Effects Evaluation of Carbon Trading Policies in China Based on Difference-in-difference Model

Abstract

Carbon emissions trading system plays a significant role in reducing carbon dioxide emissions. However, due to the limitation of carbon dioxide emission data, the evaluations of the effect of China's carbon emission trading system in the existing literature are limited to the analysis of changes in carbon emissions at the provincial and municipal levels. The marginal contribution of this paper is to study the correlation between the phenomenon of economic and environmental interests of carbon emission reduction at the subordinate district and county levels and the carbon trading pilot policies, so as to provide empirical support for the national carbon emission trading market, which has been officially launched since 2021.

Taking the carbon emission trading pilot policies implemented in seven provinces and cities including Shanghai, Beijing, Shenzhen, Guangdong, Tianjin, Chongqing, and Hubei as the research objects, this paper uses a difference-in-difference model to study the relationship between carbon trading pilot policies and economic and environmental interests in subordinate districts and counties based on the data of more than 300 districts (counties) in China from 2007 to 2017. The results show that when considering several control variables that may affect the results and eliminating the fixed effects of region and time, the carbon emission trading policy has a significant promotion effect on reducing the carbon dioxide emissions of the subordinate districts (counties) of the pilot provinces and cities as well as fulfilling economic dividend.

Key words: carbon emission trading; difference-in-difference method; carbon dioxide

Content

1 Introduction

Tackling global warming problems is one of the most significant challenges for human beings today. As the largest emitter of CO_2, China has taken carbon pricing as a market-oriented policy for reducing its emissions. At the end of 2017, the National Development and Reform Commission (NRCD) announced the implementation of a national carbon trading scheme (ETS) in the power sector, which has initiated eight pilot projects since 2013.

As pilot ETS has already been running for several years, it is essential to understand its current implementation impacts. However, currently, there are few studies on whether pilot ETS has realized environmental and economic interests, and most research is limited to establishing models for simulation analysis, lacking usage of empirical data. Besides, most research has been conducted only at the national, provincial, or city level. Actually, even within the same province or the same city, there can be obvious differences in carbon emissions among counties. Therefore, it is important to research on pilot ETS at the county-level to capture regional heterogeneity and evaluate effectiveness.

Hence, we use a difference-in-difference (DID) econometric model with county-level panel data from 2008 to 2017 to analyze the impacts of ETS in order to provide theoretical support and policy suggestions for improving it and implementing the national unified carbon trading market.

2 Literature Review

Coase has proposed the role of property rights in economic management as early as 1960s, pointing out that the issue of externality can be addressed with the tool of market and property rights definition. Croker (1966) also pointed out the possibility of reducing air pollution by the means of property rights. Later, Dales pointed out that the emission trading system should determine a total amount index of emission on the premise of recognizing the limited environmental resources, legalize the emission rights by law, allocate the emission rights to polluters in the free or paid fashions, commercialize the emission rights, and trade them in the market, so as to achieve the purpose of reducing pollution emissions. By introducing the concept of property rights into the field of pollution control, Dales has laid a solid theoretical foundation for the study of emission trading. This paper sorts out the existing literature from the aspect of environmental and economic effect assessment of emission trading, focusing on reviewing the relevant literature on environmental and economic dividend assessment of carbon trading in China.

2.1 Literature review on environmental effects

2.1.1 Literature review on environmental effects abroad

The successful experience of foreign countries has confirmed that the emission trading mechanism is effective in reducing emissions and realizes the environmental dividend. Stavins (1998) research shows that the emission trading of sulfur dioxide has successfully completed the phased emission reduction targets of the Acid Rain Program in the United States, and the actual emission reduction exceeded the emission reduction targets scheduled in the program. According to the research data of the World Bank, the carbon emission trading system has reduced the carbon emissions by 2%-5% from 2005 to 2007, with an average annual reduction somewhere between 40 million tons to 100 million tons of carbon emissions (Capoor and Ambrosi, 2011). It is found in an empirical study by Abrell and Fare (2011) that the EU carbon emissions trading system successfully achieved carbon dioxide emission reduction. The carbon emission trading mechanism also has an important impact on energy consumption. It is found in the research of Cames and Weidlich (2006) that the carbon emission trading mechanism has affected the technological innovation of emission reduction in German power industry, and changed the fuel for power generation from high-carbon emission fuel to low-carbon emission natural gas, which altered the energy consumption structure.

2.1.2 Literature review on environmental effects in China

It is a question that needs to be answered by empirical test whether the emission trading policy implemented in China has also achieved environmental dividend due to the special macroeconomic market environment and institutional conditions in China. There are few studies on whether the policy has achieved environmental and economic dividends for the carbon emission trading policy in the pilot stage in recent years. And such studies are mostly limited to establishing models for simulation analysis, and less empirical data can be used to support the research conclusions. For example, Tang Ling, Wu Jiaqian et al. have constructed a simulation model of China's carbon emission trading mechanism based on the Multi-Agent model, the research results of which show that the carbon emission trading mechanism can effectively promote China's CO_2 emission reduction. Liu Yu, Wen Danhui, et al. simulated the environmental impact of Tianjin's carbon emission trading pilot system on the whole city by setting up scenarios, the results of which show that Tianjin's carbon emission trading pilot has obvious emission reduction effect.

Since the launch of the national carbon emission trading market is on the agenda, China's carbon trading has gradually attracted more attention of the academic community recently, and new literature which use panel data for empirical analysis can be found. For example, Shen Hongtao, Huang Nan, et al. have studied the impact of China's carbon emission trading policy on CO_2 emission reduction of enterprises and emission reduction mechanism based on the balanced panel data of listed companies from 2012 to 2015. The study found that China's carbon emission trading policy mainly achieves CO_2 emission reduction of enterprises by reducing their total output. However, it uses the index of pollution charges paid by enterprises to measure the level of carbon emission. Since there is no sewage charges for CO_2 emission in China's policies, there are certain errors in using this index. Based on this, this paper uses more accurate CO_2 data inversed from satellite remote sensing night light data to make a quantitative evaluation of the environmental and economic effects of China's carbon emission trading mechanism.

2.2 Literature review on economic effects

2.1.1 Literature review on economic effects abroad

The evaluation of the economic effect of emission trading mechanism is actually a test of the Porter hypothesis. Porter (1991), Porter & Linde (1995) et. al. believe that reasonable and strict environmental regulation can improve economic benefits, and a large number of literatures have verified the Porter hypothesis since it was proposed.

Berman and Bui (2001) empirically analyzed the relationship between air quality regulation and total factor productivity in Los Angeles oil refinery industry from 1982 to 1992. It is found that if an enterprise is a regulated one, its total factor productivity will increase greatly during the sample period, while if an enterprise is an unregulated one, its total factor productivity tends to decline during the sample period. Lanoie et al. (2008) empirically studied the relationship between environmental regulation and total factor productivity, and the results also support the Porter hypothesis. Wang Bing and Wu Yanrui et al. (2008) used Malmquist-Luenberger index method to measure the growth of total factor productivity and its components considering CO2 emissions in 17 APEC regions from 1980 to 2004, and empirically studied the influencing factors of total factor productivity growth under environmental regulation, where it is shown in the results that the total factor productivity level of APEC has increased on average after considering environmental regulation, and the main reason for its growth is the increase of technical level. Chen Shiyi (2010) recalculated the industrial total factor productivity since China's reform by using the directional distance function, and the calculation results show that a series of energy conservation and emission reduction measures implemented by China since the reform have effectively improved the industrial total factor productivity. Li Shu and Chen Gang (2013) used the double difference method to study the effect of the revision of APPCL2000 on the growth of China's industrial total factor productivity. The empirical results show that the revision of APPCL2000 improves the total factor productivity of air pollution-intensive industries and has an increasing marginal effect. Foreign mature emission trading mechanism has verified its role in realizing positive economic effects. Brannlund et al. ((1998) constructed a DEA model to maximize the total profit after introducing emission trading. The research shows that the emission trading mechanism made Swedish paper products and paper industry realize the potential profit growth. Fare et al. (2013) also expanded study on this basis, considering not only the potential economic dividend of emission rights in space trading, but also that in intertemporal trading. Fare et al. (2014) calculated and compared the potential output of coal-fired power plants in the United States when emissions trading for different pollutants was implemented on the basis of previous studies. Borghesi (2015) took manufacturing enterprises as the research object, indicating that enterprises involved in carbon emission trading are more likely to carry out technological innovation in carbon dioxide emission reduction and energy efficiency.

2.1.2 Literature review on economic effects in China

In terms of the economic effect evaluation of China's emission trading mechanism in China, Geng Wei and Xu Shuangshuang (2011) used a static model to study the impact of carbon trading mechanism on technological level while achieving carbon dioxide emission reduction. On this basis, they studied the change of carbon emission trading policy on technological innovation incentives after the increase of technological level. It is found in the research results of Qiu Lei (2013) that the carbon emission trading mechanism can improve the strength of enterprises to develop low-carbon energy-saving technologies, and the incentive effect is stronger than the carbon tax policy. Ren Songyan, Dai Hancheng, etc. (2015) analyzed quantitatively the economic impact of the policy mechanism of carbon emission trading with controllable total amount on Guangdong Province and participating trading departments by constructing a dynamic model. When setting and analyzing the emission reduction scenarios, it is shown in the results that the implementation of carbon emission trading policy in Guangdong Province can reduce GDP loss by about 9 billion yuan, and the establishment of carbon emission trading mechanism in Guangdong can effectively play a win-win role in supporting economic development and saving energy and reducing carbon. Zhou Shenglu (2015) applied CGE model to simulate the impact of carbon emission trading mechanism on traditional pollutant emissions and economy under different employment conditions, indicating that if other industries can absorb and digest the labor released by carbon trading management industry in time, carbon emission trading will have an overall positive impact on GDP, and the carbon emission trading mechanism will achieve double dividends. If other industries can't absorb and digest the labor released by carbon trading management industry in time, carbon emission trading will have an overall negative impact on GDP. Liu Yu, Wen Danhui, et. al. (2016) set scenario according the elements of Tianjin carbon emission trading pilot system, having simulated and analyzed the economic effects of carbon trading in Tianjin. It is found that carbon emission trading has little negative impact on economy. Zhu Qiyan, Chen Weibin et. al. (2016) studied the impact of carbon emission trading on energy conservation and emission reduction behavior of enterprises, pointing out that after the carbon emission trading mechanism is started, the excess carbon dioxide emissions will make enterprises bear higher production costs and greater pressure from public opinion, which will encourage enterprises to increase investment in emission reduction, raise their technical level and accelerate their transformation and upgrading process of industrial structure. Carbon trading mechanism will not only bring constraints to enterprises, but help enterprises to develop a more efficient development model, improve the productivity of enterprises while reducing carbon dioxide emissions, enhance the economic benefits of enterprises, and encourage enterprises to achieve low-carbon and energy-saving transformation. In the empirical research with empirical data, Ye Liu and Zhang Xunchang (2017) used the triple difference method to study the impact of China's carbon emissions trading policy on R&D and innovation of enterprises, but they failed to pay attention to the role of this policy in carbon emission reduction.

By reviewing relevant literature, we can find that there are few studies on the evaluation on environmental and economic effects of carbon trading policies in China. And most of the research is restricted to establishing simulation models without using empirical data to support the research conclusions. This kind of simulation analysis is greatly influenced by the premise assumptions, and the choice of parameters will also greatly affect the simulation results. What's worse, such simulation methods cannot fully present the real effect of China's implementation of carbon emission trading system due to the complexity of the real world. Based on this, this paper adopts difference-in-difference model to make a quantitative evaluation of the environmental and economic effects of China's carbon emission trading mechanism.

3 Research models and data sources

3.1 Difference-in-difference model

Overall, pilot ETS in China can be perceived as a quasi-experiment. Therefore, it is reasonable to apply the difference-in-difference(DID) model to analyze its effect on reduction of carbon emission. Specifically, we take some subordinate districts and counties of Beijing, Tianjin, Shanghai, Chongqing, Guangdong (including Shenzhen), Hubei as the treatment group and some of Hunan, Zhejiang, Jiangxi, Anhui, Jiangsu, Henan and Shandong as the control group. We define the treatment period as 2013 – 2017. The influence of the pilot ETS can be assessed by comparing differences in the indicators of carbon emissions between the treatment and control groups before and after the treatment period. The DID model is given as follows:

$$\mathrm{c}_{it} = \beta_0 + \beta_1 \cdot treat_{it} \cdot post_{it} + \beta_2 \cdot X_{it} + \alpha_i + \gamma_t + \varepsilon_{it} ....(1)$$

where c_{it} is the dependent variable representing emissions of CO_2; i and t represent the region and the year, respectively; $treat_{it}$ is the policy dummy variable, if i belongs to the treatment group, then $treat_{it} = 1$, otherwise $treat_{it} = 0$; $post_{it}$ is the time dummy variable, if t belongs to the treatment period, then $post_{it} = 1$, otherwise $post_{it} = 0$; β_1 represents the estimator of difference-in-differences and measures the impacts of pilot ETS; α_i represents time fixed effects; γ_t represents region fixed effects; and ε_{it} represents random disturbances; X_{it} represents the control variable which changes over time and may affect the dependent variable.

$$\mathrm{c}_{itj} = \beta_0 + \beta_1 \cdot treat_{itj} \cdot post_{itj} + \beta_2 \cdot X_{itj} + \alpha_{\mathrm{j}} + \gamma_t + \varepsilon_{itj} ....(2)$$

where i, t, j represent the region, the year and an enterprise respectively; $treat_{itj}$ is the policy dummy variable, if i belongs to the treatment group, then $treat_{itj} = 1$, otherwise $treat_{itj} = 0$; $post_{itj}$ is the time dummy variable, if t belongs to the treatment period, then $post_{itj}=1$, otherwise $post_{itj} = 0$; $treat_{itj} \cdot post_{itj}$ indicates whether the enterprise j of region i was affected by the carbon trading policy in period t (If the enterprise j carried out the carbon trading reform in period t, then $treat_{itj} \cdot post_{itj} = 1$, otherwise $treat_{itj} \cdot post_{itj} = 0$); α_{j} represents time fixed effects of enterprises; γ_t represents region fixed effects; and ε_{itj} represents random disturbances; X_{itj} represents the control variable which changes over time and may affect the dependent variable. Including control variables is to ensure that the DID model is robust. The ones we select to be used in this research are GDP per capita, quadratic GDP per capita, population, the industrial development level and the investment level, the definitions of which are listed below in Table 1.

Table 1: Control variable definitions

Variable name	Variable meaning
gdp	*gdp* represents the level of economic development which is measured by per capita real gross domestic production. Taking year 2007 as the base year, the nominal GDP of each region in each year is converted into the real GDP.
gdp^2	gdp^2 represents quadratic real GDP per capita.
lnpop	*lnpop* represents the population scale which is measured by the number of residents in each region at the end of each year.
ind	*ind* represents the degree of industrial development level which is measured by the gross output value of industries above the designated size.
inv	*inv* represents the investment level which is measured by the total investment in fixed assets.
lnasset	lnasset represents total assets of the enterprise.
lnkl	lnkl represents net fixed assets divided by the number of employees.
lnRD	lnRD represents research and development expenses in enterprise annual reports.
ownership	ownership represents the proportion of state-owned shares in the total share capital.
roa	roa represents the profitability of the enterprise. The calculation formula is: roa = Net profit / Total assets.
lnage	lnage represents the enterprise's age.

Estimators' consistency of the DID model needs to meet the parallel trend hypothesis which means the treatment and control groups should have a consistent change trend before the pilot ETS. Otherwise, the DID model cannot accurately evaluate the effect of the pilot ETS. Therefore, on the basis of model (1), we establish another regression model (3) in order to examine the parallel trend. Model (3) is given as follows:

$$c_{it} = \beta_0 + \sum_{2007}^{2017} \beta_1 \cdot treat_{it} \cdot post_{it} + \beta_2 \cdot X_{it} + \alpha_i + \gamma_t + \varepsilon_{it} \text{.........}(3)$$

where $treat_{it} \cdot post_{it}$ is a dummy variable that represents the i^{th} region and t^{th} year, in the t^{th} year, only if i belongs to the pilot areas, then $treat_{it} \cdot post_{it} = 1$, otherwise $treat_{it} \cdot post_{it} = 0$. Therefore, assuming that ETS was implemented in 2007-2011, β_{2007} to β_{2011} are the corresponding policy effects. If β_{2007} to β_{2011} are not significant which means that the impacts of ETS on carbon emissions only occur during the pilot years, then the parallel trend hypothesis is valid.

3.2 Data sources

As for the evaluation of the environmental dividend of the carbon trading pilot policy, this paper determines that values of the dependent variable c_{it} are CO_2 emissions calculated based on two sets of nighttime light data (DMSP/OLS and NPP/VIIRS) provided by NGDC (National Geophysical Data Center).

As for the evaluation of the economic dividend of the carbon trading pilot policy, this paper puts A-share listed companies in Shanghai and Shenzhen stock markets from 2010 to 2016 into the range of research samples. Considering that the industries involved in this carbon trading pilot consist of eight major industries including chemical, petrochemical, steel, building materials, paper making, nonferrous metals, aviation and electric power, and the corresponding listed companies are classified into three major industries: manufacturing, production and supply of power, heat and gas, as well as transportation, warehousing and postal services, this paper only keeps the listed companies in these three major industries as research samples and conducts the following screening: (1) taking out St type listed companies; (2) taking out listed companies in finance and insurance industry; (3) eventually obtaining the balanced panel data including 5439 valid observations of 777 listed companies from 2010 to 2016. Among them, the data of enterprise establishment date and enterprise R&D expenses are from Wind database, and other related variable data are from CSMAR database.

In the following section, this paper will present results by illustrating two tables of regression statistics regarding the environmental and economic effects on carbon trading policies respectively.

4 Results

4.1 Evaluation of the environmental effect

In order to evaluate whether China's carbon emission trading pilot policy has reduced CO_2 emission, we first make regression analysis on model (1). The two-way fixed effect model is adopted aiming at avoiding the influence of regional heterogeneity on energy consumption structure and eliminating the influence of time effect. Table 2 shows the regression results of model (1), where the column (1) is the regression results without adding other control variables.(*、**、*** represent significance at 10%、5%、1% level.)

Table 2: Model (1) Regression results

	(1)	(2)	(3)	(4)	(5)	(6)
c_{it}	-0.528***	-0.452**	-0.468**	-0.474***	-0.525**	-0.579**
	(0.000)	(0.011)	(0.016)	(0.003)	(0.018)	(0.017)
gdp		0.0897**	0.918**		1.215***	1.329***
		(0.040)	(0.015)		(0.006)	(0.005)
gdp^2		-0.0433**	-0.0419**		-0.0471**	-0.0565**
		(0.023)	(0.047)		(0.022)	(0.039)
lnpop			-0.0263			0.0237
			(0.919)			(0.888)
ind			-0.0160			0.321
			(0.993)			(0.0898)
inv			0.442*			0.608
			(0.061)			(0.127)

It can be seen that the coefficient of C_{it} is significantly negative at the level of 1%, indicating that the carbon emission trading pilot conducted by the treatment group reduces the CO_2 emission of the province compared to the control group. The carbon emission trading pilot policy reduces the CO_2 emission of the region by about 50 million tons on average, a decrease of about 24% compared with the average. The quadratic term of per capita GDP and per capita GDP is added in the column (2), and the absolute value of the carbon emission trading pilot coefficient decreases but is still significantly negative at the level of 5%. The coefficient of per capita GDP is significantly positive, and the coefficient of the quadratic term of per capita GDP is significantly negative, which shows that there is an inverted "U" relationship between carbon emission and the level of economic development. CO_2 emission show a change characteristic of first increasing and then decreasing with economic development, which is consistent with the analysis conclusion of Li Guozhi and Li Zongzhi on the Environmental Kuznets Curve of China's carbon emission. The theory of the "Environmental Kuznets Curve" has been verified. Then, other control variables are added in column (3), and the absolute value of the carbon emission trading pilot coefficient decreases but is still significantly negative. The carbon emission trading pilot policy reduces the regional CO_2 emission by about 50 million tons on average, a decrease of about 21% compared with the average, which basically verifies the theoretical hypothesis of this paper, that is, China's carbon emission trading pilot policy has reduced CO_2 emission. In addition, column (3) also witnesses that the empirical results of other control variables are basically consistent with the conclusions of existing studies. Among them, the regression coefficient of economic development level is still significantly positive, the regression coefficient of quadratic term of economic development level is still significantly negative, and the "Environmental Kuznets" curve theory has been verified again; The coefficient of technical level is significantly positive, which is different from the expected improvement of technical level that can promote the reduction of carbon emission. This may be due to the bias caused by the inaccuracy of measuring the technical level of each region basing on the level of R&D investment; The coefficient of energy conservation and environmental protection expenditure is significantly negative, indicating that energy conservation and environmental protection expenditure has a definite effect on CO_2 emission reduction. However, the regression coefficient between the degree of industrial structure upgrading and population size fails to pass the significance level test of 10%, and the coefficient sign of the degree of industrial structure upgrading is negative, which indicates that the higher the industrial structure, the greater the relative proportion of tertiary industry and industry, and the lower the CO_2 emission. The upgrading of industrial structure has certain significance for CO_2

emission reduction. In order to eliminate the influence of the measurement method of CO_2 emission on the empirical results to a certain extent, the CO_2 emission measured by another method are taken as the explained variables in columns (4)-(6), and regression analysis is carried out on them. Among them, the column (4) is the regression results without adding other control variables, control variables pGDP and $pGDP^2$ are added in the column (5), and other control variables are added in the column (6). It can be found that the impact of carbon emission trading pilot policies on CO_2 emission is similar with different CO_2 emission measurement methods, and carbon emission trading policies have effectively played a role in reducing CO_2 emission.

The consistency of difference-in-difference estimators requires the held hypothesis of parallel trend, that is, the treatment group and the control group should have a consistent change trend before the event occurs, otherwise the double difference method cannot accurately evaluate the effect of the event, so it is necessary to carry out parallel trend test on model (1). For the environmental effect assessment of carbon trading, the parallel trend hypothesis means that the CO_2 emission of the districts in treatment group and the control group have the same change trend before the carbon emission trading pilot. This paper uses the event study method to verify the parallel trend hypothesis. In case the parallel trend hypothesis holds, the impact of carbon emission trading on CO_2 emission will only occur after the pilot, and the change trend of CO_2 emission in the treatment group and the control group should not have a significant difference before the pilot. In order to test the parallel trend hypothesis, this paper establishes a regression model (3) based on the model (1). The regression results of model (3) are shown in Table 3. (*、**、*** represent significance at 10%、5%、1% level.)

Table 3: Model (3) Regression results

Variable	(1) c_{it}	(2) c_{it}
$c_{i,2008}$	-0.0850	-0.0783
$c_{i,2009}$	-0.158	-0.150
$c_{i,2010}$	-0.138	-0.129

$c_{i,2011}$	-0.261	-0.254
$c_{i,2012}$	-0.428	-0.426
c_i	-0.709**	
$c_{i,2013}$		-0.563*
$c_{i,2014}$		-0.542*
$c_{i,20015}$		-1.075***

It can be seen from the regression results in Table 3 that the regression coefficients of the dummy variables in the carbon emission trading pilot from 2008 to 2012 are not significant, which shows that the parallel trend hypothesis is valid and it is reasonable and feasible to use the difference-in-difference method to estimate.

4.2 Evaluation of the economic effect

The regression analysis has been performed on model (2). In Table 4, Column (1) is the regression results without adding other control variables. It can be seen that the coefficient of c_{it} is significantly positive at the level of 1%, which indicates that the carbon emission trading pilot will improve the total factor productivity of listed companies in the treatment group compared with the control group, and the carbon emission trading pilot policy will increase the total factor productivity of listed companies by about 9.52% on average. Then other control variables are added in column (2). At this time, the absolute value of the coefficient of carbon emission trading pilot decreases but is still significantly positive. The average total factor productivity of listed companies increases by about 4.21%, which basically verifies that China's carbon emission trading pilot policy has improved total factor productivity. In addition, column (2) indicates that the regression coefficient of enterprise scale (lnasset) is significantly positive, and the increase of enterprise scale can improve the specialization of enterprise production, reduce their production cost, and then lead to economies of scale, thus improving the total factor productivity of enterprise; The coefficient of capital-labor ratio (lnk1) is significantly positive, which indicates that the technical effect brought by the increase of capital intensity exceeds the increased burden of environmental protection and energy saving, making the total factor productivity of enterprises increase; The coefficient of corporate ownership is significantly negative, which also confirms the inefficiency of state-owned enterprises; The coefficient of rate of return on total assets (roa) is significantly positive, which is consistent with the expectation that the higher the financial performance of listed companies, the higher the total factor productivity; The regression coefficient of enterprise age (1nage) is significantly positive, while the regression coefficient of enterprise age quadratic term (lnage2) is significantly negative, which verifies that there is an "inverted U-shaped" relationship between enterprise age and total factor productivity: the regression coefficient of technical level (InRD) fails to pass the 10% significance level test. The regression coefficient symbol of technology level (InRD) is positive, which indicates that the higher the R&D cost of enterprise, the higher the total factor productivity.(*、**、*** represent significance at 10%、5%、1% level.)

Table 4: Model (2) Regression results

	(1)	(2)
c_{it}	0.0952***	0.0421**
	(0.003)	(0.042)
lnasset		0.534**
		(0.000)
lnkl		0.259**
		(0.000)
lnRD		0.00304
		(0.129)
ownership		-0.107**
		(0.039)
roa		0.438**
		(0.013)
lnage		0.736*
		(0.093)
lnage2		-0.274*
		(0.071)

5 Conclusion

Has China's carbon emission trading pilot policy achieved environmental and economic dividends? To answer this question, this paper adopts the difference-in-difference model to construct the econometric model, uses the quasi-natural experiment that seven provinces and cities have approved carbon emission trading pilot since October 2011, and takes 2013 the year of launching the pilot as the base year, to evaluate the impact of China's carbon emission trading pilot policy on regional CO_2 emission and the total factor productivity of listed companies. Empirical results show that China's carbon emission trading pilot policy has a significant effect on reducing regional CO_2 emission as well as achieving environmental and economic dividends.

Considering the availability of energy consumption data and the accuracy of CO_2 emission measurement, this paper selects data at the district and county levels to evaluate the environmental effects of carbon trading pilot, but fails to obtain carbon emission data at the level of companies, so it is impossible to analyze the emission reduction effects of carbon emission trading policy at the micro level. In addition, this paper can only evaluate the short-term environmental and economic effects of carbon emission trading due to the limitation of data time range, while the long-term effects cannot be effectively evaluated. The long-term effect of carbon emission trading policy on emission reduction will be analyzed at the micro level in our future research.

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