Study on the Evaluation of Carbon Emission Trading's Effectiveness in Reducing Pollution and Carbon Emissions

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Abstract. Being the biggest developing nation in the world, China's huge energy consumption, widely distributed carbon emission problems, and complex and variable air pollution situation have always been topics that have attracted great attention from the academic community.The goal of this research is to fully examine whether China's recent implementation of carbon emissions trading has aided in the combined reduction of CO_2 and $PM_{2.5}$. The actual effects of carbon emissions trading policies in terms of environmental improvement and carbon emission reduction are examined by using the double-difference method and intermediary effect modeling. Panel data from 284 Chinese cities at the prefecture level from 2000 to 2019 are used, along with the seven carbon emissions trading pilot events that were fully launched in 2014 as a quasi-natural experiment.The analysis demonstrates that: (1) carbon emissions trading effectively realizes the joint reduction of CO_2 and $PM_{2.5}$; (2) the carbon trading policy has a more pronounced effect on reducing pollution and emissions in both the central and western regions, but does not lower carbon emissions in the eastern region, according to the results of the heterogeneity study; (3) The intermediary mechanism of carbon emissions trading to promote pollution reduction and carbon reduction is the significant mediating effect of energy consumption intensity on carbon dioxide and $PM_{2.5.}$ This paper enriches the research literature on carbon market and air pollutant emission reduction, and the empirical conclusions obtained are favourable for China and other similar countries and regions to carry out practical activities to reduce pollution and carbon emissions.

Keywords: carbon emission trading, $PM_{2.5}$, Multiple time points DID, Mediating effect.

1 Introduction

China is currently promoting energy savings and emission reductions and is committed to implementing a new, more sustainable and comprehensive development model. In this endeavour, the country aims to make economic development more environmentally sustainable while focusing on social inclusiveness in order to achieve comprehensive sustainable development. A key instrument for reducing emissions and saving energy under the Kyoto Protocol is the carbon trading market. On October 29, 2011, the General Office of the National Development and Reform Commission (NDRC) released the "Circular on the Pilot Work of Carbon Emission Trading," which detailed a plan to launch carbon emissions trading pilots in Beijing, Tianjin, Shanghai, Chongqing, Hubei, Guangdong, and Shenzhen.

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Many scholars discussing in depth the effectiveness of this policy for a single objective. Research by Liu et al. (2019) and Chen et al. (2022) both demonstrate that the introduction of carbon trading pilot programs has been somewhat successful in lowering CO_2 emissions.This finding provides strong support for understanding the actual effects of carbon emissions trading policies[1-2]. Cao et al. (2021) discovered that the policy improved the quality of the air in the majority of Hubei province and resulted in a considerable decrease in both the province's $PM_{2.5}$ concentration and the percentage of extremely polluted locations[3]. Effective policy constraints are the comprehensive point to achieve collaborative emission reduction of greenhouse gases and other air pollutants, and the dual control of greenhouse gases and atmospheric pollutants emissions is an important goal for China to address climate change and improve atmospheric environment [4]. Some scholars have studied whether carbon trading policies promote the reduction of air pollutant emissions while promoting CO_2 reduction. The benefits of China's national carbon emissions pricing program for the environment were thoroughly investigated by Dong et al. (2015). The study found that the carbon emissions trading scheme directly improved air quality while lowering carbon emissions[5]. However, Hu et al. (2022) explored in depth the synergistic emission reduction effects of CO_2 and SO_2 emissions trading schemes. The study found that although the ETS was effective in controlling SO_2 emissions, its effect on reducing CO_2 emissions appeared to be relatively limited[6]. Although the effects of carbon trading policies have been extensively researched by academics, it remains unclear whether and how the policy have had an impact in terms of reducing air pollutants and lowering greenhouse gas emissions.

This essay is based on a detailed examination of the carbon emissions trading, with a primary focus on the policy's ability to encourage the reduction of carbon dioxide emissions while simultaneously reducing other air pollutants. Second, if it can help to reduce pollution and carbon, does this effect vary by region? What is the mechanism of this effect?

2 Literature Review and Theoretical Mechanisms

2.1 Relevant Literature Review

2.1.1 Carbon emissions trading related research

Recent studies on the implementation consequences of the policy have been conducted by domestic and international scholars, who have thoroughly investigated the policy's many implications. For example, Burniaux (1992) used dynamic general equilibrium modeling to find that the implementation of the policy is expected to achieve reductions in total carbon emissions globally, providing an effective means for countries to work together to reduce their carbon footprint[7]. Bohringer et al. (2004) use a multiregional dynamic CGE model to study the difference between implementing a carbon trading policy and not implementing a carbon trading policy, and find that implementing such a policy significantly improves carbon emissions efficiency[8]. Demailly and Quirion (2008) find that carbon trading promotes technological innovations in firms[9], but the findings of Anger and Obeindorfer (2008) are the opposite[10]. Furthermore, using various techniques and data sets, Rogge et al. (2011), Martin et al. (2011), and Schmidt et al. (2012) investigated the implementation implications of carbon emissions trading in Europe[11,12,13]. Scholars in China have also carried out comprehensive research on the policy implications, examining the true impact of this environmental measure on the country from various angles. For example, production frontiers constructed by Fan Dan et al. (2017) and the global Data Envelopment Analysis (DEA) approach were used to compare total factor productivity and its decomposition variables between 2010 and 2014 for China's carbon emissions trading pilot provinces and non-pilot provinces[14]. It was discovered that the policy significantly boosted technical innovation.Tan and Zhang (2018) discovered that, although the extent of the effect varies based on the features of the pilot territory, the carbon trading mechanism has a considerable "forcing" effect on the upgrading of the industrial structure in the area[15].

2.1.2 Research on carbon and air pollution synergistic emission reduction

China is facing a complex double challenge due to global climate change and environmental pollution. CO_2 and $PM_{2.5}$ have the same root and homology characteristics, and the relevant measures of carbon reduction may have positive significance for improving environmental pollution. Taking Beijing as a case study, Yang et al. (2016) thoroughly investigated the interrelationship between CO_2 and $PM_{2.5}$ at the consumption and production levels, respectively, and proposed a series of comprehensive measures to synergistically mitigate environmental pollution and reduce CO_2 emissions[16]. According to Zhang et al.'s (2016) investigation into the impact of low-carbon urban development on air pollution, base effects and environmental management can greatly lower air pollution[17]. We can learn a lot from the Dong et al. (2019) study regarding the mutually beneficial relationship between $PM_{2.5}$ and carbon emission reduction[18]. According to the study, there has been a noticeable decline in $PM_{2.5}$ concentration after carbon emission reduction has been implemented. Most of these changes can be attributed to the synergistic effect of reduced carbon emissions. In order to confirm the existence of synergistic emission reduction effects, Li et al. (2020) conducted a thorough examination of the spatial distribution characteristics of carbon emissions and $PM_{2.5}$ in China using grid data[19].

2.2 Theoretical Mechanisms of Carbon Emissions Trading Affecting Pollution and Carbon Reduction

With the introduction of carbon emissions trading, economic incentives have prompted enterprises to restrain their production and consumption behaviors, thereby effectively reducing carbon emissions. First, at the strategic level, source-based actions have been implemented to modify the energy consumption structure and lessen dependency on fossil fuels like coal and oil; At the same time, hydropower and wind power has been gradually increased, so as to achieve a double reduction in corporate carbon emissions and air pollutant emissions.

Second, moderate environmental regulation is thought to act as a catalyst to encourage businesses to participate in low-carbon technological innovation activities, which maximizes resource allocation and thereby increases resource efficiency[20]. This is in line with Porter's hypothesis.In regions where carbon emissions trading is implemented, enterprises that take the lead in low-carbon technological innovation will have a competitive advantage. On the one hand, companies will embark on cleaner production strategies to minimise carbon emissions from the production process. On the other hand, due to technology spillovers, emerging technologies will diffuse into the production processes of other firms, leading to a green transformation of society as a whole.

Finally, the "pollution haven" hypothesis suggests that developed countries will move polluting industries to less developed countries or regions before implementing carbon emissions trading[21]. However, when less developed regions implement carbon emissions trading, they will attract cleaner investments that are technologically advanced and less carbon intensive and polluting, thus contributing to emissions reductions in the region.

In conclusion, as shown in figure 1, this study makes the following three arguments on how the policy can affect the reduction of carbon dioxide and air pollution.

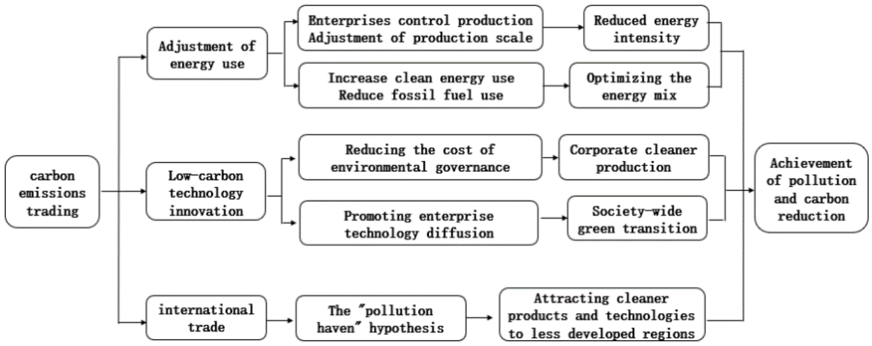

Fig.1. Diagram of the mechanism of carbon emissions trading affecting pollution and carbon reduction

3 Model Construction and Data Description

3.1 Model Construction

One popular technique for evaluating the impact of policy implementation is the double-difference approach, which has the advantage of being able to evaluate the net effect of policies without endogeneity issues interfering. This study employs a quasi-natural experiment utilizing the 2014 carbon emissions trading pilot program. There were 37 prefecture-level cities in the experimental group, which was made up of the seven provinces and cities that started the pilot program in 2014; the control group, which was made up of the remaining provinces without the pilot policy, included 247 prefecture-level cities. As shown in equation (1), the study model was constructed using the difference-in-differences (DID) method.

$$\ln CO_2 \ (\ln PM_{2.5}) = \alpha + \beta_1 Time_{it} + \beta_2 Treated_{it} + \beta_3 Did + \sum control_{it} + \mu_i + \sigma_t + \varepsilon_{it} \quad (1)$$

In this case, the year range is 2000–2019, the city is represented by the subscript *i*, and the year is represented by *t*. The DID model to assess how carbon emissions trading affects carbon emissions and air pollution is built by adding the time dummy variable $Time_{it}$ and the city dummy variable $Treated_{it}$ at the prefecture level. The primary emphasis lies in coefficient β_3.The random disturbance term is ε_{it}, the time fixed effect is σ_t, the city fixed effect is μ_i, and the control variable group is $control_{it}$.

3.2 Indicator Selection and Explanation

This study thoroughly gathers and organises a wealth of data using a number of data sources, including the China Urban Statistical Yearbook, China Regional Economic Statistical Yearbook, China Energy Statistical Yearbook, China Urban Construction Statistical Yearbook, and statistical yearbooks of various regions. These data offer a strong foundation of knowledge for our study by encompassing important details on numerous facets of the energy, social, and economic growth of Chinese cities.

In this study, the following variables are taken into account when choosing dependent variables.(1) Carbon emissions: There are two primary sources of carbon emissions in cities: direct energy consumption from sources, as well as emissions produced during the use of electrical and thermal energy [22].The carbon emissions from direct energy consumption, electrical consumption, and thermal energy consumption can be added up to determine the total carbon emissions for any city.(2) Air pollution: the annual mean value of $PM_{2.5}$ is obtained by processing data that are derived from the raster data of the Atmospheric Composition Analysis Group and matched with vector data of China's administrative divisions [23].

The following variables were taken into consideration when choosing the control variables for this article.(1) Real GDP per capita: This paper deflates GDP per capita using 2000 as the base period. (2) Foreign Direct Investment: The control variable in this study is the logarithm of the total amount of FDI that prefecture-level cities actually utilize.(3) Year-end Resident Population: The demographic indicators are represented by the year-end resident population of prefecture-level cities; heteroskedasticity is minimized by taking the logarithm.(4) Industrial Structure: The value added of the secondary industry is divided by the nominal GDP for the year to determine the regional industrial structure.(5) Environmental Regulation: Determine the composite index of urban three-waste emissions to characterize the level of environmental regulation in cities [24].

The following variables are considered for the selection of the moderating variables in this paper.(1)Energy Consumption Intensity: Energy consumption divided by GDP in tons of standard coal per million yuan. (2)technical Innovation: To gauge the degree of technical innovation, prefecture-level cities award a yearly number of patents, which is logarithmic in nature.(3)International commerce: The prefecture-level cities' total import and export commerce, treated logarithmically, as a gauge of international trade.

4 Analysis of empirical results

4.1 Descriptive statistics of variables

The descriptive statistics of the major variables for 5680 samples taken from 284 Chinese prefecture-level cities are shown in the following table1.

Table1 Descriptive Statistics of Variables

Variable	Obs	Mean	Std. Dev	Min	Max
$\ln CO_2$	5680	2.798	0.861	0.0881	5.441
$lnPM_{2.5}$	5680	3.750	0.329	2.572	4.690
lnPgdp	5680	9.659	0.787	4.252	11.72
lnPeople	5680	5.851	0.695	2.770	8.136
lnFDI	5568	9.233	2.092	1.099	13.66
Industry	5680	46.82	11.26	10.68	90.97
Regulation	5680	0.247	0.635	4.93e-07	12.10

4.2 Parallel trend test

Prior to the policy's implementation, the treatment and control groups must pass the parallel trend test in order for the DID technique to be used to analyze the effects of the policy. In other words, the treatment group control group itself did not exhibit a systematic difference and exhibited the same development trend prior to the implementation of the policy. The parallel trend test figure2 shows us that prior to the policy's adoption, the policy's temporal impacts on ln CO_2 and $lnPM_{2.5}$ have been very close to the zero neighbourhood, and these effects are not statistically significant. Both show a significantly negative impact of carbon emissions trading on carbon dioxide and air pollution, with the policy-time impacts of both being much smaller than zero when the carbon emissions trading pilot program is launched or in the year following the policy's introduction.The pilot and non-pilot regions appear to meet the parallel trend assumption, indicating that the preconditions of the DID model are satisfied.

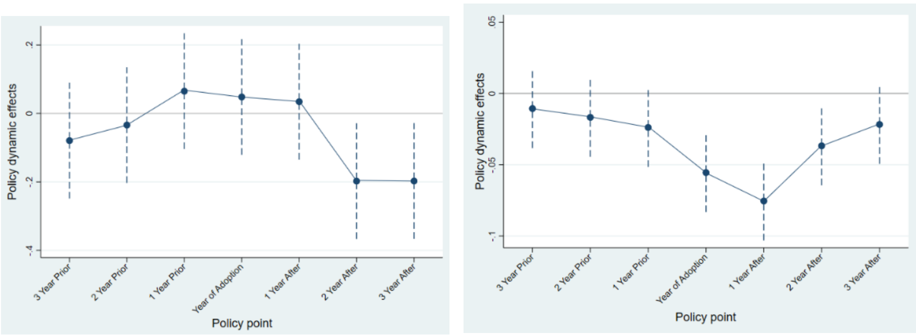

Fig.2. Plot of parallel trend test (left: estimated coefficient of ln CO_2; right: estimated coefficient of ln$PM_{2.5}$)

4.3 Benchmark regression analysis

This section looks at if carbon emissions trading, a market-based approach to environmental incentives, promotes the reduction of both air pollution and carbon emissions at the same time. The baseline regression results in table 2 show that, following the addition of the control variables, the coefficients of the policy dummy variable are -0.129 and -0.057 respectively, both of which are significant at the 1% level;The inclusion of control factors had no significant impact on the significance or sign of the primary explanatory variables.This suggests that carbon trading policies significantly curb regional carbon intensity while contributing to the reduction of air pollutants in cities. As CO_2 and $PM_{2.5}$ have the characteristic of "the same root and the same source", both of them are caused by energy consumption and other factors. Therefore, the carbon trading policy has not only been effective in reducing carbon emissions, but also in reducing $PM_{2.5}$ concentrations and improving environmental quality.

Table 2 Estimated pollution and carbon reduction effects of carbon trading: the DID model

variables	ln CO_2	ln CO_2	$lnPM_{2.5}$	$lnPM_{2.5}$
did	-0.144^{***}	-0.129^{***}	-0.052^{***}	-0.057^{***}
	(0.024)	(0.019)	(0.006)	(0.006)
control variable	NO	YES	NO	YES
City FE	YES	YES	YES	YES

Year FE	YES	YES	YES	YES
Constant	2.047***	-1.155*	3.607***	4.147***
	(0.011)	(0.653)	(0.005)	(0.192)
Observations	5680	5568	5680	5568
R^2	0.919	0.933	0.700	0.706

Robust standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1

4.4 Robustness Tests

4.4.1 PSM-DID test

The difficulty with DID estimation is excluding meaningful differences between the control and treated groups that were present before the carbon emissions trading pilot program was put into place. These differences could lead to distortion in the estimation results due to sample selection bias. For our analyses, we used the propensity score-matched double-difference technique (PSM-DID) in accordance with Rosenbaum and Rubin's (1983) methodology[25]. The results of the DID regression of the samples following propensity score matching demonstrate that, for both $\ln CO_2$ and $lnPM_{2.5}$, the coefficients of the dummy policy variables are negative at the 1% significance level from table 3. This is in line with the baseline regression results and provides full confirmation of the pollution-reducing and carbon-reducing effects of carbon emissions trading.

Table 3 Estimated pollution and carbon reduction effects of carbon trading: PSM-DID test

variables	$\ln CO_2$	$lnPM_{2.5}$
did	-0.133***	-0.053***
	(0.019)	(0.006)
control variable	YES	YES
City FE	YES	YES
Year FE	YES	YES
Constant	-0.983	4.117***
	(0.680)	(0.187)
Observations	5060.000	5060.000
R^2	0.939	0.720

Robust standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1

4.4.2 Multi-temporal DID test

The policy's time points are 2012, 2013, and 2016 since different pilot cities launch the carbon market at different periods. Next, a multi-temporal DID regression test is performed to examine the relationship between pollution reduction and carbon reduction as well as the impact of the carbon emissions trading scheme. The findings confirm the existence of the pollution reduction and carbon reduction impacts that are the main focus of this paper by demonstrating that the coefficients of the interaction terms before $\ln CO_2$ and $lnPM_{2.5}$ are both negative at the 1% significance level from table 4. The aforementioned discovery serves to reinforce the validity of the DID regression outcomes and offers robust backing for scholarly discourse concerning the ecological consequences of carbon emissions trading regulations.

Table 4 Estimated pollution and carbon reduction effects of carbon trading: Multi-temporal DID test

variables	$\ln CO_2$	$lnPM_{2.5}$
did	-0.133***	-0.056***
	(0.017)	(0.007)
control variable	YES	YES
City FE	YES	YES
Year FE	YES	YES
Constant	-1.103*	4.171***
	(0.647)	(0.193)
Observations	5568.000	5568.000
R^2	0.933	0.706

Robust standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1

4.4.3 Placebo test

In order to deepen the elimination of potential effects of other unknown factors on the selection of pilot cities and strengthen the credibility of the results of the baseline regressions, we had to conduct a placebo test.The placebo test provides robustness assurance for the original findings by randomly selecting a number of sub-dummy experimental groups in all samples to conduct regressions consistent with the benchmark regression[26]. 500 samples covering all 284 prefecture-level cities were used in this investigation; 37 samples were randomly selected to function as the virtual experimental group in each sample. The remaining 247 cities served as the control group for the benchmark regression.

As shown in figure 3, the placebo test is passed by the benchmark regression findings in this work because the estimation coefficients of $\ln CO_2$ and $lnPM_{2.5}$ (-0.129 and -0.057, respectively) are located in the lower tails of the probability distribution of the estimation coefficients in the test statistics.

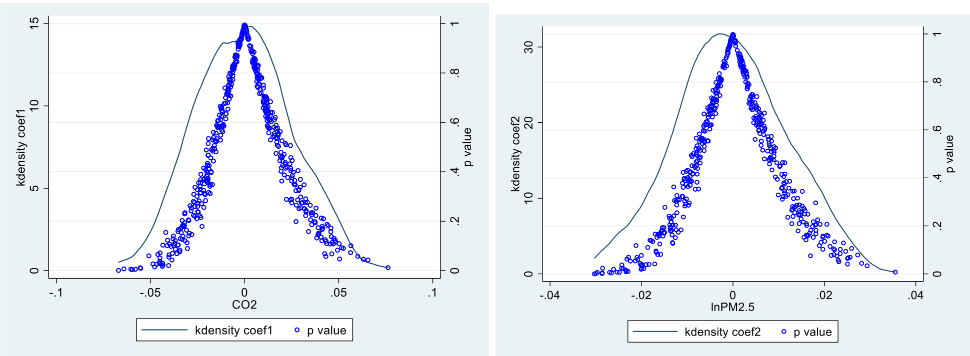

Fig.3. Placebo test (left: estimated coefficient of $\ln CO_2$; right: estimated coefficient of $\ln PM_{2.5}$)

4.5 Heterogeneity Analysis

One significant aspect of China's economic development is uneven regional development. For instance, the coastal areas in the east are more developed than other regions, but the middle and western parts are less developed. In order to perform independent regression analyses for each of the three sub-samples of Chinese prefecture-level cities, we first partition the entire sample into the eastern, central, and western sub-samples.The Table **5** illustrates that the did coefficients of both $\ln CO_2$ and $lnPM_{2.5}$ are negative at the 1% level in the central and western regions, indicating a clear reduction in pollution. The did coefficients of $\ln CO_2$ is not significant in the eastern region, and only the did coefficient of $lnPM_{2.5}$ is considerably negative at the 1% level. The fact that industry predominates in the central and western regions while the industrial structure in the eastern regions is more service-oriented may be the cause of this discrepancy. This means that while the policy has a relatively little impact in the eastern regions, it has a considerable impact on lowering pollution and carbon emissions in the central and western regions.

Table 5 Tests of Heterogeneity: Eastern, Central and Western Regions

	Eastern Regions		Central Regions		Western Regions	
	$\ln CO_2$	$lnPM_{2.5}$	$\ln CO_2$	$lnPM_{2.5}$	$\ln CO_2$	$lnPM_{2.5}$
did	-0.039	-0.058***	-0.221***	-0.054***	-0.172***	-0.077***
	(0.025)	(0.009)	(0.027)	(0.009)	(0.024)	(0.013)
control variable	YES	YES	YES	YES	YES	YES
City FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Constant	0.387	3.559***	-2.928***	5.288***	2.056**	3.835***
	(0.953)	(0.199)	(0.840)	(0.240)	(0.970)	(0.378)
Observations	1960.000	1960.000	2412.000	2412.000	1159.000	1159.000
R^2	0.946	0.805	0.939	0.685	0.927	0.743

Robust standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1

Since port cities are usually centers of trade and logistics, there will be more freight activities, including a large number of ships, trucks, and railroads, and these activities in ports and logistics centers will lead to more carbon emissions. According to the Ministry of Transportation and Communications (MOTC) on the cargo and container throughput of ports nationwide in 2020, the full sample of prefecture-level cities in China is divided into two sub-samples, port cities and non-port cities, and regressed separately.

Table 6 Heterogeneity test: port cities and non-port cities

	Port Cities		Non-Port Cities	
	$\ln CO_2$	$lnPM_{2.5}$	$\ln CO_2$	$lnPM_{2.5}$
did	-0.115***	-0.050***	-0.162***	-0.051***
	(0.024)	(0.008)	(0.037)	(0.008)
control variable	YES	YES	YES	YES
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Constant	-0.206	3.348***	-2.926***	4.440***
	(0.601)	(0.176)	(0.986)	(0.422)
Observations	2078.000	2078.000	3471.000	3471.000
R^2	0.948	0.818	0.926	0.663

Robust standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1

It can be inferred from the regression results (Table 6) that the effects of carbon emissions trading in reducing pollution and carbon emissions are quite significant in both port and non-port areas. The DID coefficients of the dummy policy variables of $\ln CO_2$ and $lnPM_{2.5}$ are both negative at the significant level (1%) for both port and non-port cities.

5 Mechanism analysis

According to the theoretical analysis of the impact mechanisms, carbon credits can influence pollution and carbon reduction through energy intensity, low-carbon technological innovation, and international trade. In this section, the mediation effect equation is used to examine whether carbon emissions trading has an impact on carbon reduction through a range of mechanisms. This study aims to reveal the specific pathways through which carbon emissions trading works and provide more detailed analyses to explain the effects of the policy.The recursive equation constructed is as following formulas (2)-(4):

$$ln\, CO_{2_{it}}\left(or\ lnPM_{2.5_{it}}\right) = \alpha + \beta_1 Time_{it} + \beta_2 Treated_{it} + \beta_3 Did + \beta_4 \sum control_{it} + \mu_i + \sigma_t + \varepsilon_{it} \quad (2)$$

$$W_{it} = \alpha + \beta_1 Time_{it} + \beta_2 Treated_{it} + \beta_3 Did + \delta \sum control_{it} + \mu_i + \mu_i + \sigma_t + \varepsilon_{it} \quad (3)$$

$$\ln CO_{2_{it}}\left(or\ lnPM_{2.5_{it}}\right) = \alpha + \beta_1 Time_{it} + \beta_2 Treated_{it} + \beta_3 Did + \theta W_{it} + \beta_4 \sum control_{it} + \mu_i + \sigma_t + \varepsilon_{it} \quad (4)$$

In the context of the carbon trading pilot policy, W_{it} serves as the mediating variable and produces pollution reduction and carbon reduction through three channels: energy intensity, low-carbon technology innovation, and international commerce.

5.1 Mediating effect of energy intensity

Table 7 analyzes whether the carbon trading policy will achieve carbon dioxide and air pollution reduction through the mediating variable of energy intensity. The DID coefficients for the dummy policy variables in column (1) are significantly negative at the 10% level. It demonstrates how carbon trading programs do indeed lower energy intensity.Column (3) shows that when the dummy policy variable did and energy intensity are simultaneously regressed on ln CO_2, the dummy policy variable's absolute value decreases in comparison to the baseline DID model. This suggests that energy consumption has a mediating impact and that lowering energy consumption intensity can really reduce carbon emissions. Additionally, as column (5) demonstrates, when energy intensity and the dummy policy variable did are jointly regressed on $lnPM_{2.5}$, the dummy policy variable's absolute value falls relative to the benchmark DID model, and the coefficient of did is notably negative at the 1% level.

Table 7 Mediated Effects Test-Energy Intensity

	(1) lnEE	(2) ln CO_2	(3) ln CO_2	(4) $lnPM_{2.5}$	(5) $lnPM_{2.5}$
did	-0.126*	-0.099***	-0.098***	-0.051***	-0.038***
	(0.069)	(0.020)	(0.009)	(0.007)	(0.009)
lnEE			0.013***		0.145*
			(0.004)		(0.074)
control variable	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Constant	-2.510***	0.190	0.167	5.090***	5.094***
	(0.023)	(0.640)	(0.204)	(0.304)	(0.163)
Observations	3723	3647	3646	3647	3646
R^2	0.361	0.793	0.794	0.761	0.761

Robust standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1

5.2 Mediating effects of low-carbon technological innovation

Second, by encouraging greater levels of technical innovation, does the policy reduce carbon dioxide and other air pollutants? That is the second goal of this study. The study's findings (table 8) indicate that the policy dummy variable does's coefficient is not significant, suggesting that carbon emissions trading does not encourage the development of innovative technologies or encourage businesses to transition to low-carbon operations. This may be because enterprises need long-term planning and a predictable market environment to support technology R&D and investment decisions, while the instability and policy uncertainty of the carbon market may constitute barriers. In order to promote low-carbon technology innovation and mitigation measures, carbon market policies need to be made more stable and predictable so that firms can formulate long-term development plans and undertake technology R&D and low-carbon investments with confidence.

Table 8 Mediating effects of low-carbon technological innovation

	(1) lnPL	(2) $\ln CO_2$	(3) $\ln CO_2$	(4) $lnPM_{2.5}$	(5) $lnPM_{2.5}$
did	-0.017	-0.119***	-0.113***	-0.054***	-0.056***
	(0.066)	(0.021)	(0.021)	(0.007)	(0.007)
lnPL			0.027***		-0.020***
			(0.008)		(0.004)
control variable	Yes	Yes	0.027***		-0.020***
City FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Constant	4.904***	-0.665	-0.466	5.120***	4.970***
	(0.032)	(0.677)	(0.662)	(0.306)	(0.290)
Observations	4265	4194	4187	4194	4187
R^2	0.880	0.879	0.881	0.738	0.742

Robust standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1

5.3 Mediating effects of international trade

Thirdly, it examines whether international trade may reduce pollution and carbon emissions through carbon emissions trading. The findings of table 9 demonstrate that the policy dummy variable's coefficient is not significant, suggesting that selling carbon emissions has no appreciable impact on global trade. The reason for this is worth exploring. China has been actively attracting foreign investment into the domestic market with policy preferences and other measures. Whether the entry of foreign investors will transfer high-pollution and high-energy-consuming low-technology industries to the host country and increase China's environmental pollution [27]; or whether it will introduce relatively more advanced clean technology or excellent talents and sufficient funds [28], there is no definitive conclusion.

Table 9 Mediating effects of international trade

	(1) lnINT	(2) $\ln CO_2$	(3) $\ln CO_2$	(4) $lnPM_{2.5}$	(5) $lnPM_{2.5}$
did	-0.050	-0.119***	-0.117***	-0.054***	-0.054***
	(0.083)	(0.021)	(0.021)	(0.007)	(0.007)
lnINT			0.015*		-0.004
			(0.009)		(0.005)

control variable	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Constant	12.665***	-0.665	-0.720	5.120***	5.129***
	(0.037)	(0.677)	(0.658)	(0.306)	(0.308)
Observations	4269	4194	4192	4194	4192
R^2	0.523	0.879	0.880	0.738	0.738

Robust standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1

In conclusion, this study's empirical test of the mediating effects hypothesis reveals that the impact of the carbon emissions trading policy on pollution and carbon reduction is not transmitted through global trade or low-carbon technology innovation. On the other hand, energy intensity reduction is the primary means by which the policy encourages the combined decrease of carbon dioxide and air pollutants.

6 Conclusions and policy recommendations

6.1 Conclusion

In order to examine the effects of the carbon trading pilot policy on pollution and carbon reduction, this study uses the twofold difference method (DID), and heterogeneity analysis is conducted as a result. Additionally, a thorough analysis of the mechanisms influencing the impact of the policy on pollution and carbon reduction was conducted using the mediation effect model. The empirical findings demonstrate that both the DID coefficients of $\ln CO_2$ and $lnPM_{2.5}$ are significantly negative, indicating that China's carbon emissions trading pilot policy is effective in lowering carbon emissions and pollution. This conclusion is supported by the results of the placebo, multi-temporal DID, and parallel trend tests. The results of the heterogeneity test revealed that while the impacts of pollution abatement and reduction were not significant in the eastern region, they were in the central and western regions. Ultimately, the mechanism analysis results utilizing the mediator model demonstrate that, while reducing energy intensity can help reduce pollution and carbon emissions, it cannot improve technical innovation or foster international trade.

6.2 Policy recommendations

The empirical study presented above leads to the following policy suggestions:

The Government is expected to formulate more detailed carbon emissions trading support policies to reduce costs and improve the effectiveness of carbon emissions trading; at the same time, it should encourage enterprises to actively participate in trading and expand carbon emissions trading pilots to a wider geographical area.

Secondly, in response to the irrationality of the carbon quota allocation mechanism, there is an urgent need to improve the legal system of the carbon trading market. The introduction of an auction mechanism as a means of quota allocation enables enterprises to acquire carbon emission quotas in a paid manner, so as to make fuller use of the market mechanism and realise the effective play of the market in resource allocation, thereby allocating carbon emission rights on a fair and reasonable basis. In order to achieve this goal, it is necessary to strengthen the regulatory framework of the carbon emissions trading market, establish a comprehensive system of laws and regulations to support it, and promote the carbon emissions trading market in the direction of legalisation and scientification.

Third, adjust the energy structure. Enterprises should reduce energy use and improve energy efficiency, which can be achieved by adjusting the scale of production; Simultaneously, businesses should step up their efforts in independent research and development and keep funding the development of green and low-carbon technology in order to bolster the "Porter effect".

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References

[1] Liu C, Sun Z, Zhang J. Research on the effect of carbon emission reduction policy in China's carbon emissions trading pilot[J]. China population, resources and environment, 2019 ,29(11):49-58.
[2] Chen Y, Xu Z, Zhang Z, et al. Does the carbon emission trading scheme boost corporate environmental and financial performance in China?[J]. Journal of Cleaner Production,2022,368: 133151.
[3] Cao L, Tang Y, Cai B, et al. Was it better or worse? Simulating the environmental and health impacts of emissions trading scheme in Hubei province, China[J]. Energy. 2021, 217: 119427.
[4] Zhang G, Fan M, Ma R, et al. Effects of the carbon emission trading policy on collaborative emission reduction[J]. China population, resources and environment, 2022,32(3):1-10.
[5] Dong Z, Xia C, Fang K, et al. Effect of the carbon emissions trading policy on the co-benefits of carbon emissions reduction and air pollution control[J]. Energy Policy,2022,165:112998.
[6] Hu Y, Li R, Du L, et al. Could SO2 and CO2 emissions trading schemes achieve co-benefits of emissions reduction?[J]. Energy Policy, 2022,170:113252.
[7] Burniaux J M, Martin J P, Nicoletti G, et al. Green: A Multi — sector,Multi — Region Dynamic General Equilibrium Model for Quantifying the Costs of Curbing CO2 Emissions: A Technical Manual[J]. OECD Economics Department. 1991,104:102-159
[8] Bohringer C,Welsch H. Contraction and Convergence of Carbon Emissions: An Intertemporal Multi — Region CGE Analysis[J]. Journal of Policy Modeling, 2004,26 (1): 21-39.
[9] Demailly D, Quirion P. European Emission Trading Scheme and competitiveness: A case study on the iron and steel industry[J]. Energy economics,2008,30(4): 2009-2027.
[10] Anger, N. and U. Oberndorfer,"Firm Performance and Employment in the EU Emissions Trading Scheme: An Empirical Assessment for Germany"[J]. Energy Policy, 2008,36 (1) : 12-22.
[11] Rogge K S, Schneider M, Hoffmann V H. The innovation impact of the EU Emission Trading System—Findings of company case studies in the German power sector [J]. Ecological Economics, 2011,70 (3):513-523.
[12] Martin R, Muûls M, Wagner U. Climate change, investment and carbon markets and prices– evidence from manager interviews[R]. Climate Strategies, Carbon Pricing for Low-Carbon Investment Project. 2011.
[13] Schmidt T S, Schneider M, Rogge K S, et al. The effects of climate policy on the rate and direction of innovation: A survey of the EU ETS and the electricity sector [J]. Environmental Innovation and Societal Transitions, 2012,2: 23-48.

[14] Fan D, Wang W G, Liang P F. Analysis of Policy Effects of Carbon Emission Trading Right Mechanism in China - Estimation Based on Double Difference Models [J]. China Environmental Science, 2017,37(6):10.
[15] Tan J, Zhang J H. Has the Carbon Trading Mechanism Forced Industrial Structure Upgrading? -- An analysis based on the synthetic control method [J]. Economic and Management Studies, 2018, 39(12):16.
[16] Siyuan Yang, Bin Chen, Sergio Ulgiati. Co-benefits of CO2 and PM2.5 Emission Reduction[J]. Energy Procedia, 2016, 104: 92-97.
[17] Zhang T F, Yang J, Sheng P F. Impact of urbanization on China's carbon emissions and its channels of action[J]. China Population-Resources and Environment. 2016, 26(02):47-57.
[18] Dong F, Yu B L Pan Y L. Examining the synergistic effect of CO2 emissions on PM2.5 emissions reduction: Evidence from China[J], Journal of Cleaner Production, 2019,223: 759-771.
[19] Li Y, Cui Y, Cai B, et al. 2020. Spatial characteristics of CO2 emissions and PM2. 5 concentrations in China based on gridded data[J]. Applied energy, 266: 114852.
[20] Porter M E, Linde C. Toward a new conception of the environment-competitiveness relationship[J]. Journal of economic perspectives, 1995,9(4): 97-118.
[21] Becker R, Henderson V. Effects of air quality regulations on polluting industries[J]. Journal of political Economy, 2000,108(2): 379-421.
[22] Bai Y, Deng X, Gibson J, et al. How does urbanization affect residential CO2 emissions? an analysis on urban agglomerations of China[J]. Journal of cleaner production, 2019,209: 876-885.
[23] Van Donkelaar A, Hammer M S, Bindle L, et al. Monthly global estimates of fine particulate matter and their uncertainty[J]. Environmental Science & Technology, 2021. 55(22): 15287-15300.
[24] Qin Y E , Gang Z , Shao-Qing D ,et al. Research on the effects of different policy tools on China's emissions reduction innovation:based on the panel data of 285 prefectural-level municipalities[J].China Population,Resources and Environment. 2018,28(2):115 - 122.
[25] Rosenbaum P R, Rubin D B. The central role of the propensity score in observational studies for causal effects[J]. Biometrika, 1983,70(1): 41-55.
[26] Nie C F, Lu J X, Feng Y, et al. 2021, Impact of innovative city construction on green total factor productivity[J]. China population, resources and environment, 31(3): 117-127
[27]Liu Y L, Wen H D. FDI, human resources and environmental pollution loss in Chinese economic growth[J]. World Economy Studies, 2007,(11):48-55+87
[28] Dangi R N. FDI in Indian retail sector: Opportunities and challenges[J]. Innovative Journal of Business and Management. 2013,67(2):165-181.