Dean&Francis
ISSN 2959-6149

Why did the Chinese government introduce the carbon emissions trading scheme, and to what extent has it been effective in controlling carbon emissions in China?

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Abstract:
By constructing the panel data of 30 provinces in China, this research studies the reasons for the introduction of a carbon emission trading system in China and to what extent this system affects the reduction of carbon emissions. The government has taken measures to control carbon emissions in line with the global climate goals China joined the world in the Paris Agreement and the national goal of achieving carbon neutrality by 2026. However, the ineffectiveness of the carbon tax policy could not achieve the government's goals, so the carbon emission trading system was established. This research uses the DID model to evaluate the effectiveness of the carbon emission trading system. Through the benchmark regression results, it can be concluded that the carbon emission trading policy can promote the reduction of carbon emissions in Chinese provinces. Through the heterogeneity test, it can also be concluded that this policy has a greater impact on the eastern provinces of China, while it has almost no impact on the central region. This research provides policy implications for China facing carbon emission reduction.

Keywords: carbon emission trading policy, carbon emission reduction, efficiency, DID Model, carbon tax

1. Introduction

The Paris Agreement, which was adopted in 2015, set the goal of limiting the global average temperature increase to no more than 2 degrees Celsius by the end of this century and striving to limit it to within 1.5 degrees Celsius [1]. During this period, China established a carbon emissions trading system and announced its aim to achieve carbon neutrality by 2060.

When people think of carbon, it is essential to consider carbon dioxide, the primary emission. However, one must clarify: Is carbon dioxide emission a problem? Carbon dioxide is one of the greenhouse gases, and excessive carbon dioxide emissions may cause global warming, melting glaciers, and rising

ISSN 2959-6149

sea levels. On the other hand, plants can convert carbon dioxide and water into organic compounds and release oxygen, providing essential support for human survival. Considering these, people can conclude that carbon dioxide emissions are not a problem, but excessive emissions will affect human life. The Figure below shows China's carbon dioxide emissions relative to the rest of the world. There is a significant increase in carbon dioxide emissions in China after entering the 21st century. Therefore, governments need to take measures to control carbon dioxide emissions rather than prohibit them entirely.

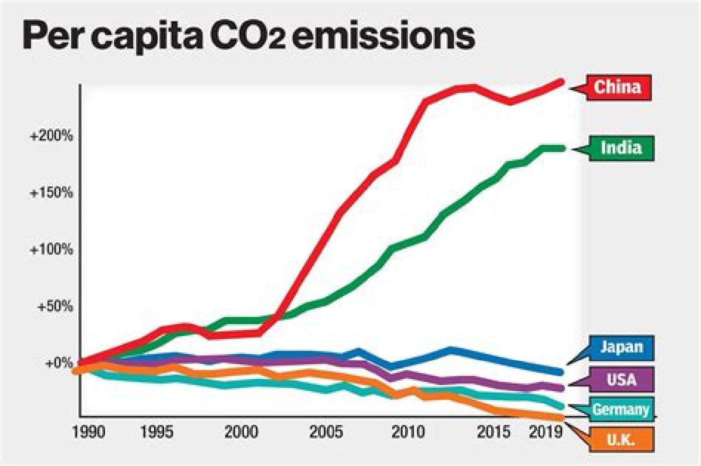

Figure 1 Carbon emissions in different countries in the past few years [2]

The Chinese government has adopted many policies to control carbon emissions. Since information asymmetry makes green tax not effective enough, this article selects another emission reduction measure, China's carbon emission trading policy, to study its effectiveness in controlling carbon emissions. This research is beneficial to reflect the effects of the policies implemented by the Chinese government, promoting the government to improve China's environmental protection policies and make contributions to maintaining the world's climate.

2. Literature Review

2.1 Carbon Emission Trading System

2.1.1 Establish Background

Since the early 21st century, China's rapid industrial development has led to a sharp increase in carbon emissions, surpassing the United States in 2006 and making China the world's largest annual greenhouse gas emitter [3]. Excessive carbon emissions contribute to global warming, causing rising sea levels and species extinction. In response, the Paris Agreement was adopted in 2015, aiming to limit global temperature increases to below 2 degrees Celsius, with efforts to stay within 1.5 degrees [1].

As the country with the largest emissions, China has implemented various measures to reduce carbon emissions to align with other countries in achieving the goals of the Paris Agreement. Initially, a carbon tax policy was used, which involved taxing companies with high emissions to incentivize them to reduce their emissions. Lewis [4] argues that taxes are very easy to manage. With the existing energy taxation policy, the government could quickly and effectively establish a carbon emission tax policy, as there was already related experience. However, due to frequent occurrences of information asymmetry, the tax policy was gradually considered ineffective by the government. A few years later, by learning from the operation of the European Union's carbon emission trading system, the Chinese government launched a pilot carbon emission trading policy in 2013.

2.1.2 Operating Mechanism

Carbon emission trading is a market mechanism adopted to promote national greenhouse gas emission reduction and decrease global carbon dioxide emissions. In the carbon emission trading market, companies trade carbon dioxide emissions as a commodity. Specifically, the state sets a total carbon emission based on actual conditions and allocates it to specific companies. For companies that apply green technology for production or have lower carbon emissions, their emission volume usually falls below the allocated allowance. Conversely, companies with higher emissions will exceed their allowance. In this process, suppliers and demanders of carbon allowances emerge, thus creating a carbon trading market [5].

2.2 Relevant Articles and the research values of this project

Today, many companies can flexibly buy or sell allowances based on their emission reduction costs. Large Chinese companies like Alibaba and Huawei have gradually started to develop new energy technologies and green production methods under the incentive of carbon trading permits. The figure below shows how Tesla's net income turned positive from the purchase of carbon credits in more than 2020 and has steadily risen since then. It is not difficult to conclude that Tesla has profited from selling carbon credits in recent years, thereby turning its long-standing revenue deficit into a profit [6].

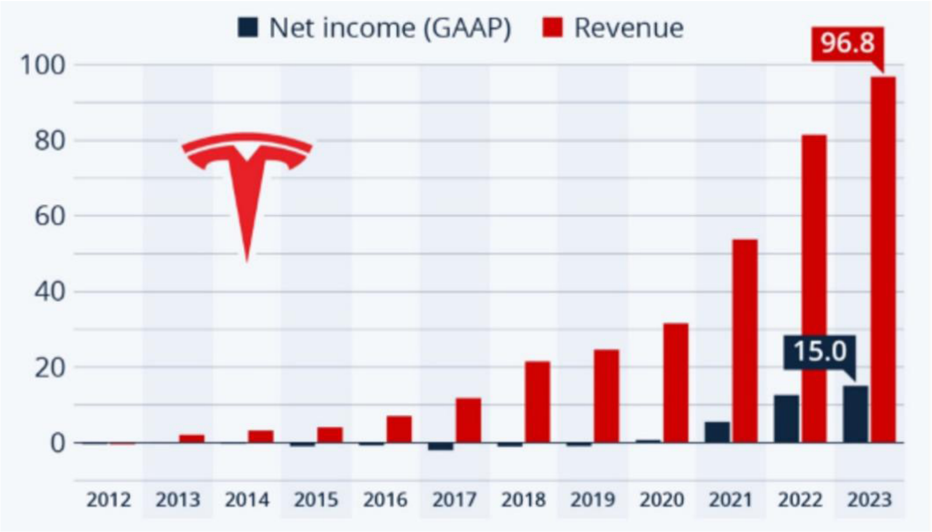

Figure 2 Yearly net income and revenue of Tesla (in billion U.S. dollars) [6]

Based on this, many scholars have studied the role of the carbon trading system, especially China's carbon trading system. Li and Huang [7] analyzed the impact of China's carbon trading pilot policy on the energy efficiency of industrial companies from 2008 to 2019. Yang et al. [8] constructed balanced panel data for 285 cities at the prefecture level and above in China from 2003 to 2020 and used the DID model to study the impact of the carbon trading pilot policy on carbon emissions. Furthermore, to know whether the carbon emission trading system has reduced carbon emissions and how it affects carbon leakage, Gao et al. [9] conducted in-depth research using data from 30 provinces in China across 28 industries from 2005 to 2015. Hong, Cui, and Hong [10] used a sample of 276 cities in China from 2003 to 2016 and employed a Difference-in-Differences model to evaluate the impact of carbon emission trading on energy efficiency. Based on these studies, it can be found that previous research often used cities as the research subject to assess the effectiveness of the carbon trading system.

Since using provinces as the analysis unit is more general and the data is more accessible, this research chooses provinces as the research subject for experimentation. In addition, previous research mostly discussed the carbon emission trading system in isolation. This research compares the carbon trading policy with the carbon tax policy to further explore the effectiveness and positive impacts of the carbon trading policy.

3. Model construction and research design

3.1 Model Construction

Economists have widely employed the Difference-in-Differences (DID) Model in recent years to assess the effects of policy adjustments. This research primarily uses the DID model to analyze and validate the policy effects and effectiveness of the carbon emission trading system. The carbon emission trading system plays a crucial role in China's green development. Therefore, by employing the DID model to observe the impact of the carbon trading policy on the green total factor productivity in the studied provinces, an accurate evaluation of the implementation effectiveness of the carbon trading policy can be achieved, which can provide valuable insights for China's future efforts in carbon reduction.

Given that many scholars like Yang et al. [8] have considered Chinese cities as experimental units. To highlight the novelty and distinctiveness of this research, Chinese provinces are selected as the experimental units. Based on data availability and the explanations provided earlier, data were collected from 30 provinces in China (excluding Hong Kong, Macao, Taiwan, and Tibet) [11]. The data sources include "China Statistical Yearbook for Reginal Economy" and "China Statistical Yearbooks."

In October 2011, the National Development and Reform Commission issued the Notice on Pilot Carbon Emission

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Trading, approving seven provinces and cities, including Beijing, Shanghai, Tianjin, Chongqing, Hubei, Guangdong, and Shenzhen, to carry out pilot carbon trading [12]. The carbon trading pilot programs for Beijing, Shanghai, and Guangdong (excluding Shenzhen) were approved in 2014, along with the issuance of the "Notice on Conducting Nationwide Carbon Emissions Trading Pilot Work." In 2017, China established a national carbon trading policy framework. Therefore, this research considers 2014 as the policy implementation point and selects 2017 as the data termination point, with Beijing, Shanghai, Chongqing, Tianjin, Guangdong, and Hubei serving as the experimental group and the remaining provinces as the control group. Based on this, the regression model is as follows:

$$Y_{it} = \beta_0 + \beta_1 \left(treat_{it} \times time_{it} \right) + \phi X_{it} + \gamma_t + \delta_i + \epsilon_{it}$$

In the formula, the subscript *i* represents the region, *t* represents the year, and Y_{it} is the dependent variable, the green total factor productivity (GTFP). Moreover, *treat* is a dummy variable indicating the implementation of the carbon emission trading pilot. *time* is a time grouping variable. γ_t representing time-fixed effects, and δ_i denotes individual (provincial) fixed effects. X_{it} represents a series of control variables, including industrial structure (stru), innovation level (inno), and population density (poden). ϵ_{it} the random error term.

3.2 Variable declaration and measurement

3.2.1 Explained variable

The degree of green development can reflect the effectiveness of carbon emission reduction in a region. Considering various dimensions covered by indicators that reflect green development, green total factor productivity (GTFP) was ultimately chosen as an indicator to measure the effectiveness of the carbon emission trading policy. It considers the relationship between economic output and resource input, while also considering the influence of environmental factors. The improvement of GTFP implies that, under the same resource input, the economy can generate more output, and the utilization of environmental resources becomes more efficient [13].

3.2.2 Core Explanatory Variables

The carbon emission trading policy is the product of time dummy variables and between-group dummy variables. β_1 is the coefficient of the interaction term between treat and time [14] The value of this coefficient indicates the positive or negative impact of the carbon emission trading pilot policy implemented in 2014 on provinces. If β_1 is positive, it indicates a positive effect of carbon emission trading on GTFP; otherwise, it suggests a negative impact.

3.2.3 Control Variables

Based on existing scholars' research and the objectives of this research, industry structure (stru), innovation level (inno), and population density (poden) are chosen as control variables. The development of a region is closely tied to industrial progress and innovation. Therefore, the percentage of the secondary industry in provincial GDP is selected to represent industry structure (stru) [15]. Innovation encourages professionals to apply for patents based on their research and development. The success of an invention or creation is determined by the number of granted patents rather than the number of applications [16]. Hence, the selected number of granted patents is used as an indicator of innovation level (inno). Finally, labor force and productivity are related to population quantity and density. Population density (poden) is chosen as a control variable to ensure the reliability of results.

Table 3-1 is the statistical result of all the data used in this research. Additionally, due to the vast geographical expanse of China and the complexity of provincial delineations, Figure 3 shows the distribution of provinces in China.

Table 1 The descriptive statistics of the main variables in the benchmark regression.

variable type	name	symbol	obs.	mean	Std. Dev.	min	max
explained variable	green total factor productivity	GTFP	420	1.514431	0.57006	0.608019	4.97891
explanatory variable	Whether a carbon trading policy has been implemented	DID	420	——	——	0	1
controlled variable	industrial structure	stru	420	45.49402	8.5366	16.2	61.5
	innovation level	inno	420	38347.3786	65128.6	97	527390
	population density	poden	420	451.6691	669.981	7.611111	3913.249

Figure 3 China map

4. Results and analysis

4.1 Parallel trend hypothesis testing

An essential assumption for the application of the Difference-in-Difference model is the common trends assumption. Therefore, it is necessary to examine whether there is a parallel trend between the carbon emissions trading pilot areas and non-pilot areas. This research chose 2014 as the base year and conducted a parallel trends hypothesis test. Figure 4-1 shows the results obtained by analyzing the data in STATA. Before the policy implementation, the confidence interval crosses zero, indicating no significant difference in the trends between the control group and the experimental group. There is no policy effect before implementation. In contrast, after the policy implementation, the regression coefficient is positive and significantly different, indicating a noticeable distinction between the control and experimental groups. This implies that the carbon emissions trading policy positively impacts the green total factor productivity of the pilot cities. In conclusion, the parallel trends assumption holds.

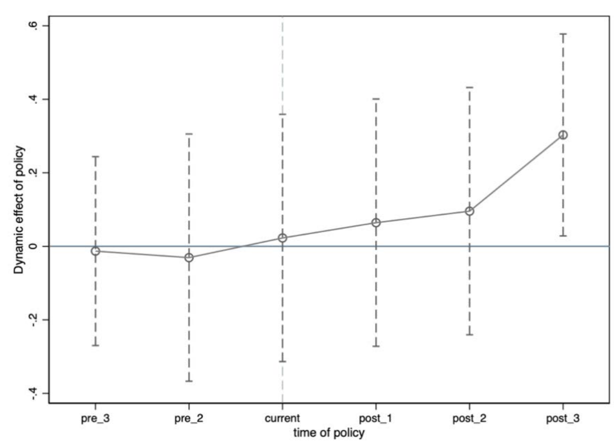

Figure 4-1 Results of parallel trend hypothesis testing

4.2 Benchmark regression model

This research uses the Difference-in-Difference model for empirical testing, selecting panel data from 30 provinces nationwide in China from 2011 to 2017 as the research object. Data from Tibet, Hong Kong, Macau, and Taiwan

ISSN 2959-6149

are excluded. The benchmark regression results which result from STATA are presented in Table 4-1.

Table 4-1 linear regression results

Variables	green total factor productivity(GTFP)	
	(1)	(2)
policy	0.263*** (0.067)	0.261*** (0.072)
stru		1.133*** (0.436)
inno		-0.011** (0.004)
poden		0.211* (0.386)
constant	1.498*** (0.137)	-1.124* (2.100)
observations	420	420
year FE	Yes	Yes
province FE	Yes	Yes

Note: Standard errors (SE) are reported in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

In Table 4-1, the first column (1) presents the regression results without the inclusion of three control variables, employing a fixed-effects Difference-in-Difference model absorbing individual and time effects. In this model, the regression coefficient for the carbon emission trading pilot policy (policy) is positive (0.223) and statistically significant at the 1% level. This indicates that the carbon emission trading pilot policy has a positive and significant impact on the green total factor productivity (GTFP) of the pilot provinces. Additionally, the second column (2) shows the regression results after including three variables: industrial structure (stru), innovation level (inno), and population density (poden). The model still absorbs individual and time effects using a fixed-effects approach. Similar to the model without control variables, the regression coefficient for the carbon emission trading pilot policy (policy) remains positive (0.223) and statistically significant at the 1% level. This suggests that the carbon emission trading pilot policy can positively influence the GTFP of the pilot provinces.

Regarding the control variables, both industrial structure and population density have positive effects on GTFP. The increasing share of the secondary industry in GDP implies ongoing progress and development in the second industry. This development can facilitate the improvement and advancement of green technology and industry, thereby enhancing the efficiency of green technology. Furthermore, the rise in population density signifies an increase in labor force and talent, providing favorable opportunities for innovation in green technology and serving as a significant driving force for green development. However, the innovation level has a negative impact on GTFP. This is because an increase in the level of innovation implies a rise in expenditure, which may to some extent compete with expenditures in green development, thereby reducing green total factor productivity.

4.3 Robustness test

4.3.1 Winsorize of the dependent variable

Considering the possibility of outliers or extreme values in the selected data, this research conducts a robustness test to investigate whether these values impact the research results. Therefore, extreme values are trimmed from the data at the 1% significance level, and the data undergoes winsorization [17]. Subsequently, the benchmark model is reanalyzed through regression analysis, and the results are presented in Table 4-2.

Table 4-2 Robustness test regression results

variables	GTFP
	(1)
policy	0.146*** (0.496)
stru	1.296*** (0.304)
inno	-0.014*** (0.003)
poden	0.001* (0.001)
constant	0.890*** (0.180)
observations	420
year FE	Yes
province FE	Yes

Note: Standard errors (SE) are reported in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

The regression results indicate that the coefficient of the carbon emissions trading policy remains positive (0.146) and is significant at the 1% level. Thus, it can be observed that the benchmark regression results presented earlier in this research are essentially robust.

4.3.2 Policy time lag effect treatment

Based on the results of the previous parallel trend test, the carbon emissions trading pilot policy has a time lag effect, of approximately two years. Therefore, the base year of the policy is shifted forward by one year to 2015 and two years to 2016, and then a benchmark regression is conducted again.

Table 4-3 Time lag effect test regression results

Variables	green total factor productivity(GTFP)		
	(1)	(2)	(3)
policy	0.261*** (0.072)	0.296*** (0.075)	0.345*** (0.814)
stru	1.133*** (0.436)	1.117** (0.435)	1.105** (0.434)
inno	-0.011** (0.004)	-0.012*** (0.004)	-0.012*** (0.004)
poden	0.211* (0.386)	0.277* (0.379)	0.359* (0.374)
constant	-1.124* (2.100)	-0.472* (2.064)	-0.911* (2.034)
observations	420	420	420
year FE	Yes	Yes	Yes
province FE	Yes	Yes	Yes

Note: Standard errors (SE) are reported in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

In Table 4-3, the first column (1) presents the regression results with the base year of 2014, and the second column (2) and the third column represent the regression results with the base year of 2015 and 2016 respectively. The regression results indicate that the coefficient of the carbon

ISSN 2959-6149

emissions trading policy remains positive (0.296 in the year 2015 and 0.345 in the year 2016) and is statistically significant at the 1% level. Thus, it can be observed that the benchmark regression results presented earlier in this research are fundamentally robust. Since the absolute value of the coefficient is increasing year by year, the impact of this policy on carbon reduction in Chinese provinces is increasing, which is an accumulative effect. It can be concluded that there is indeed a time lag effect.

4.4 Heterogeneity Analysis

Due to the extensive territory of China, the analysis of the impact of China's carbon trading policy on GTFP may ignore the differences in economic level among regions. Thus, the regional heterogeneity of the carbon emissions trading policy's impact on GTFP will be tested here. Based on the economic and cultural differences, the 30 provinces previously considered are categorized into three groups: Eastern, Central, and Western regions [18]. Specifically, there are 13 provinces in the eastern region, 6 provinces in the central region, and 11 provinces in the western region. The Figure 4-2 shows the distribution of three regions.

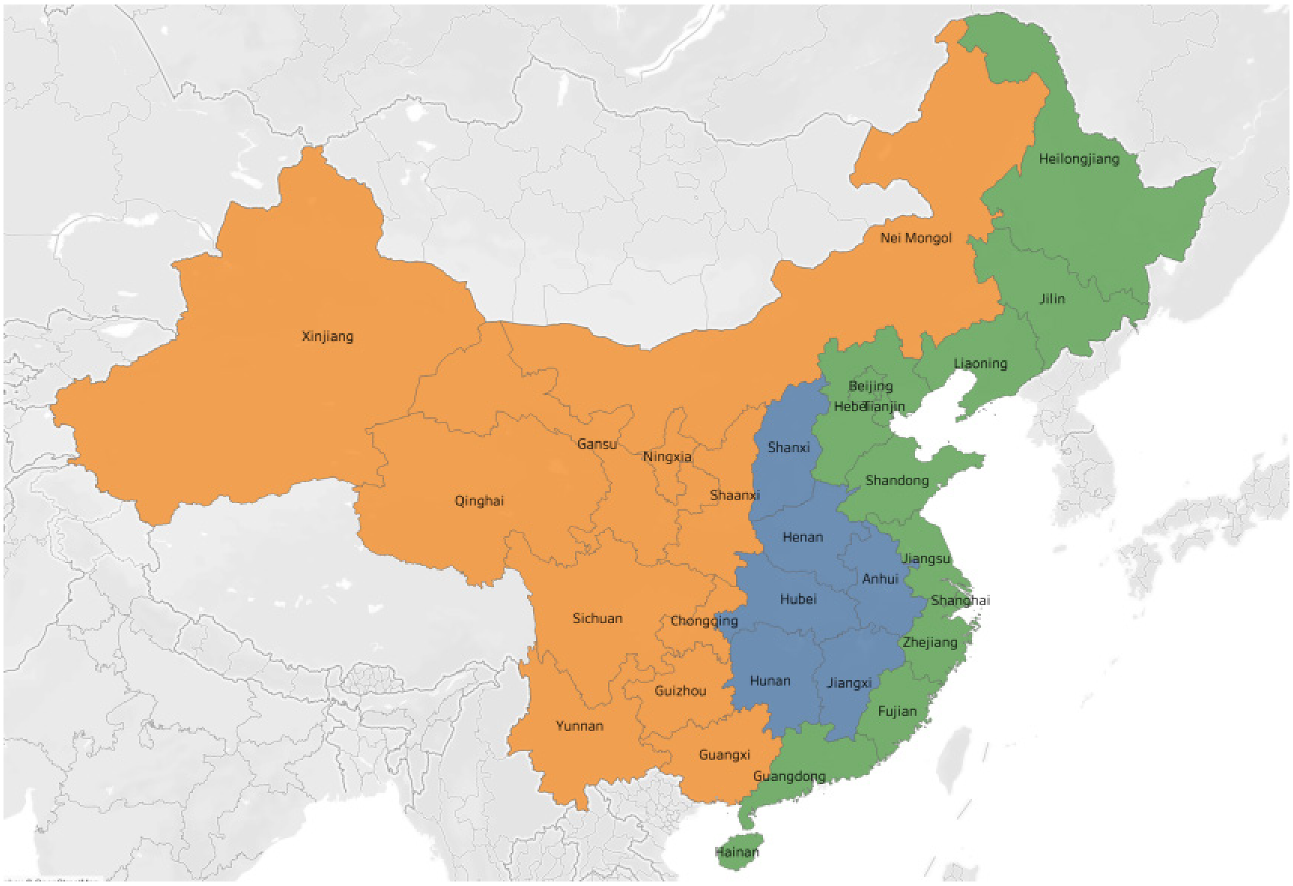

Figure 4-1 The distribution of three regions

Table 4-4 displays the regression results for the three regions: Eastern, Central, and Western. Among them, the coefficient of the carbon emissions trading policy is highest for the Eastern region (0.5), indicating a more significant positive effect of this policy in the Eastern region. This observation may be attributed to the fact that the Eastern region boasts a more developed economy, with a predominant focus on the service industry and technology sectors. Since these industries are more likely to generate greater amounts of carbon emissions, the carbon emissions trading policy appears to exert a more restrictive effect on carbon emissions in the Eastern region.

Table 4-4 Regression results by region

Variables	green total factor productivity(GTFP)		
	Eastern	Central	Western
policy	0.500*** (0.109)	0.005* (0.064)	0.184* (0.129)
stru	2.003*** (0.615)	3.715*** (0.469)	0.473* (0.896)
inno	0.004* (0.021)	-0.093*** (0.016)	-0.016** (0.007)
poden	0.582* (0.628)	-0.687* (1.162)	0.478* (0.651)
constant	-1.916* (2.708)	-3.795* (6.814)	-1.533* (3.929)
observations	154	84	182
year FE	Yes	Yes	Yes
province FE	Yes	Yes	Yes

Note: Standard errors (SE) are reported in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

5. Discussion

5.1 Regional Impact Analysis

Table 6-4 illustrates the varying impacts of China's carbon emissions trading system across its eastern, central, and western regions. In the economically advanced eastern region, the policy's influence is more significant, as evidenced by a higher coefficient. This region, located along the coast, benefits from abundant coastlines and port resources, facilitating extensive domestic and international trade and logistics. These activities have driven the development of advanced industrial and high-tech sectors, which are heavily reliant on energy, leading to substantial carbon emissions. Consequently, carbon emission permits play a critical and effective role in this region by imposing constraints. Faced with higher carbon prices, businesses are incentivized to reduce emissions and adopt greener production practices, demonstrating the policy's effectiveness in curbing the carbon footprint of advanced economic activities [19].

In contrast, the central and western regions, with their different economic structures, have seen less impact from the carbon trading policy. These regions are predominantly driven by agriculture and energy development industries [20]. Despite significant investments in high-carbon energy sources like oil and natural gas, leading to increased emissions, the sparser populations and vast geographical areas mean that additional emissions are less significant compared to the transportation-heavy eastern region. Furthermore, the carbon emissions from energy development are often unavoidable, making it difficult for the government to reduce or restrict emissions through policy interventions during the extraction process. Specifically, for the western region, scholars such as Wang et al. [21] argue that there is no clear trend in its development, largely due to the less favorable investment environment compared to the central and eastern regions. This explains why the impact of the carbon trading system in the western region is not as pronounced as in the eastern region.

5.2 Regulation Comparison

Carbon emissions are an inevitable byproduct of industrial production. In classical economics, air is considered a free resource, allowing carbon emissions to occur without cost [22]. However, as shown in Figure 5-1, without government intervention, the equilibrium point E occurs where marginal private cost (MPC) equals marginal private benefit. This neglects the marginal external costs, causing the marginal social cost (MSC) to exceed the MPC, shifting the supply curve from S_1 to S_2 and moving the equilibrium to point A [23]. The vertical distance between these curves represents the marginal external cost (MEC). To address this, the Chinese government imposes a carbon tax on emitting companies, aiming to align the marginal social cost with the marginal private cost. This Pigouvian tax internalizes the externalities, raising the cost of production and energy, thus encouraging reductions in carbon

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emissions [24].

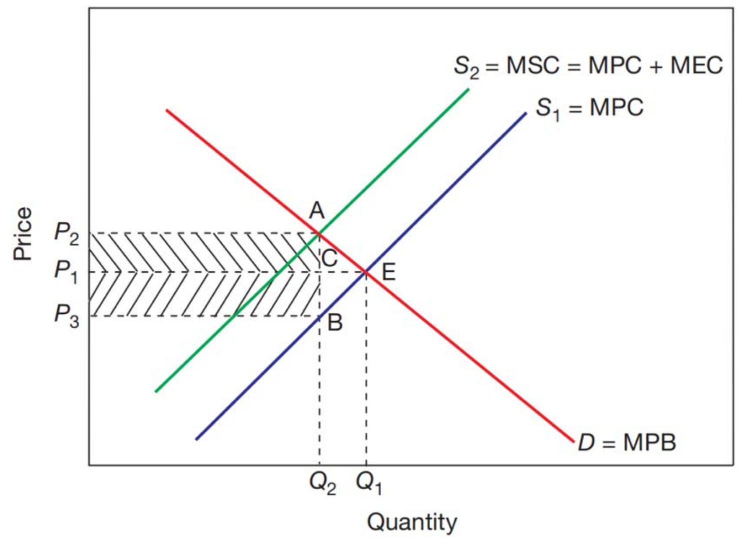

Figure 5-1 External costs and use of indirect taxation [24]

However, Pigouvian taxes have certain limitations. Asymmetric information makes determining the optimal tax rate challenging, possibly resulting in a non-Pareto optimal tax rate. For instance, if the government cannot accurately determine marginal external costs and immediate harm costs, the set tax rate may not be the most effective [25]. Additionally, efficiency differences among companies exist, implying that if the government does not set specific tax rates for each company and opts for a uniform rate, inappropriate incentives may arise, hindering the ideal implementation outcome.

Given these limitations, the Chinese government needs to establish a new policy to reduce the country's carbon emissions. Carbon emissions trading policies offer an alternative method for the government to address the negative externalities of carbon emissions. Economist Ronald Coase argued that if property rights are defined, transactions between economic agents can effectively solve externalities. Carbon trading follows Coase's theorem, recognizing the need to regulate greenhouse gases represented by carbon dioxide, incurring cost differentials for companies. Through the exchange of greenhouse gas emission rights, carbon trading becomes the most efficient way to address carbon emissions issues within a market economy framework.

5.3 Economic Analysis of Carbon Emissions Trading Scheme

The Carbon Emission Trading System (ETS) in China introduces a market-based mechanism for trading emission allowances, encouraging cost-effective emission reductions. Companies can flexibly buy or sell carbon allowances based on their emission reduction costs, incentivizing them to adopt economically efficient measures. Financially constrained companies may focus on reducing emissions and developing greener production methods to minimize the purchase of permits. On the other hand, wealthier companies may avoid merely buying permits to protect their reputation, as being perceived as environmentally negligent could harm their profits. For example, Baosteel Group, a major steel manufacturer in China, significantly reduced its carbon emissions by adopting advanced low-carbon technologies, thereby decreasing its reliance on emission allowances and enhancing its competitiveness and brand image both domestically and internationally [26].

The ETS also establishes a carbon price, providing companies with a clear economic signal to internalize the environmental costs of carbon emissions and adapt to changing market dynamics. This allows companies to forecast and plan for carbon-related costs, setting long-term goals and development strategies. Huaneng Group, a leading Chinese electricity producer, developed a long-term green and low-carbon plan by analyzing and forecasting carbon prices, leading to increased investments in clean energy projects to accommodate potential future increases in carbon prices [27].

Compared to carbon taxes, China's carbon trading system demonstrates a significant advantage in promoting dynamic efficiency [28]. This system enables companies to adapt to continuously changing market conditions and technological advancements. During periods of economic growth, companies might purchase additional emission allowances to support production expansion, while in economic downturns, they could sell surplus allowances for income. This flexibility ensures the stable operation of China's ETS under various economic conditions, while also encouraging companies to embrace technological innovation. For instance, BYD, a Chinese electric vehicle company, has developed and sold low-carbon electric vehicles, reducing its reliance on emission allowances and increasing profits, while also promoting the adoption of new energy vehicle technologies [29].

In summary, China's Carbon Emission Trading System effectively incentivizes companies to adopt economically efficient emission reduction measures through a market-based mechanism. It also fosters innovation in environmentally friendly technologies, contributing positively to global climate change mitigation efforts. By promoting dynamic efficiency and encouraging companies to adapt to market changes, the ETS not only supports China's environmental goals but also enhances its economic resilience and technological progress.

6. Conclusion and policy recommendation

This research utilizes a Difference-in-Difference model to examine the reasons behind the Chinese government's introduction of a carbon emissions trading policy and evaluate its effectiveness. The study aims to assess the necessity and impact of this mechanism on reducing environmental pollution and improving resource allocation. The results indicate that the carbon emissions trading policy positively influences China's emission reduction efforts and proves more effective and feasible than tax policies.

Regional analysis reveals that the policy has the greatest impact on the eastern region, with minimal effects on the central region. This highlights the need for the government to develop more targeted and region-specific policies. Given the regional disparities in carbon emissions, the government should implement differentiated carbon trading rules, applying stricter measures in the eastern region while adopting more pragmatic, locally tailored approaches in the central and western regions.

Additionally, the government should allocate revenues from the ETS and other sources into a dedicated fund for environmental projects. Investment and R&D efforts should focus on new energy sources and systems, which are crucial for reducing air pollution and emissions in China.

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