The Carbon Emission Reduction Effect of Carbon Emission Trading Policy in China

Kunli Tang

Zhejiang Gongshang University, Hangzhou, 310018

tangkunli2022@163.com

Abstract. The carbon emission trading policy attributes carbon dioxide emission rights to commodities, representing an important exploration to reduce carbon emissions by the market mechanism. Since 2013, China has implemented the carbon emission trading policy. In order to study whether the carbon emission reduction effect of emission trading policy in pilot areas and what is the pathway , this paper uses multi-period difference-in-differences method and the medintion effect method. An empirical analysis of panel data from 283 prefecture-level cities in China between 2006 and 2019.The research findings demonstrate that: (1) The policy about carbon emission trading significantly reduced carbon emissions,which is still valid after a series of robustness tests, and had a synergistic effect. (2) The policy primarily promotes carbon dioxide emission reduction through innovation in green technology and adjustments in industrial structure. (3) In comparison to the eastern and western regions, the policy performs better in central regions. Furthermore, the effectiveness of emission reduction depends on the intensity of environmental regulations, thus, stricter regulations are more conducive to carbon reduction. This paper provides strong evidence to the expansion of carbon emission trading pilots, and guides the operation of carbon emission trading market in China.

Keywords: carbon emission trading policy, multi-period difference-in-differences, medintion effect， carbon reduction， synergistic effect.

1. Introduction

Climate change has become the most pressing challenge for humanity, resulting in worldwide climate, ecological, and energy crises that have drawn high levels of attention globally. The main reason is the sharp increase in carbon dioxide emissions by human activities. Thus, reducing carbon emissions, and achieving carbon peak and carbon neutrality have become the collective effort and pursuit of all humanity in the 21st century. Being the largest carbon-emitting nation and the second-largest economy, China always prioritises the issue of climate change. Through systematic planning, coordinated deployment, and variable measures, China targets to promote carbon reduction and facilitate green-oriented transition of energy. Therefore, China roll out range of policies about carbon emission trading policy, which employs market mechanisms to promote low-carbon transformation. In 2011, the "12th Five-Year Plan" announced to establish the domestic carbon emission trading market. Simultaneously, China took a lot of preparation for the establishment of carbon emission trading and set seven pilots: Beijing, Tianjin, Shanghai, Chongqing, Shenzhen, Hubei Province, and Guangdong Province. In 2016, Fujian province became the second pilot region in China regarded as a voluntary zone. From 2013 to 2016, China officially launched carbon emission trading markets online in the pilot regions, which were the beginning of carbon emission trading project. The national carbon emission trading market was successfully launched in July 2021. According to statistics from the First Financial Research Institute, the annual trading volume of carbon reached 50.8895 million tons with a turnover of 2.814 billion yuan in 2021.[1]The report of the 20th CPC National Congress stresses the need to further "improve the system of carbon emission statistics and accounting, and improve the system of carbon emission rights market and trading". And in the future, China will build

[1] Source: China Carbon Market Annual Report 2022, China Carbon Trading Network., http://www.tanjiaoyi.com/article-4528 4-1.html

the world's largest carbon market in terms of greenhouse gas emissions, which is significant in accelerating the process of global low-carbon emission reduction cause.

Since the proposal of the carbon emissions trading market plan to the second cycle in 2023, the carbon emissions trading market has developed for more than ten years, and the basic framework system has also been established initially. However, compared with developed countries in Europe and the United States, the establishment of China's carbon market started late, and there remains many problems such as inadequate market systems (Liu et al, 2015)[i], Poor transparency of information (Chai et al., 2022)[ii], and high requirements for inclusion in the emission control list (Hu et al, 2023)[iii], which lead to low participation of enterprises, low efficiency of market operation, and small amount of carbon allowances. Combined with the existing researches, this paper raises the following questions: Does the pilot carbon emission trading policy actually reduce carbon dioxide emissions in the pilot areas? What is its main pathway of carbon mission reduction? These questions are of great significance for perfecting China's carbon emissions trading market, promoting China's low-carbon economic transformation, and even dealing with global warming issues in theory and practice

2. Literature review

Global warming has spurred economists to search for solutions. Arthur Cecil Pigou, a welfare economist, suggested imposing a "Pigovian tax" as a solution to the externality problem, while Ronald H. Coase, a new institutional economist, suggested that property rights could be purchased and sold freely in the market to reduce transaction costs and attain maximum allocation of resources if the transaction costs are minimal and property rights are clear, which has significantly impacted the development of the carbon emissions trading system. Scholars evaluate the preceding two carbon emission reduction approaches primarily by reviewing diverse aspects such as the marginal cost of emission reduction (Wu et al., 2014)[iv], social welfare (Shi et al., 2013)[v], emission reduction effect (Liu et al., 2023)[vi], and the influence of the price mechanism (Brink et al., 2018)[vii]of the carbon emissions trading system, all of which mainly explore the theoretical benefits of such a system. The research indicated that while a solitary carbon tax has a lower abatement cost and causes minimal loss of social welfare, carbon emissions trading can lower carbon emissions intensity by a further 5% (Shi et al., 2013), and the strategy of achieving a balance between them, which is primarily designed to prompt businesses to join the carbon market by increasing the price of the carbon tax, can lead to a cut in energy consumption by 18%—28% (Li et al., 2017)[viii].

Before the implementation of the carbon emissions trading policy, many scholars conducted theoretical simulations to analyze its potential impact on emission reduction. The carbon emissions trading market has the potential to promote carbon emission reduction in China (Cui et al., 2014)[ix] while reducing carbon costs (Dai et al., 2012)[x], but what is its actual impact? Can it achieve the theoretical expectations for emission reductions? As China's pilot policy for carbon emissions trading gained momentum, scholars endeavored to analyze its effects based on real-life situations. They took the site's official launch, between 2013 to 2016, as a natural experiment to analyze its impact perspectives including carbon emissions (Zhang et al., 2017)[xi], carbon intensity (Yu et al., 2022)[xii] green total factor productivity (Li et al., 2022)[xiii], and regional green innovation (Du Jun et al., 2021)[xiv]. Several studies demonstrate that the carbon emissions trading market can considerably promote carbon emission reduction. For instance, Zhang et al. (2020)[xv] analyzed at a provincial level and found that the carbon emissions trading policy reduced carbon dioxide emissions in the pilot region by 24%. According to Cui et al.'s (2021)[xvi] research, the pilot industrial enterprises managed to reduce their carbon emissions by 16% due to the policy's effective contribution. Liu et al.'s (2019)[xvii] research also shows that the policy has led to a significant reduction in carbon emissions in pilot provinces and cities. The study suggests that the policy achieves emission reductions mainly through channels such as corporate profits and costs, market incentives, and government support while promoting green technology and process innovation.

The innovation of this paper based on three aspects. Firstly, it begins at the prefecture level and and uses regional carbon emission data adjusted with China's night lighting data provided by Chen et al. (2020)[xviii] as explanatory variables. Limited by the data, the existing studies mostly start from the provincial level, and the calculation method of carbon dioxide is only estimated based on the data provided by the local statistical yearbook, which may have a high error with the actual carbon emission data. However, Chen et al. (2020) used PSO-BP algorithm, which combined the DMSP/OLS and NPP/VIIRS image scale with vegetation carbon sequestration data, and produced CO_2 emission data with better fitting effects than normal measurement experiments. This approach facilitated the discovery of some results that could not be obtained through the testing of provincial data and had theoretical value for enhancing the policy's emission reduction effect. Secondly, most studies directly consider 2014 as the time point of policy impact, which is relatively rough. Instead, this study employs a multi-temporal double-difference model that considers 2013, 2014, and 2016 as time points for different pilots, according to the policy's actual situation. In addition, the voluntary carbon market in Fujian Province is also included in the scope of the pilot study, which permits the examination of results that cannot be obtained through normal double-difference approaches.

3. Theoretical analysis and hypotheses

3.1. Emission reduction and synergistic effects of carbon trading

Reducing pollutant emissions and improving air quality are the foundation of carbon emission trading policy. The China's carbon trading market is divided into primary and secondary market. The primary market allocates carbon emissions, based on economic development and ecological targets. Therefore, the distribution is policy bias, it will reduce emissions for industries with high energy consumption, high pollution, high emission and excess production capacity. The secondary market is a carbon trading platform for emission control enterprises. Enterprises whose actual emissions are higher than their allocated allowances must purchase additional emissions from other enterprises whose actual emissions are lower than their allocated allowances, or else they will be severely penalized by the regulatory authorities. Therefore, the enerprises will spare no effort to reduce carbon emissions so as to diminish production costs and obtain extra carbon emission benefits. In the sametime, this will promote the improvement of regional air quality through synergistic effect of emission reduction[xix].

Hypothesis 1: Carbon emission trading policy can significantly promote carbon emission reduction.

Hypothesis 2: Carbon emission trading policy has a synergistic emission reduction effect.

3.2. The channels of carbon emission trading in reducting carbon emission

3.2.1 Intermediary effect of green technology innovation

According to the "Porter hypothesis", reasonable and strict environmental regulations will force enterprises to carry out technological innovation. Such innovation activities can offset the environmental protection costs of enterprises and improve their profitability, resulting in the "innovation compensation effect" [xx] . Carbon emission trading imposes high "environmental compliance costs" on enterprises by restricting their emissions and regulating their emission behaviors. Moreover, the supply and demand of carborn emission rights cause the fluctuation of carbon price[xxi]that compounds uncertainties of corporate management. Therefore, in order to pursue high profits and hedge risks, the constrained enterprises must increase green technology innovation, introduce green production processes, and innovate industrial technology, reducing the pollutants emissions[xxii]and production costs.

Hypothesis 3: Carbon emissions trading policy reduce carbon emission by enhancing the innovation of green technology.

3.2.2 The intermediary effect of industrial structure upgrading

The market mechanism obliges industrial structures to upgrade through carbon emission trading[xxiii]. While industrial structure upgrading is a crucial way to transforming the development of economic and achieving reduction effcect as well as constructing the ecological civilization. Industrial structure upgrading is generally divided into advanced industrial structure and rationalisation of industrial structure[xxiv]. According to the research conducted by several scholars, advanced industrial structures is regarded as an important strategy for reducing emissions in carbon trading policies. Looking closely at advanced industrial structures, it's a gradual progress from primary sector dominance to secondary and tertiary sectors in quantity; While it's a transformation from low-level industries, which are labour-intensive, to high-value-added industries with technology and knowledge in quality. Carbon emissions trading mainly triggers the development of green enterprises that focus on low energy consumption and high levels of technology through the market mechanism. As a result, it diminishes the petential profit of enterprises of high-energy-consuming and high-polluting. The rationalization of the industrial structure refers to the process to develop the input and output structures of production factors simultaneously. This process is essential for the gradual transformation between industries. However, the carbon emissions trading policy will prompt capital and production factors towards green industries through market mechanisms, which disrupts the original factor structure. Consequently, it is not suitable for rationalization and advancement of the industrial structure and may hinder Industrial structure upgrading[xxv]. Nonetheless, this policy does not prevent the promotion of carbon reduction through industrial structure upgrading.

Hypothesis 4: Carbon emission trading promotes carbon emission reduction through industrial structure upgrading.

4. Data and model specification

4.1. Identifcation strategy

The main topic of this paper is to determine if the carbon emission right trading policy can effectively reduce carbon emissions. Due to the different launch times of the pilot carbon trading markets, this paper uses the multi-period dual difference method to evaluate how the impact of carbon emission trading policy affects regional carbon emissions. By keeping other facts unchanged, the multi-stage dual difference method can determine if there is a significant difference in carbon emissions between pilot areas and non-pilot areas before and after the implementation of the carbon emission trading policy. The multilevel dual-difference model is shown below:

$$CO_{2_{i,t}} = \alpha_0 + \beta_0 \times DID_{i,t} + \gamma_0 Control_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \tag{1}$$

In Equation(1), t represents the year, and i represent the city. $CO_{2_{i,t}}$ is the dependent variable of this study, indicating carbon dioxide emissions in city i in year t. $DID_{i,t}$ reflects the core independent variable, measureing the difference in carbon dioxide emission between the pilot and non-pilot areas before and after the implementation of the policy. If $\beta_0 < 0$, it indicates that the carbon emissions trading policy can reduce the emissions of CO_2 in the pilot area, otherwise it has negative influence on the emission.The multi-period double-difference variable $DID_{i,t} = treatment_i \times post_{i,t}$, $treatment_i$ indicates if city i is a treatment group, if it is, the value is 1; otherwise, it is 0. And $post_{i,t}$ indicates whether city i opens the carbon market in year t or not. $Control_{i,t}$ represents a set of control variables. u_i denotes city-level fixed effect, controlling for city-level factors that do not change over time; λ_t is time fixed effects, controlling for time-level factors that do not change over time and over time. $\varepsilon_{i,t}$ represents a random disturbance term.

4.2. Variables

4.2.1 Dependent variable

In this paper, the total amount of carbon dioxide emissions (CO_2) at the prefecture-level city is considered as the dependent variable. Based on the carbon emission data of 2735 counties in China from Chen et al.(2020) 1997 to 2017, the carbon dioxide emissions at the county level are aggregated and associated with the prefecture-level city. Through linear interpolation, the carbon emission of 283 cities from 2006 to 2019 is obtained in the logarithmic form.

4.2.2 Dependent variables

The core independent variable in this paper is the policy dummy variable (DID).In 2011, China's National Development and Reform Commission issued the Notice on Carbon Emission Trading Pilot Work, the document proposes that seven provinces and cities, namely Guangdong, Hubei, Shenzhen, Beijing, Tianjin, Shanghai and Chongqing will be used as the pilot of carbon emission trading, and since then, the regions have carried out preparatory work for the establishment of the carbon emission trading market, leading to the launch of carbon trading markets in multiple provinces and cities: Shenzhen (Jun. 2013), Beijing (Nov. 2013), Tianjin, Shanghai, and Guangdong (Dec. 2013), and Hubei and Chongqing (Apr. and Jun. 2014, respectively). In addition, the Fujian Provincial carbon emission trading market was officially launched in Dec. 2016. Therefore, if $t \geq 2013$ and i is Beijing, Tianjin, Shanghai and Guangdong Province, $post_{i,t} = 1$; if $t \geq 2014$ and i is Chongqing and Hubei Province, $post_{i,t} = 1$; if $t \geq 2016$ and i is Fujian Province, $post_{i,t} = 1$; otherwise $post_{i,t} = 1$. To address potential serial correlation and heteroskedasticity, this paper reports robust standard errors for province clustering.

4.2.3. Control variables

As carbon emissions are closely linked to regional economic development levels, and in order to ensure greater comparability between the control and treatment groups, This paper controls for heterogeneity in the following ten dimensions(Wu et al.,2021)[xxvi]: level of local economic development, industrial structure, economic structure, degree of economic agglomeration, degree of openness to the outside world, level of finance, level of energy consumption, level of transportation development, level of technological development and degree of environmental protection. Specifically, ① Level of local economic development, measured through the logarithm of GDP (GDP) and GDP per capita ($PGDP$); ② Industrial structure, measured by the ratio of output value of secondary industry to total output value ($STRIND$); ③ Economic structure, measured by the ratio of social retail sales to GDP ($STRLS$);④ Degree of economic concentration, measured by population density (POP); ⑤ Degree of openness, measured in logarithmic form of Foreign Direct Investment (FDI); ⑥ Financial level, measured through the logarithmic form of regional government fiscal tax revenue (TAX); ⑦ Energy consumption level, measured through total energy consumption ($ENERGY$) and energy consumption intensity ($PENERGY$), with the latter calculated by dividing total energy consumption by regional GDP; ⑧ Traffic development level, measured by per capita road area ($ROAD$); ⑨ Technological advancement, measured in the logarithmic form of regional government science and technology financial expenditure ($TECH$); ⑩ Degree of environmental protection, measured through regional green coverage rate ($GREEN$).

Table 1. Descriptive statistics of variables

Variables	Observations	Mean			Std. Dev.	Min	Max
		Total	Treatment Group	Control Group			
CO_2	3962	3.030	3.101	3.017	0.766	1.340	4.843
DID	3962	0.071	0.438	0.000	0.257	0.000	1.000
GDP	3962	7.066	7.530	6.976	1.011	3.950	10.550
$PGDP$	3962	1.790	2.071	1.735	0.611	0.279	3.993
$STRIND$	3962	47.890	46.98	48.070	10.910	11.700	90.970
$STRLS$	3962	36.550	41.43	35.600	10.650	0.003	99.580
POP	3962	3.856	3.478	3.929	2.791	0.248	20.090
FDI	3962	2.681	3.375	2.546	1.581	0.002	7.625
TAX	3962	13.570	14.020	13.48	1.209	9.722	18.090
$ENERGY$	3962	0.016	0.035	0.013	0.032	0.000	0.4220
$PENERGY$	3962	0.093	0.076	0.097	0.290	0.004	14.900
$ROAD$	3962	1.198	1.274	1.183	0.855	0.033	11.040
$TECH$	3962	8.928	10.010	8.718	1.976	0.693	15.530
$GREEN$	3962	38.470	40.140	38.140	6.568	2.500	71.810

4.3. Sample and data

This paper utilizes panel data from 283 prefecture-level Chinese cities between 2006 and 2019 to evaluate the carbon emission reduction effects of carbon emissions trading policies. The sample excludes the Tibet Autonomous Region, Turpan City, Hami City, Haidong City, Tongren City, Bijie City, Danzhou City, Sansha City, Suihua City, Qinzhou City, and Chaohu due to their serious data deficiencies.

Carbon emissions data are obtained from the China Carbon Accounting Data (Chen, 2020) while control variables data are sourced from the China City Statistical Yearbook and EPS database. Apart from the databases mentioned above, additional data on mediating effects are obtained from the State Intellectual Property Office and CNRDS database.

5. Empirical results

5.1. Baseline regression results

Using the multi-period DID method, we aim to examine the causal relationship between carbon emission trading pilot and emission reduction effect. The baseline regression results are presented in Table 2. It is crucial to note that only the core independent variable, city fixed effects, and time fixed effects are included in the regression equations of Column (1). Control variables are subsequently added to enhance the model in the regression equations of Column (2) and Column (3). The estimate of Column (1) and Column (2) indicates that coefficient are significantly negative and after control with the coefficients after adding the control variables being -0.086 at the 1% level. Considering the carbon peaking and carbon neutrality goals, the paper also regressed the carbon emission intensity, and Column (3) shows that the policy has not significantly affected the carbon emission intensity. Hence, the hypothesis 1 is verified

Table 2. Results of benchmark regression.

Variable	(1) CO_2	(2) CO_2	(3) PCO_2
DID	-0.084**	-0.086***	0.013
	(-2.755)	(-2.938)	(1.117)
$STRIND$		0.001	0.000
		(0.360)	(0.572)
$STRLS$		-0.002	-0.000
		(-1.678)	(-0.261)
GDP		0.164**	-0.160***
		(2.424)	(-5.563)
$PGDP$		-0.016	0.012
		(-0.347)	(0.739)
$ROAD$		0.036**	0.003
		(2.259)	(0.556)
POP		-0.002	-0.001
		(-0.815)	(-1.129)
FDI		-0.011	-0.006
		(-1.514)	(-1.662)
TAX		0.005	-0.002
		(0.154)	(-0.119)
$TECH$		0.007	0.008**
		(0.929)	(2.524)
$GREEN$		0.001	-0.001
		(1.570)	(-1.663)
$ENERGY$		-1.823**	0.227
		(-2.472)	(1.190)
$PENERGY$		0.053**	-0.006
		(2.162)	(-0.807)
Constant	3.036***	1.817***	1.309***
	(1,401.538)	(4.608)	(6.362)
City fixed effect	YES	YES	YES
Year fixed effect	YES	YES	YES
Observations	3,962	3,962	3,962
R^2	0.985	0.987	0.929

Note: The values in parentheses are the province-level clustering standard error, and *, * *and *** indicate the significance levels of 10%, 5% and 1%, respectively. The following tables are the same.

5.2. Parallel trend test

the parallel trend assumption is the prerequisite of the multi-period DID which means that treatment and control groups must experience similar changes before the policy shack while experiencing different changes after the policy shack because the impact of the carbon trading policy on carbon dioxide emissions will only be felt in the pilot areas. To test the parallel trend hypothesis, this paper uses the methodology developed by Jacobson et al.[xxvii] , the model is as follows:

$$CO_{2_{i,t}} = \alpha_0 + \sum_{t=-4}^{6} \delta_t \times DID_{i,t} + \gamma_0 Control_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (2)$$

In Equation(2), $DID_{i,t}$ is the dummy variable for the interaction term of policy, if the region i implements the carbon emission trading policy in the year t, then $DID_{i,t} = 1$, otherwise $DID_{i,t} = 0$. The meaning of the remaining variables are the same as that in Equation (1). δ_t is the core variable we need to focus on, when $\delta_t$is not significant, the two groups have same changing trends, otherwise the two group tend to be very different.

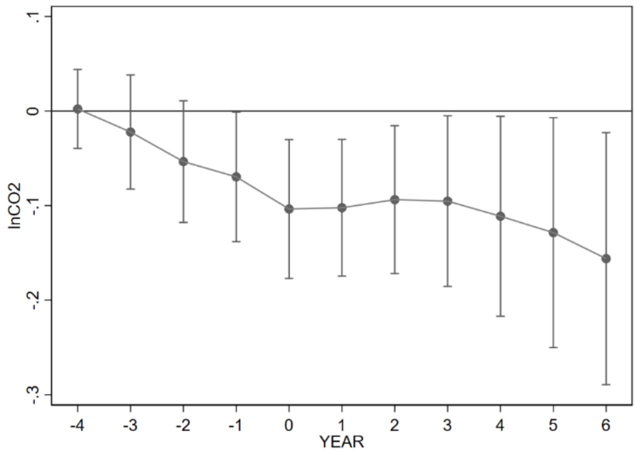

Figure 2. Parallel trend test based on dynamic effect.

Due to the scattered time points of the policy, this paper collates the data from the 4 years prior to policy implementation as the -4th period, and the data from the 6 years after the policy implementation as the 6th period, using the policy implementation's 4th period as the benchmark year. The Figure 2 shows that the coefficients of interaction terms are not significant before the benchmark year but are significant after the benchmark year, which means treatment and control group have same changing tends before and became difference after the benchmark year. This reveals that the carbon dioxide emissions trends in the treatment and control group satisfy the parallel trend hypothesis.

5.3. The placebo test

We employed a placebo test to eliminate potential confounding variables from affecting the outcomes. We used the approach of Cai et al(2016)[xxviii] to perform a non-referential substitution test. Specifically, we randomly selected 123 cities as false treatment group, while the other cities as false control group. In order to acquire the estimated coefficients of DID, the above procedure was repeated for 500 times. The kernel density distribution and p-value of the estimated coefficients are shown in Figure 3. The regression coefficients are always around 0, following a normal distribution, and most of the regression results are not significant. The coefficients in the benchmark regression are at the high tail of the false regression coefficient distribution, which is a small probability event in the placebo test. Hence, the phase baseline regression results pass the placebo test.

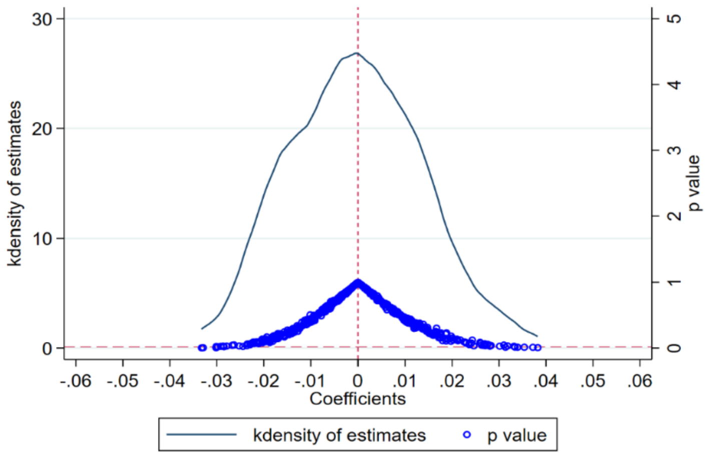

Figure 3. The placebo test.

5.4. Other robustness test

The benchmark regression results show that the pilot policy of carbon emission right trading significantly promotes the regional carbon emission reduction. However, in order to eliminate the interference of confounding factors on the research results, this paper conducted a series of robustness tests, respectively from multiple dimensions such as sample data screening, the interference of other policies during the study sample and the impact of alleviating the selection of adding benchmark variables.

5.4.1 Sample data screening

In order to avoid the influence of extreme values on the baseline regression, dependent variable was winsorized at the 1% and 99% quantiles and 5% and 95% quantiles, respectively. The regression results are shown in columns (1) and (2) of Table 3. After excluding the extreme values, the estimated coefficients are significant and similar to the baseline regression.

5.4.2 Consider the competition policy during the same period

Other related environmental policies will affect the final effect estimates during 2006-2019. Based on this, we choose the 2010-2017 low-carbon city pilot policy, the 2012 12th Five-Year Plan for the Prevention and Control of Air Pollution in key regions, and the 2010 pilot policy on new-energy vehicle subsidies. To avoid the interference of other related policies during the same time, dummy variables for relevant policies are added in the benchmark regression equation. If the area is a low-carbon city pilot during that time, then the dummy variable is 1,or is 0; if the key area of air pollution control in those years, then the dummy variable is 1,or is 0; if the area belongs to the pilot city of new energy vehicle subsidy at those time, then the dummy variable is 1,otherwise is 0. The results are shown in Table 3 columns (3)~(6), and the coefficient is still significant at the 1% level and similar to the benchmark regression, indicating that other environmental policies do not bias the final estimator of carbon trading policies.

Table 3. Robustness tests I.

Variable	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2
	winsorize1%	winsorize5%	Consider the competition policies during the same period.			
	(1)	(2)	(3)	(4)	(5)	(6)
DID	-0.085***	-0.062**	-0.084***	-0.091***	-0.085***	-0.091***
	(-2.930)	(-2.175)	(-2.902)	(-3.625)	(-2.937)	(-3.524)
Constant	1.779***	2.064***	1.778***	1.780***	1.779***	1.779***
	(4.672)	(5.424)	(4.692)	(4.780)	(4.661)	(4.791)
Low carbon city			YES	NO	NO	YES
Key pollution control areas			NO	YES	NO	YES
New energy automobile			NO	NO	YES	YES
Control variables	YES	YES	YES	YES	YES	YES
City fixed effect	YES	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES	YES
Obeservations	3,962	3,962	3,962	3,962	3,962	3,962
R^2	0.987	0.985	0.987	0.988	0.987	0.988

5.4.3 The inclusion of benchmark variables mitigate the impact of selection

The ideal pilot choice of multi-point double difference is random, while the choice of carbon emission trading pilot policy may be affected by the local history, economy and geographical location, and these factors will have different effects on carbon emissions over time, thereby biasing the results. In order to avoid the influence of non-randomness in the pilot policy selection of carbon emission trading policy, this paper draws on Song Hong et al.(2019) [xxix] and incorporates the interaction term between urban benchmark factors and linear trend practice into Equation. (1). The specific model is as follows:

$$CO_{2_{i,t}} = \alpha_0 + \beta_0 \times DID_{i,t} + \gamma_0 Control_{i,t} + \xi Q_c \times trend_t + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (3)$$

In Equation(3), Q_c indicate the geographical location, political and economic characteristics, including whether the city is a provincial capital city, whether it is a special economic zone, whether it belongs to the pilot city of "two control zones" in 1998 and whether it is located on the east side of Hu Huanyong Line. $trend_t$ is the temporal linear trend. Therefore, $Q_c \times trend_t$ controls the influence of variations in cities on carbon emissions from a linear viewpoint, thereby reducing the bias in estimates resulting from the non-randomization of the control group.

Table 4. Robustness tests Ⅱ.

Variable	CO_2	CO_2	CO_2	CO_2	CO_2
	Inclusion of benchmark variables mitigate the impact of selection				
	(1)	(2)	(3)	(4)	(5)
DID	-0.077**	-0.081***	-0.094***	-0.067**	-0.067**
	(-2.671)	(-2.829)	(-3.213)	(-2.355)	(-2.419)
Two control area×Time trend	YES	NO	NO	NO	YES
Provincial capital cities×Time trend	NO	YES	NO	NO	YES
Special economic zone×Time trend	NO	NO	YES	NO	YES
Hu Huanyong line×Time trend	NO	NO	NO	YES	YES
Constant	9.039**	0.482	0.998	48.751**	51.355**
	(2.527)	(0.618)	(1.412)	(2.541)	(2.715)
Control variables	YES	YES	YES	YES	YES
City fixed effect	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES
Obeservations	3,962	3,962	3,962	3,962	3,962
R^2	0.988	0.987	0.988	0.988	0.989

According to the results of Table 4, after adding the interaction terms of urban benchmark variables and time linear trends, the estimated coefficients of DID are still significantly negative whether added one by one or all, and the carbon emission trading policy significantly promotes carbon emission reduction, which is consistent with the benchmark regression results.

5.5. Synergistic effect

The other air pollutants, such as SO_2 and $PM_{2.5}$,have the same origin as carbon emissions, therefore, the carbon emission trading policy may reduce the emission of other pollutants, having the synergistic reduction effect. Results are shown in Table 5, this policy can indeed significantly impact on reducing annual sulphur dioxide emissions and average annual concentrations of $PM_{2.5}$, which is the support for the implementation of the carbon emission trading pilot policy. Hence, the hypothesis 2 is verified.

Table 5. Synergistic effect.

variable	(1) SO_2	(2) $PM_{2.5}$
DID	-1.732**	-0.399***
	(-2.263)	(-3.058)
Constant	70.674***	6.308***
	(5.311)	(3.685)
Control variables	YES	YES
City fixed effect	YES	YES
Year fixed effect	YES	YES
Obeservations	3,906	3,962
R^2	0.949	0.850

6. Mechanism analysis

Base on the above results, the carbon emissions trading policy play an important role in carbon emission reduction and pollution control. What are the exact pathways through which carbon trading contributes to the carbon emission reduction? On the basis of the theoretical hypothesis, this policy may reduce the carbon emission through two pathways: green technology innovation and industrial restructuring.

To elucidate the path of influence, we utilized the mediating effect model to scrutinize the mechanism of influence. We considered two mediating variables for discussion: green technology innovation and industrial structure upgrading. The model is structured as follows. [xxx]

$$M_{i,t} = \alpha_0 + \beta_1 DID_{it} + \gamma_1 Control_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (4)$$

$$CO_{2it} = \alpha + \beta_2 \times DID_{it} + \beta_3 M_{i,t} + \gamma_2 Control_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (5)$$

In Equation (4) and (5), $M_{i,t}$ is the intermediary variable, which specifically indicates the green technology innovation and industrial structure upgrading of each city. First, to test whether the policy has an influence on carbon emission we need to regress Equation (1), and in the baseline regression already reveals that the policy does reduce the carbon emissions. Second, Equation (4) was used to examine the effect of the policy on the mediating variables. If the coefficient of mediating variables β_1 proved significant, the policy has something to do with the mediating variable. Third, we need to pay attention to β_2 and β_3 in Equation (5), t carbon emission trading can achieve carbon emission reduction through the above two intermediary variables if both of them are significant.

6.1. Green technology innovation

The development of green technology is the fundamental motivation of effective carbon emission trading policy. According to the Porter hypothesis, a carbon emission trading policy could stimulate technological innovation, reduce pollutant emissions, and promote regional air quality improvement. In this paper, We categorise green technology innovation into quantitative and qualitative dimensions. The quantity of green technological innovation is measured by the number of green invention applications (GI_1) and green utility model patent applications (GU_1); the quality of green technological innovation is measured by the number of green invention grants (GI_2) and green utility model patent grants (GU_2).

According to Column(1)(3)(5)(7) in Table 6, the coefficients of green invention applications, green utility model patent applications, green invention grants and green utility model patent grants are significantly positive at 1% level, which indicates that this policy contribute to the quantity and quality of green technological innovations. It also reveals that carbon emission trading policy promote enterprises and the government pay more attention for green technology innovation output and improve pollutant processing capacity so as to avoid the increase of excess production costs. Table 6 Column(2)(4)(6)(8) demonstrate that green technology innovation is an important pathway for carbon emission trading policy to reduce carbon dioxide emission. All of them are significantly negative at the level of 1%, which significantly promotes carbon emission reduction in both quality and quantity. Hence, the hypothesis 3 is verified.

Table 6. Mechanism Test Results I

Variable	GI_1	CO_2	GU_1	CO_2	GI_2	CO_2	GU_2	CO_2
	The amount of green technology innovation				The quality of green technology innovation			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
DID	0.265***	-0.073***	0.286***	-0.071***	0.070***	-0.075***	0.237***	-0.071***
	(3.418)	(-3.557)	(4.700)	(-3.478)	(3.201)	(-3.646)	(4.904)	(-3.464)
GI_1		-0.031***						
		(-5.242)						
GU_1				-0.034***				
				(-4.279)				
GI_2						-0.090***		
						(-4.398)		
GU_2								-0.042***
								(-4.170)
Constant	0.994**	-4.893***	0.605**	-4.903***	0.284**	-4.898***	0.496**	-4.903***
	(2.093)	(-27.737)	(2.196)	(-27.829)	(2.052)	(-27.746)	(2.218)	(-27.808)
City fixed effect	YES	YES	YES	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES	YES	YES	YES
Obeservations	3,962	3,962	3,962	3,962	3,962	3,962	3,962	3,962
R^2	0.604	0.872	0.552	0.872	0.668	0.872	0.581	0.872

6.2. Industrial structure upgrading

Industrial structure upgrading is the ultimate purpose of carbon emissions trading which mainly refers to the advanced industrial structure. Carbon emission trading reduces emissions and enhances air quality through promoting the development of intensive enterprises, guiding the transformation of high energy-consuming enterprises, fostering the coupled development of industry and employment, and facilitating the efficient allocation of resources among production sectors.

Industrial structure advanced (AIS) refer to Yuan et al.(2018)[xxxi], the specific calculation formula is as follows:

$$AIS_{i,n,t} = \sum_{n=1}^{3} Y_{i,n,t} \ , n = 1,2,3 \tag{6}$$

In Equation (6), $Y_{i,n,t}$ denotes the gross product of n industriey in region i in period t. By assigning values to primary, secondary and tertiary industries to measure the degree of advanced industrial structure of different regions.

Industrial structure rationalization (RIS), draw on Gan et al. (2011) [xxxii], the model is as follows:

$$RIS_{i,n,t} = \left| \frac{Y_{i,n,t}/L_{i,n,t}}{Y_{i,t}/L_{i,t}} - 1 \right|, n = 1,2,3 \tag{7}$$

In Equation (7), $Y_{i,n,t}$ is the same as Equation (6). $L_{i,n,t}$ refers to the employment rate of industry n in city i in year t. $Y_{i,t}$ is the GDP in city i in year t. And $L_{i,t}$ denotes the total employment in city i in year t. The rationalization of industrial structure reflects the degree of rational industrial development attained through a coupling between industrial structure and employment structure.

According to Column(1)(3) in Table 7, carbon emission trading considerably inhibits the upgrading of industrial structure. This may because the allocation of green factors and the increase in labour productivity disrupt the movement and allocation of the initial production factors, resulting in obstructions to the rationalization and upgrading of the industry. Column(2)(4) shows that through the rationalization and upgrading of industrial structure this policy considerably promotes the reduction of carbon emissions. Hence, the hypothesis 4 is verified.

Table 7. Mechanism test results Ⅱ

Variables	AIS	CO_2	RIS	CO_2
	Industrial structure advanced		Industrial structure rationalization	
	(1)	(2)	(3)	(4)
DID	-0.029***	-0.104***	-0.175***	-0.086***
	(-4.956)	(-4.965)	(-3.923)	(-4.075)
AIS		-0.785***		
		(-12.478)		
RIS				-0.030***
				(-2.803)
Constant	1.535***	-3.719***	0.924***	-4.896***
	(42.487)	(-20.288)	(3.097)	(-27.534)
City fixed effect	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES
Obeservations	3,962	3,962	3,962	3,962
R^2	0.769	0.876	0.504	0.871

7. Heterogeneity Analysis

7.1. Differences in economic development

Table 8. Analysis of the heterogeneity

variable	CO_2	CO_2	CO_2	CO_2	CO_2
	eastern	central	western	Strong environmental regulation	Weak environmental regulation
	(1)	(2)	(3)	(4)	(5)
DID	0.000	-0.118**	-0.121	-0.107***	-0.065**
	(0.005)	(-2.787)	(-1.705)	(-3.469)	(-2.302)
Constant	1.236**	1.550	2.572***	1.606***	1.443***
	(2.442)	(1.695)	(4.205)	(3.776)	(3.360)
Control variables	YES	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES
Obeservation	1,680	1,120	1,162	2,113	1,829
R^2	0.989	0.991	0.988	0.989	0.989

The economic development levels, geographical locations, and resource endowments vary greatly across regions, which will also variations in the effectiveness of carbon emission trading policies. Therefore, 283 prefecture-level cities are divided into eastern, central and western regions according to the economic development. As is shown in Column (1)~(3) of Table 8 , the carbon emission trading policy on reducing carbon emissions varies from region to region. It does not have significant impact in the eastern region while have vital influence in central. The reason is that the central region's economic development pattern remains largely unsophisticated. What's more, this policy has a significant effect mainly on polluting enterprises who have high energy consumption, high pollution, and high emission. The economic development and low-carbon policy in the eastern region of China, being the pilot areas, have acchive remarkable achievements in ecological civilisation. Also, industrial transformation is in the mid to late stages, with the emission reduction potential being limited. While, the opposite is true in the central region,which is in a critical period of economic transformation. As a result, the carbon emission trading policy doesn't had a substantial effect in reducing emissions in the eastern region which is totally different from the central region. The policies in the west have the comparable impact as east on decreasing emissions, however, it may caused by policy lag.

7.2. Differences in environmental regulation intensity

The effect of emissions reduction may differ depending on the degree of environmental regulation adopted by companies. Therefore, this paper draws on Chen et al. (2018) [xxxiii] and Wang et al.(2017) [xxxiv], regarding the frequency of key environmental words in government work reports [2] as environmental regulation intensity.We set the tatal median frequence as boundary point, if the frequency of key environmental words in government work reports over median, it belongs to strong environmental regulation, otherwise is weak environmental regulation. According to Column (4) and (5) of Table 8, environmental regulation reduces carbon emissions, regardless of its strength. However, the coefficient of strong environmental regulation is significantly higher than weak environmental regulation, demonstrating that the influence of carbon emission reduction is more pronounced when the environmental regulation is stronger. On the one hand, the carbon emissions trading policy makes use of the market mechanism to increase the pressure on the emission costs of enterprises. On the other hand, intensing governmental supervision and fines compel enterprises to

[2]Key environmental word frequency can be mainly classified into several categories, including environmental protection (such as controlling pollution, promoting green development, improving air quality, etc.), environmental pollution (including sulphur dioxide, dust, waste, etc.), energy consumption (involving recycling, intensive practices, clean energy, etc.), synergistic development and environmental co-governance (covering synergistic governance, joint defence, complementary advantages, etc.), and other areas (such as returning farmland to forests, establishing ecological barriers, improving river systems, etc.).

invest in environmental governance, reduce pollutant emissions, and decrease the cost of pollutant discharge.

8. Conclusions and discussions

8.1. Conclusions

The policy of carbon emission trading is one of the most essential environmental policies to achieve the target of carbon peak and carbon neutrality, playing an vital role in reducing carbon dioxide emissions. This research studies the effect of carbon emission reduction and synergistic emission reduction of the policy. Moreover, the paper analyzes the heterogeneity of the policy sorted by different economic regions and intensities of environmental regulation. The summaries are as follows:

Firstly, the carbon emission trading policy can significantly promote the reduction of carbon emissions, while it doesn't work in reducing the intensity of carbon. We conducted parallel trend test that is the prerequisites of the DID and the basis for observation the performance of the reducion effect. It reveals that the policy can significantly promote the reduction of carbon emissions from the first year of policy implementation, and the effect increases with more pilots established and more experience accumulated. Through a series of robustness tests, such as placebo test, sample data screening, exclusion of competition policies during the study period and inclusion of a benchmark variable to mitigate the effects of selection, the benchmark regression remains significiant.

Secondly, the policy promotes a synergistic emission reduction effect besides carbon emission effect, which significantly promotes the reduction of sulfur dioxide emissions and the average annual concentration of $PM_{2.5}$.

Thirdly, the heterogeneity analysis indicates that the emission reduction effect will have different effects due to different economic regions and degrees of environmental regulation intensity. The heterogeneity of economic region reveals that the policy enhanced the ability to reduce emission in the central region, but had no significant influence in the eastern and western regions. Furthermore, the heterogeneity analysis about the intensity of environmental regulations shows that environmental regulations are able to significantly promote the reduction of carbon emissions. Nevertheless, strong environmental regulations play a more significant role compared to weak environmental regulations. Fourthly, the mechanism analysis demonstrates that the carbon emission trading policy develops rapidly through the advancement of green technology and the adjustment of industrial structure in quantity and quality.

8.2. Policy Recommendations

Following the above discussions, this paper proposes three policy recommendations to promote carbon emission trading policy, reduce carbon emissions, and achieve the carbon peak and carbon neutrality goals.

First of all, it is time to take advice of expanding the carbon emission trading market and put special emphasis on the improvement of carbon trading market system to establish the emission market in advance throughout the country. Based on the emission reduction effect in pilot areas, it is predictable that the causes of green and low-carbon circular has a promising future. Therefore, spreading carbon trading market knowledge and providing related trainings in the pilot areas is a upernacular way to promote policy. Only in this way can the policy attracts more businesses to participate. Furthermore, share the development experience can be exchanged between different the regions, which is beneficial for eliminating trading barriers, and establishing the free transaction of carbon elements, and promoting the construction and development of carbon trading market.

Secondly, in implementing carbon emission trading policy, greater consideration should be given to the central region and the intensity of regional environmental regulation. The market for carbon emission trading should be developed according to local conditions. Therefore, it is advisable to prioritize the deployment and development of the central carbon trading market, perfect the design of central policy, accelerate the establishment of systems, decrease the risk of market, making full use the market mechanism to encourage enterprise to transformate and upgrade. The western region should also speed up the establishment of carbon trading market and deepen the implement of carbon emission trading policy harmoniously. For governments, focusing on different dimensions and areas of environmental protection in the region, such as strengthening supervision on pollutant emissions, introducing clear reward and punishment policies, encouraging companies to innovate in green technologies, improving pollution facilities, and recruiting talents etc. All in all, combine market mechanisms and government regulations to implement carbon emission trading strategies.

Third, pathways of the carbon emission trading need unblocking. In green technology innovation pathway, the government should increase financial and policy support, actively trigger companies to carry out innovative research and develop green technology, improving the conversion rate of green technology achievements continuously. As the adjustment of industrial structure, policies that support industrial development should be issued, focusing on the transformation and upgrading of manufacturing industries, stimulating development of productive services, ensuring the channel of labour factors, promoting the optimal allocation of production factors among different departments, coupling development of factors and industries, and advancing the upgrading and rationalisation of industrial structure.

References

[1] Liu, L.;Chen, C.;Zhao, Y.;Zhao, E. China′s Carbon-Emissions Trading: Overview, Challenges and Future.Renewable and Sustainable Energy Reviews.2015,(49):254-266.

[2] Chai, S.;Sun, R;Zhang, K.;Ding, Y.;Wei, W. Is Emissions Trading Scheme an Effective Market-Incentivized Environmental Regulation Policy?Evidence from China’s Eight ETS Pilots. International Journal of Environmental Research and Public Health.2022,19(6).

[3] Hu,J.;Fang, Q.;Long, W. Carbon Emission Regulation, Corporate Emission Reduction lncentive and TotaFactor Productivity: A Natural Experiment Based on China’s Carbon EmissionTrading System. Economic Research.2023,58(04):77-94.

[4] Wu, L.;Qian, H.;Tang, W. Selection Mechanism between Emission Trading and Carbon Taxbased on Simulation of Dynamic Marginal Abatement Cost. Economic Research,2014,49(09):48-61+148.

[5] Shi, M.;Yuan, Y.;Zhou, S.;Li, N. Carbon Tax, Cap-and-Trade or Mixed policy:Which is Better for Carbon Mitigation?Journal of Management Science in China.2013,16(09):9-19.

[6] Liu, H.;Zhong, Y. Carbon trading and "Carbon Tax" Emission Reduction Effect and Action Path. Commercial Research,2023(01):98-107.

[7] Brink, C.;Vollebergh, R H;Werf, D V E.Carbon Pricing in the EU: Evaluation of Different EU ETS Reform Options. Energy Policy.2016,97.

[8] Li, W.;Jia, Z.Carbon Tax, Emission Trading, or the Mixed Policy:Which is the Most Effective Strategy for Climate Change Mitigation in China?Mitigationand Adaptation Strategies for Global Change.2017.

[9] Cui L.;Fan Y.;Zhu, L. How Will the Emissions Trading Scheme Save Cost for Achieving China’s 2020 Carbon Intensity Reduction Target?Applied Energy.2014,136(C).

[10] Dai H.;Masui, T. Assessing the Contribution of Carbon Emissions Trading in China to Carbon Intensity Reduction.Energy Science and Technology,2012,4(1).

[11] Zhang, Y.;Peng, Y.;Ma, C. Can Environmental Innovation Facilitate Carbon Emissions reduction? Evidence from China. Energy Policy,2017,100.

[12] Yu, W.;Luo, J. Impact on Carbon Intensity of Carbon Emission Trading-Evidence from a Pilot Program in 281 Cities in China.International Journal of Environmental Research and Public Health.2022,19(19).

[13] Li, C.;Qi, Y.;Liu, S.;Wang X. Do Carbon ETS Pilots Improve Cities’ Green Total Factor Productivity?Evidence from a Quasi-Natural Experiment in China.Energy Economics.2022,108:1-9

[14] Du, G.;Yu, M.;Sun, C.;Han Z. Green Innovation Effect of Emission Trading Policy on Pilot Areas and Neighboring Areas: An Analysis Based on the Spatial Econometric Model.Energy Policy,2021,156(1).

[15] Zhang, W.;Li, J.;Li, G.;Guo, S. Emission Reduction Effect and Carbon Market Efficiency of Carbon Emissions Trading Policy in China.Energy,2020,196(C).

[16] Cui, J.;Wang, C.;Zhang J.;Yang, Z. The effectiveness of China's Regional Carbon Market Pilots in Reducing Firm Emissions. Proceedings of the National Academy of Sciences of the United States of America.2021,52.

[17] Liu, C.;Sun Z.;Zhang, J.Research on the effect of carbon emission reduction policy in China's carbonemissions trading pilot. China Population, Resources and Environment.2019,29(11):49-58.

[18] Chen, J.;Gao, M.;Cheng, S.;Hou, W.;Song, M.;Liu, X.;Liu Y.;Shan Y. County-level CO2 Emissions and Sequestration in China during 1997-2017. Scientific data,2020,7(1).

[19] Cheng, B.;Dai, H.;Wang P.;Zhao D.;Masui, T. Impacts of Carbon Trading Scheme on Air Pollutant Emissions in Guangdong Province of China. Energy for Sustainable Development.2015,27.

[20] Porter M E. America’s Green Strategy. Scientific American.1991,264(4):168-264.

[21] Chen, D.;Liao H.;Tan, H. Study on the Emission Reduction Effect and Mechanism of China's Carbon Trading Policy. Technology Economics.2022,41 (7): 106-119.

[22] Goodchild A.; Toy, J. Delivery by Drone: An Evaluation of Unmanned Aerial Vehicle Technology in Reducing CO2 Emissions in the Delivery Service Industry. Transportation Research.2016, 61(PT.A): 58-67.

[23] Cheng, Z.; Li, L.; Liu, J. Industrial Structure, Technical Progress and Carbon Intensity in China's Provinces. Renewable and Sustainable Energy Reviews.2018,81.

[24] Siedenburg, J.; Brown S.; Hoch. S. Voices from the Field-Carbon Markets and Rural Poverty as Seen from Madagascar and Mali. Climate and Development.2016,8(1).

[25] Liu, M.;Cheng, S. Does the Carbon Emission Trading Scheme Promote the Optimization and Upgrading of Regional Industrial Structure? Management Review.2022,34(7):33-46.

[26] Wu, Y.;Qi, J.;Xian, Q;Chen, J. The Carbon Emission Reduction Effect of China's Carbon Market--from the Perspective of the Coordination between Market Mechanism and Administrative Interventior.China Industrial Economics.2021 (08):114-132.

[27] Jacobson, L. S.; La Londe, R. J.;Sullivan, D. G. Earnings Losses of Displaced Workers. The American Economic Review.1993,83(4):685-790.

[28] Cai, X.;Lu, Y.;Wu M.;Lin, Y. Does Environmental Regulation Drive Away Inbound Foreign Direct Investment? Evidence from a Quasi-Natural experiment in China.Development Economics.2016,123.

[29] Song, H.; Sun, Y.; Chen, D. Assessment for the Effect of Government Air Pollution Control Policy: Empirical Evidence from "Low-carbon City" Construction in China. Management World. 2019, 35(06): 95-108+195.

[30] Wen, Z.;Hou J.;Zhang, L. A Comprarison of Moderator and Mediator and Their Applications. Acta Psychologica Sinica.2005,37(2):268-274.

[31] Yuan, H.;Zhu, C.Do National High-Tech Zones Promote the Transformation and Upgrading of China'sindustrial Structure?China Industrial Economics. 2018 (08): 60-77.

[32] Gan, C.;Zheng, R.;Yu, D. An Empirical Study on the Effects of lndustrial Structure on Economic Growth and Fluctuations in China. Economic Research. 2011,46(5):4-16,31.

[33] Chen, S.;Chen, D. Air Pollution, Government Requlations and High-quality Economic Development. Economic Research.2018,53(02):20-34.

[34] Wang, Y.;Li, M. Study on Local Government Attention of Ecological Environment Governance: Basedon the Text Analysis of Government Work Report in 30 Provinces and Cities (2006-2015). China Population, Resources and Environmen, 2017,27(02):28-35.