Note: *** p<0.01, ** p<0.05, * p<0.1, t-statistics in parentheses

6. Conclusions and suggestions

As China's economy shifts from high-speed growth to a high-quality development stage featuring green and low-carbon development, promoting the economical and intensive use of resources and improving the carrying capacity of the ecological environment have become core propositions for achieving sustainable development. As a market-oriented mechanism to promote green and low-carbon development, carbon emission trading is an important system to stimulate the vitality of enterprise green innovation and improve the utilization efficiency of resource and environmental factors. Based on the theoretical framework of new quality productivity, this paper analyzes the impact of carbon emission trading on the utilization efficiency of resource and environmental factors from multiple dimensions of technological breakthrough, industrial upgrading and factor allocation. This paper further uses panel data of 30 provinces and municipalities from 2004 to 2023, constructs multi-period difference-in-differences model and mediating effect model, and systematically tests the impact of carbon emission trading policy on the utilization efficiency of resource and environmental factors and its mechanism. The main research conclusions of this paper are as follows: First, carbon emission trading significantly promotes the utilization efficiency of resource and environmental factors, which still holds after a series of robustness tests. Second, mechanism analysis shows that carbon emission trading improves the utilization efficiency of resource and environmental factors by nurturing new quality productivity. Specifically, carbon emission trading promotes industrial structure upgrading, improves the level of green technology innovation, and enhances resource allocation efficiency, thereby improving the utilization efficiency of resource and environmental factors. Among the three paths, green technology innovation has the highest marginal contribution, indicating that carbon emission trading incentivizes enterprises to carry out green technology research and development through price signals and forms endogenous momentum for emission reduction, which is the dominant mechanism for improving factor utilization efficiency at present; the industrial structure upgrading path ranks second, reflecting that the carbon trading mechanism guides the transformation of industrial layout to low-carbon and high-end directions by changing the marginal return rate of high-carbon industries and green industries; although the contribution rate of the resource allocation efficiency path is relatively low, it has high elasticity in improving factor mobility and correcting misallocation, indicating that the carbon pricing mechanism still has great potential in guiding the reallocation of capital, labor and other factors to high-efficiency sectors. Third, the promoting effect of carbon emission trading on the utilization efficiency of resource and environmental factors has multiple heterogeneity. In terms of pilot types, the marginal benefit of comprehensive pilots is higher than that of industrial pilots, reflecting that the systematic integration effect of multi-field collaborative reform has more potential for policy

dividend release than the partial breakthrough of a single industry; in terms of regional types, the marginal benefit of provinces and municipalities where national-level urban agglomerations are located is greater than that of other types of provinces and municipalities, indicating that the agglomeration effect and institutional synergy advantage within urban agglomerations can amplify policy effects more than the scattered layout of a single administrative region.

Based on the above research conclusions, this paper puts forward the following policy suggestions: First, continue to promote the construction of the national carbon emission trading market, improve the quota allocation mechanism, enhance the stability and predictability of carbon prices, and guide enterprises to form long-term emission reduction expectations. Second, in the design of carbon trading mechanism, gradually introduce the industry baseline method to increase the emission reduction pressure of high-carbon industries, and combine industrial policies to guide factors such as capital and labor to flow to low-carbon, efficient and high value-added industrial fields, and promote the transformation of industrial structure to green and high-end directions. In addition, increase support for the research, development and application of green and low-carbon technologies, set up special funds for green technology innovation, improve the rapid review and transformation mechanism of green patents, and stimulate the vitality of enterprise green innovation. At the same time, optimize the market-oriented allocation mechanism of factors, promote the agglomeration of capital, talents, data and other factors to green and low-carbon fields, and improve resource allocation efficiency. Third, gradually expand the scope of included industries, improve market activity, and enhance the guiding force of carbon pricing on resource allocation. At the same time, national-level urban agglomerations should continue to play a leading role, deepen the construction of carbon market synergy mechanisms, promote the establishment of regional carbon trading linkage mechanisms and shared emission reduction projects, and further enhance the scale effect and institutional integration capacity of policy implementation. Encourage local governments within urban agglomerations to strengthen cooperation in the joint construction of green infrastructure, coordinated layout of low-carbon industries, and sharing of environmental information, so as to form a regional joint force for green development. Non-urban agglomeration areas should actively learn from the experience of urban agglomerations, explore cross-administrative collaborative governance models suitable for their own reality, such as establishing regional carbon emission reduction cooperation platforms, promoting policy connection between neighboring areas, and carrying out cross-regional green technology exchanges and industrial transfers, to gradually improve the level of institutional synergy.

References

- [1] Cai J, Luo D N, Xiao S Y. Analysis of Emission Reduction Effect of Carbon Emission Trading Pilot Policy — From the Perspective of Carbon Emission and Carbon Emission Efficiency [J]. *Systems Engineering — Theory & Practice*, 2024, 44(09): 2838-2858.
- [2] Wang W J, Xie P C, Li C M, et al. Evaluation of Emission Reduction Effectiveness and Influencing Factors of China's Carbon Emission Trading Pilot Mechanism [J]. *China Population, Resources and Environment*, 2018, 28(04): 26-34.
- [3] Cheng B B, Dai H C, Wang P, et al. Impacts of low-carbon power policy on carbon mitigation in Guangdong Province, China [J]. *Energy Policy*, 2016, 88: 55-527.
- [4] Zhang Y J, Peng Y L, Ma C Q, et al. Can environmental innovation facilitate carbon emissions reduction? evidence from China [J]. *Energy Policy*, 2017, 100(1): 18-28.
- [5] Qiu L D, Zhou M H, Wei X. Regulation, innovation, and firm selection: The porter hypothesis under monopolistic competition [J]. *Journal of Environmental Economics and Management*, 2017, 92: 638-658.
- [6] Liu C, Xia J C. Online Market, Digital Platform and Resource Allocation Efficiency: The Role of Price Mechanism and Data Mechanism [J]. *China Industrial Economics*, 2023, (07): 84-102.

- [7] Wang Y, Yang Z, Hu S. Carbon Emission Trading, Ownership Heterogeneity, and Corporate Green Innovation: The Synergistic Role of Information Disclosure and Financing Constraints [J]. *Sustainability*, 2026, 18(8): 4060-4060.
- [8] Wang Z, Kang C, Ge H, et al. Differentiated peak pathways and driving factors of industrial CO₂ emissions at the provincial level in China [J]. *Carbon Balance and Management*, 2026.
- [9] Zhao X G, Nie J D, Chen H. How to improve the market efficiency of carbon trading: A perspective of China [J]. *Renewable and Sustainable Energy Reviews*, 2016(59): 1229-1245.
- [10] Qian W J, He C F. Research on Regional Differences and Influencing Factors of Water Resources Utilization Efficiency in China [J]. *China Population, Resources and Environment*, 2011, 21(02): 54-60.
- [11] Wang M, Chen C, Huang X, et al. Carbon emission evaluation for regional public institutions operation phase based on improved LightGBM and carbon emission efficiency ratio [J]. *Energy*, 2026, 351: 140748-140748.
- [12] Shi D, Li S L. Emission Trading System and Energy Utilization Efficiency — Measurement and Empirical Study on Prefecture-level and Above Cities [J]. *China Industrial Economics*, 2020, (09): 5-23.
- [13] Li T, Zheng X, Li Z. Energy transformation, green finance, and energy utilization efficiency [J]. *Finance Research Letters*, 2025, 85(PA): 107914-107914.
- [14] Park N R, Yun H S, Choi C H. Green trade and cultural innovation: examining the impact on GTFP and greenhouse gas emissions in OECD countries [J]. *Sustainability*, 2024, 16(19): 8339.
- [15] Lee C C, Lee C C. How does green finance affect green total factor productivity? Evidence from china [J]. *Energy Economics*, 2022, 107: 105863.
- [16] Yanbing L, Fei L, Chaofan X, et al. Urban development and resource endowments shape natural resource utilization efficiency in Chinese cities [J]. *Journal of Environmental Sciences*, 2023, 126: 806-816.
- [17] Li Z G, Wang J. Spatial Emission Reduction Effect of Carbon Emission Trading in China: Quasi-natural Experiment and Policy Spillover [J]. *China Population, Resources and Environment*, 2021, 31(01): 26-36.
- [18] Hu J, Fang Q, Long W B. Carbon Emission Regulation, Enterprise Emission Reduction Incentive and Total Factor Productivity — A Natural Experiment Based on China's Carbon Emission Trading Mechanism [J]. *Economic Research Journal*, 2023, 58(04): 77-94.
- [19] Xingang Z, Haowei C, Shuran H, et al. The impact of carbon quota allocation and low-carbon technology innovation on carbon market effectiveness: a system dynamics analysis [J]. *Environmental Science and Pollution Research International*, 2023, 30(42): 96424-96440.
- [20] Xiujie T, Gufeng L, Si C. How does ESG performance affect green transformation of resource-based enterprises: Evidence from Chinese listed enterprises [J]. *Resources Policy*, 2024, 89: 104559-.
- [21] Fan D, Fu J W, Wang W G. How Does Carbon Emission Trading Affect Enterprise Total Factor Productivity? [J]. *Systems Engineering — Theory & Practice*, 2022, 42(03): 591-603.
- [22] Hu Y F, Ding Y Q. Can Carbon Emission Trading Mechanism Balance Enterprise Benefit and Green Efficiency? [J]. *China Population, Resources and Environment*, 2020, 30(03): 56-64.
- [23] Qianqian H, Linhao C, Penghui H. The impact of carbon emissions trading on energy efficiency: Evidence from quasi-experiment in China's carbon emissions trading pilot [J]. *Energy Economics*, 2022, 110.
- [24] Research Group of Institute of Economics, Chinese Academy of Social Sciences, Huang Q H, Yang Y W, et al. Structural Change, Efficiency Change and Developing New Quality Productivity [J]. *Economic Research Journal*, 2024, 59(04): 4-23.
- [25] Zhaoyang Z, Shuning Z, Siying W, et al. The Impact of Carbon Emissions Trading Pilot Policy on Industrial Structure Upgrading [J]. *Sustainability*, 2022, 14(17): 10818-10818.
- [26] Jin G, Shen K R. Beggar-thy-neighbor or Benefiting-thy-neighbor? — Interaction of Environmental Regulation Enforcement and Urban Productivity Growth [J]. *Management World*, 2018, 34(12): 43-55.
- [27] Li Q Y, Xiao Z H. Heterogeneous Environmental Regulation Tools and Enterprise Green Innovation Incentives — Evidence from Green Patents of Listed Enterprises [J]. *Economic Research Journal*, 2020, 55(09): 192-208.
- [28] Qi S Z, Lin S, Cui J B. Can Environmental Rights Trading Market Induce Green Innovation? — Evidence from Green Patent Data of Listed Companies in China [J]. *Economic Research Journal*, 2018, 53(12): 129-143.
- [29] Zhang C, He B J. Resource Allocation Effect of Carbon Emission Trading Policy — Based on the "Dual Circulation" Perspective of Resource Factors Inside and Outside Enterprises [J]. *Resource Development & Market*, 2024, 40(06): 860-873.
- [30] Wen Z L, Zhang L, Hou J T, et al. Testing and Application of the Mediating Effects [J]. *Acta Psychologica Sinica*, 2004, (05): 614-620.
- [31] Shan H J. Reestimating the Capital Stock of China: 1952~2006 [J]. *The Journal of Quantitative & Technical Economics*, 2008, 25(10): 17-31.
- [32] Wei C, Shen M H. Energy Efficiency and Its Influencing Factors: An Empirical Analysis Based on DEA [J]. *Management World*, 2007, (08): 66-76.

- [33] Ding X H, He J H, Wang L Y. Research on Provincial Water Resources Utilization Efficiency and Driving Factors Considering Undesirable Output — Investigation Based on SE-SBM and Tobit Models [J]. *China Population, Resources and Environment*, 2018, 28(01): 157-164.
- [34] Bian Z Q, Zhang Q H. Dynamic Evolution, Spatial Difference and Convergence of Green Land Use Efficiency in Resource-based Cities [J]. *Journal of Soil and Water Conservation*, 2025, 39(02): 325-337+377.
- [35] Li Q Y, Zhang Y S N. Financial Opening and Resource Allocation Efficiency — Evidence from Foreign Banks Entering China [J]. *China Industrial Economics*, 2021, (05): 95-113.
- [36] Kuang P, Xie R R, Liang S G. Pollution Reduction and Carbon Reduction Effects of Carbon Emission Trading Pilot Policy — Empirical Evidence Based on Multi-period Difference-in-Differences Model [J]. *Review of Economy and Management*, 2025, 41(06): 148-160.
- [37] Liu T, Che J N, Du S J, et al. Research on the Impact of Carbon Emission Trading Pilot Policy on Green Total Factor Productivity [J]. *Statistics and Management*, 2025, 40(12): 120-128.
- [38] Tao F, Zhao J Y, Zhou H. Does Environmental Regulation Achieve "Increment and Quality Improvement" of Green Technology Innovation — Evidence from the Environmental Target Responsibility System [J]. *China Industrial Economics*, 2021, (02): 136-154.
- [39] Shao S, Ge L M, Zhu J L. How Can Humans and Nature Coexist Harmoniously: Environmental Regulation and Environmental Welfare Performance from the Perspective of Geographical Factors [J]. *Management World*, 2024, 40(08): 119-146.
- [40] Wen D W. Resource Misallocation, Total Factor Productivity and Growth Potential of China's Manufacturing Industry [J]. *China Economic Quarterly*, 2019, 18(02): 617-638.
- [41] Li J Q, Li X, Gao Y. Environmental Regulation Policy and Dynamic Structural Change of Labor Market — From the Perspective of Search Friction and Specific Skill Heterogeneity [J]. *Management World*, 2025, 41(10): 58-97.
- [42] Yu L H, Ma B W. Support Policies for Resource-exhausted Cities, Manufacturing Upgrading and Regional Coordinated Development [J]. *China Industrial Economics*, 2022, (08): 137-155.