EVALUATION OF CHINA’S CARBON EMISSION TRADING POLICY SCHEME AND IMPACT ANALYSIS TOWARDS ENTERPRISES TECHNOLOGY INNOVATION

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Abstract

China's economic development, the rapid growth of national industry and manufacturing has resulted in a substantial increase in CO2 emissions in recent decades. Thus, China's carbon emissions trading policy aims to force relevant enterprises to implement low-carbon technology innovation to address environmental challenges. Our study reviews the agenda-setting, formulation, adoption, implementation, impact analysis, and the logic model evaluation of the carbon emission trading policies. Then, we have got two main conclusions. One conclusion is that the carbon emissions trading policies positively impact the green innovation of enterprises. However, this impact has industries, regions and enterprises' scale heterogeneity. Another is that China's legislation and market mechanisms of the carbon emission trading policies should be strengthened and improved. Based on the above conclusions, some crucial implications are suggested to optimize China's carbon trading policy and green innovation of enterprises.

Key Words

Carbon EmissionTrading Policy, Green Innovation, Enterprises, Logic Model

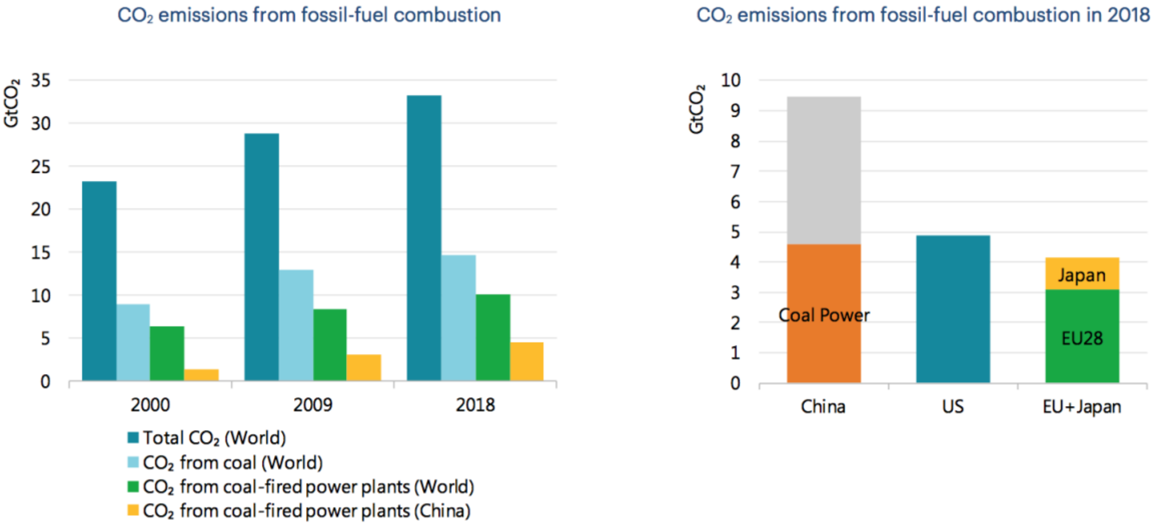
Introduction

As a globally wide environmental issue, global warming is strongly connected with continuously increasing CO2 concentration in the atmosphere and affecting the global temperature (IPCC, 2014). Various policies and strategies are launched to control greenhouse gas emissions. One of the popular market-oriented regulation mechanisms is the emission trading scheme (ETS), which has been adopted in the U.S., New Zealand, and the European Union. China is the world’s second largest carbon emitter, accounting for 27% of global emissions of carbon dioxide equivalent (CO2e) (OECD, 2020). Under such circumstances, the China government promised to reach the goal of reaching the peak of CO2 emission by 2030 and achieve carbon neutrality by 2060. China has implemented carbon trading in pilot areas since 2013 and actively started to establish the national carbon market based on ETS as an environment policy designed within a quasi-experimental framework. This national wide policy generates a wide impact towards national economics, energy industry, and enterprise entities. This paper aims to evaluate China’s carbon emission trading policy through policy life cycle including agenda setting, policy formulation, policy adoption, policy implementation and policy evaluation. Firstly, the background of ETS policy will be introduced, and then the QED experiment used in ETS policy formulation stage will be analysed. Thirdly, prior to implementation analysis, the stakeholder analysis framework will be applied, and this paper mainly focuses on enterprise entities and their interest connection with ETS policy based on Porter hypothesis (1995). Next, the policy carrying out phase will be discussed on the basis of data quality and credibility analysis. As for the impact evaluation part, the DID model is applied to test impacts of ETS policy on enterprise innovation based on R&D, patent measurement and regional analysis. Finally, leveraging a logical model conducts policy evaluation and generates policy implication.

Agenda Setting and Policy Formulation

International responsibility and economic transformation are two main driving forces of ETS policy. With rapid development of China's economy, industrialization and urbanization these years, the energy consumption has also increased rapidly. According to IEA (2019), China CO2 emissions from coal-fired power plants increased between 2000 and 2018 to reach 4.6 GtCO2 demonstrated in Figure1. In this case, the government People’s Republic of China (hereafter, “China”) takes its corresponding Nationally Determined Contribution (NDC) to the Paris Agreement on climate change and its long-term low-carbon strategy. The specific climate goals and promises including China's carbon intensity will be reduced by 60% to 65% compared with 2005 by 2030, and the peak will be realized by 2030 at the latest, meanwhile, strive to achieve carbon neutrality by 2060 (IEA, 2019). Another macro context of this policy is China's economy entering a “new normal state”, with economic growth rate gradually slowed down and facing resources and environment challenging (Song et al., 2018) and it is necessary to transfer energy construct.

Figure 1: IEA (2019), CO2 Emissions from Fuel Combustion 2019 and IEA (2019b), World Energy Outlook 2019 for 2018 data



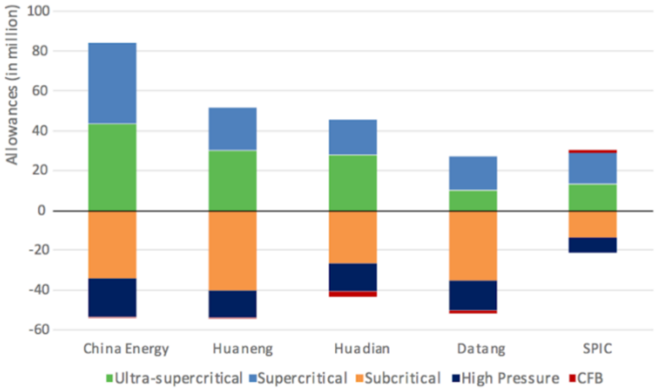
In face of tremendous international community pressure and severe domestic environmental and economic problems, ETS policy is introduced nationwide, aiming to promote the application of market mechanisms and control green gas emission with relatively lower cost. Meanwhile, the government also intended to force enterprises to carry out low carbon technology innovation, which can accelerate the economic development mode transformation (Zhang et al., 2019).

The policy is formulated based on the Quasi-experimental design (QED) framework. QED means, instead of randomly assigning subjects to intervention group and control group, two groups are formulated through various and non-random processes, which is an effective method to determine the impacts of policy or program (Newcomer, Hatry & Wholey, 2015). The carbon trading pilots in China are not randomly selected but are artificially selected according to the observable factors. The city pilots have three phases in total. Firstly, in 2010, the National Development and Reform Commission of China (NDRC) initiated the first low-carbon pilot program, including five provinces (Guangdong, Hubei, Liaoning, Shaanxi, and Yunnan) and eight cities across the country. In the second phase, in 2012, Hainan province and 28 cities were included in the pilot cities. In the third phase, in 2017, 45 more cities were included. Due to the data availability, there are 71 low-carbon pilot cities in the final sample. Compared with the control group, these pilots are mainly concentrated in China’s western region and to the right of “Hu line” which divides China geography into two zones with significant diversities in both socioeconomic conditions and natural environment. The outcome indicates the difference between control groups, i.e. cities without low-carbon policy and treatment group, i.e. these pilot cities with low-carbon policy are statistically significant at the 1% confidence level using a two-tailed t-test (Yu & Zhang, 2021). The relevant indicators include labor force, capital input, energy consumption. This result provides evidence that low-carbon city pilot policy plays a vital role in driving carbon mitigation across cities in China. Moreover, the impact of low-carbon policy in the treated cities was 0.017 and the impact on neighboring untreated cities is about 64% of that on the treated cities (Ibid). This Quasi-experiment provides references for low-carbon strategy and improving carbon emission efficiency and endorsement for ETS introduction.

Enterprise Entities as Key Stakeholder

Stakeholder refers to individual, group or organizations, who can impact or be impacted by a policy evaluation process or its result (Newcomer, Hatry & Wholey, 2015). ETS policy is a way to add carbon prices to leverage market mechanisms. In this market, enterprises, as a major source of green gas emission, are the main entity to transact the emission quota. Thus, the enterprise is a critical stakeholder of ETS policy. As for concentrated industry of enterprise, the power sector and manufacturing, with electricity (40%) and industry (29%) alone making up more than two-thirds of the nation's total greenhouse gases emissions. Additionally, such sectors are dominated by large state-owned enterprises (SOE) in China, for example, 5 biggest SOEs in China power sector including CHN Energy, Huaneng Group, Huadian Group, Datang Corporation and State Power Investment Corporation make up more than half of China's installed coal capacity. Meanwhile, in 2018, these companies produced approximately 2.5GtCO2 from their planets, which account for more than 50% of China's annual emissions from the entire coal-fired power fleet. According to the IEA report (2021), three of the top five power SOEs could receive an allowance surplus in the Balanced Case, opening the possibility of windfall profits and remaining two companies could face great stringency with a deficit of CNY 36.2 million, as demonstrated in figure 2.

Figure 2: IEA (2019 b), Allowance balance by technology and company in the Balanced Case



Company	Allowance Balance (million)	Value (million CNY)
China Energy	29.8	1 283
SPIC	9.2	397
Huadian	1.6	68
Huaneng	-2.9	-126
Datang	-25.2	-1 082
Other companies	-8.1	-347

However, whether related enterprises are motivated to react in the way which meets the expectation in the policy formulation stage is worthy to be discussed. The key government expectation through ETS policy is to motivate companies to upgrade technology and achieve energy transition. According to Porter Hypothesis (Porter & Linde, 1995), the correlation between environmental policy and enterprise innovation do exist. Innovation offset effect can be generated through reasonable environment policies in terms of enterprises being motivated to conduct innovation activities. Such technology innovation activities improve enterprises competitiveness and productivity, and the social welfare created can make up or even exceed environmental regulation costs. Nevertheless, whether enterprises can benefit from environmental policy largely depends on whether the policy can promote the technology innovations of enterprises, and the effect scale matters. There are three mainstream perspectives. Firstly, environmental policy could obstruct enterprise technology innovation (Carrionflores, Innes, & Sam, 2013) as increasing cost weaken enterprise innovation ability and increase enterprise cash flow stress. Secondly, environmental policies promote the technology innovation of enterprises and increase environmental related patents (Chang & Sam, 2015; He & Shen, 2017; Rubashkina, Galeotti, & Verdolini, 2015). Thirdly, the relationship is uncertain, and the impact could be insignificant (Ibid).

The enterprise, as a significant policy stakeholder, is tied to the policy. If the ETS policy can generate a positive effect, enterprises tend to cooperate and actively participate in this policy, as a result, it can be implemented to a great extent and be more sustainable, furthermore make policy impact more significant. An evidence-based analysis of policy impact towards enterprise will be discussed later.

Implementation and Data quality

Policy implementation refers to the phase when action is taken to address public problem and High-quality data is critical to the implementation of ETS policy and the continued expansion of policy coverage. At this stage, the policy proposal is implemented by the respective government departments and agencies, in cooperation with other relevant organizations (Newcomer, Hatry & Wholey, 2015). Currently, China's ETS policy has already entered the “Market Operation” implementation phase, which is outlined by National Development and Reform Commission (NDRC) (China Dialogue, 2021). In this stage, the government needs to first decide covered industries, greenhouse gas ranges and thresholds in this carbon transact market, and then set the allowed carbon emission quota of greenhouse gas in every sector. With the total industry quota set, the carbon emission quotas among enterprises needed to be decided by the government, which can be freely transacted between companies. In this mechanism, enterprises need to pay the government a carbon quota equal to actual carbon emission at the end of each trading period.

During the implementation process of the market operation, it is critical for the government to determine the quota and develop a credible CO2 emission accounting system, both in industry level and enterprise level. Hence, the supporting data source and data quality is of great importance. Since 2011, eight regional emissions trading systems (including Shenzhen, Shanghai, Beijing, Guangdong, Tianjin, Hubei, Chongqing and Fujian) were consecutively introduced in different parts of China. These pilots provide supporting data of carbon pricing and the regulation volume of caps based on carbon emissions per unit of GDP. However, China gains enterprise emission data through enterprise self-report, which could lead to more widespread data manipulation when the government lacks monitor funds and expertise. Meanwhile, enterprises may not have full capacity to measure and report data accurately. Considering China's administrative system, local governments need to assemble local companies self-reported emission data and report them to higher level governments. And the data will serve as a basis for higher levels of government to evaluate the performance of lower levels of government (Ghanem and Zhang, 2014). As a result, the reliability of data source could be questionable.

A study (Zhang et al., 2019) compared enterprises' self-report CO2 emission with emissions verified by third party in Beijing and Hubei pilot emission trading system. The outcome is that the average discrepancy is statistically significant in Beijing, falling from 17% in 2012 to 4% in 2014 and 2015, while statistically insignificant in Wuhan, decreasing form 6% in 2014 to 5% in 2015 (ibid). Currently, the report verification process in Beijing is that each report is rated by three independent experts and the process is fully funded by Beijing government on some occasion to guarantee independence of external monitor. Nevertheless, such pattern is challenging to replicate nationwide in terms of the high financial cost of third-party verification and corresponding high government administrative cost.

Currently, the national carbon market mainly covers power industries with more than 2,000 power generation facilities enlisted thanks to its complete, accurate, standardized basic data (Carbon Brief, 2021). Petrochemical, chemical, building materials, steel, nonferrous metals, paper, aviation and other high-emission industries will be added into carbon trade market subsequently. Moreover, firms' carbon emission data will gradually open to financial institutions as a reference for them to provide financing service and financial derivatives such as carbon futures, options and forward contracts. In conclusion, the reliability and accuracy of current data quality needs to be further improved as the mechanism needed to include more enterprises from various sectors and individuals as trading subjects, and financial carbon products in the future implementation phase.

Impact Evaluation and Data Analysis

Impact evaluation provides information about the impacts produced by an intervention. The ETS policy mainly targets carbon-intensive enterprises in pilot regions. In the impact evaluation part of this paper, we will represent the concept of green innovation by the number of innovation patents and the amount of R&D investment, respectively, and then measure the impact of ETS on green innovation from both enterprises and regional perspectives.

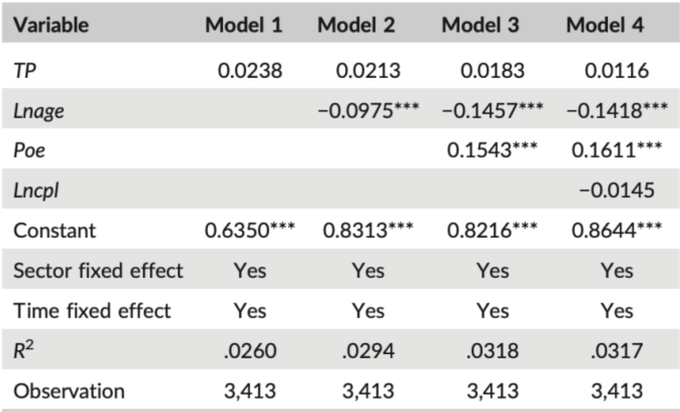
The difference-in-differences (DID) model can be applied to dividing samples into experimental groups and control groups according to the time and location of the effect, based on which the ETS policy can be evaluated and compared. Years before 2011, namely before the introduction of the policy, are taken as non-pilot years, while those after 2011 are taken as pilot years. In this regard, the experimental group includes enterprises affected by the policy in pilot cities, while the control group includes those from other non-pilot cities and provinces. Therefore, the three studies involved in the following part fall into the Quasi-experimental design (QED). In the DID model, the dependent variables serve as indicators of green innovation, which differ from each other in measuring green innovation. Among the independent variables, the interaction term “TP” is the most important one, which is obtained by multiplying T and Pilot. Before the implementation of the policy, T=0, while after that T=1. If the ETS covers the target enterprises, then Pilot=1, otherwise Pilot=0 (Zhang et al., 2020). TP is applied to show whether the policy is implemented and whether the policy covers relevant enterprises. In addition, different studies tend to contain other different independent variables related to respective purposes.

The data mentioned in the study is panel data in China from 2008 to 2017, covering 456 companies in 8 industries: namely, Steel, Building, Power, Aviation, Petrochemical, Chemical, Nonferrous, and Paper. Specific sources for data include State Intellectual Property Office, Wind database, China Energy Statistical Yearbook, etc.

The effect of ETS on green innovation in patent aspect

In this research, the total number of green innovation patents each year is applied to measuring the enterprises' green innovation. Invention patents are characterized by novelty, creativity, and practical application value, which implies it can be taken as an indicator measuring the innovation capability of enterprises. The independent variables include four elements as follows. TP is used to indicate whether the policy is implemented and covers relevant enterprises. Image shows the logarithm of the number of years after listing enterprises; Poe shows whether an enterprise belongs to state-owned enterprises. If it is, Poe=1, otherwise Poe=0; Lncpl means the logarithm of per capita fixed assets. Model 1, a benchmark model, only contains one independent variable, TP; based on Model 1, Lnage, Poe, and Lncpl are added to Models 2, 3, and 4 (Zhang et al., 2020).

Table 1: The effect of ETS on enterprises’ green innovation (patent)

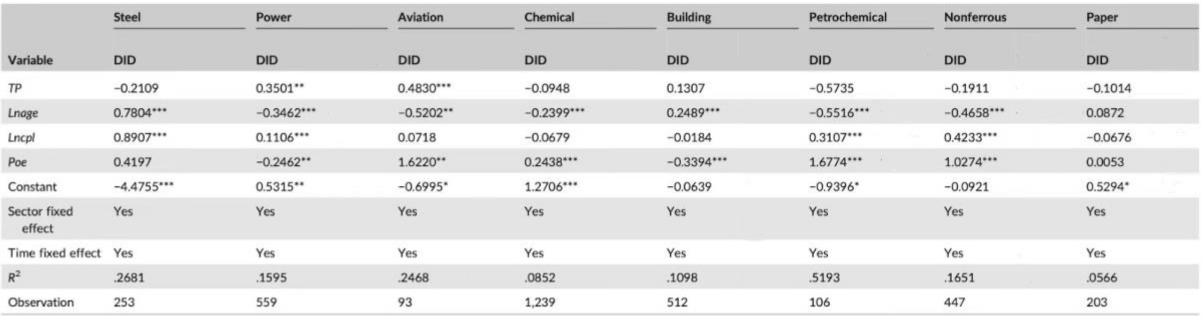


Variable	Model 1	Model 2	Model 3	Model 4
TP	0.0238	0.0213	0.0183	0.0116
Lnage		−0.0975***	−0.1457***	−0.1418***
Poe			0.1543***	0.1611***
Lncpl				−0.0145
Constant	0.6350***	0.8313***	0.8216***	0.8644***
Sector fixed effect	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes
R^2	.0260	.0294	.0318	.0317
Observation	3,413	3,413	3,413	3,413

Through Table 1, it can draw the following findings. Firstly, for the most critical variable, TP, its coefficient is valued between 0.011 and 0.025, the p-value is greater than 0.1. It indicates the higher technology innovation in enterprises covered by ETS, which is not statistically significant. In terms of the number of patents, the effect of the policy is not obvious. After implementing the policy, enterprises would try to reduce carbon emissions through measures such as investment adjustment, changes in energy structure, and advanced equipment procurement (Mi et al., 2018). However, such efforts have not significantly improved the level of technology innovation of enterprises. In addition, it has been short since the introduction of China’s ETS policy, but it takes quite a long period for enterprises to innovate their technology (Wicki & Hansen, 2019). In this sense, it is hard for an enterprise to produce a large number of new invention patents in a short time. But conditions may improve over time, leading to more significant results.

Moreover, the listing years of an enterprise and its nature, namely whether it is a state-owned enterprise, tend to greatly impact the green innovation, with p-value less than 0.01. On the one hand, the listing years of an enterprise have a negative relation with green innovation since young enterprises are often more willing to engage in innovation (Atanassov, 2013). On the other hand, the nature of an enterprise, whether it is a state-owned enterprise, significantly impacts green technology innovation. In China, state-owned enterprises are more abundant in the capital and are more subject to policies. Meanwhile, it is easier for them to improve technology innovation through administrative and other means.

Table 2: The effect of ETS on enterprises' green innovation in various industries (patent)



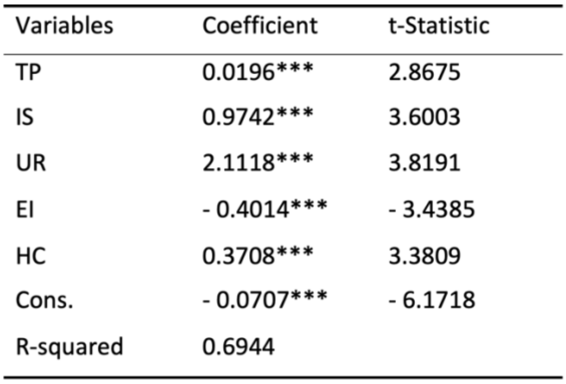
	Steel	Power	Aviation	Chemical	Building	Petrochemical	Nonferrous	Paper
Variable	DID	DID	DID	DID	DID	DID	DID	DID
TP	−0.2109	0.3501**	0.4830***	−0.0948	0.1307	−0.5735	−0.1911	−0.1014
Lnage	0.7804***	−0.3462***	−0.5202**	−0.2399***	0.2489***	−0.5516***	−0.4658***	0.0872
Lncpl	0.8907***	0.1106***	0.0718	−0.0679	−0.0184	0.3107***	0.4233***	−0.0676
Poe	0.4197	−0.2462**	1.6220**	0.2438***	−0.3394***	1.6774***	1.0274***	0.0053
Constant	−4.4755***	0.5315**	−0.6995*	1.2706***	−0.0639	−0.9396*	−0.0921	0.5294*
Sector fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	.2681	.1595	.2468	.0852	.1098	.5193	.1651	.0566
Observation	253	559	93	1,239	512	106	447	203

Even though ETS exerts a slight impact on enterprises' green innovation, regarding each industry, it shows an influence of industrial heterogeneity. The p-value of TP is less than 0.05 for the Power industry, while less than 0.01 for the Aviation industry, which are statistically significant. In the other six industries, the coefficient of TP is not significant. ETS has significantly improved green innovation in the Power and Aviation industries. In China, the Power industry ranks top 1 for carbon emissions (Wen et al., 2017). In 2020, China reached 1,245 GW regarding the thermal power installed capacity, accounting for more than 60% of the overall installed capacity. The Power industry recorded 37% of the national carbon emissions. In this sense, the Power industry tends to be the number one covered by the ETS policy and suffers the most influence. Relevant policies have imposed tremendous pressure on the Power industry, in which case enterprises in this field have further reduced carbon emissions through technology innovation. Therefore, these enterprises have witnessed enhancement in their technological innovation capabilities. The Aviation industry ranks last in carbon emissions, but it grows at the fastest speed (Nava et al., 2018). Given the low-profit margin of the Aviation industry, the increase in the price of carbon emissions may further squeeze their profit. In this case, the Aviation industry hopes to reduce the cost of carbon emissions while instead striving for innovation in various forms.

The effect of ETS on province green innovation

The second research applies the number of patents to measure green innovation. The difference lies in the changes in the research objects from the original enterprises to the current provinces. A province can be represented by all enterprises in the pilot area covered by the policy. Independent variables also include industrial structure (IS), urbanization level (UR), human capital (HC), energy consumption intensity (EI), which are the control scalars that could affect green innovation at the provincial level (Liu et al., 2022).

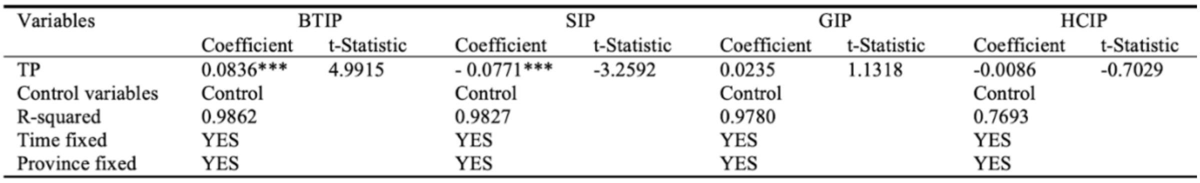
Table 3: ETS and green innovation



Variables	Coefficient	t-Statistic
TP	0.0196***	2.8675
IS	0.9742***	3.6003
UR	2.1118***	3.8191
EI	- 0.4014***	- 3.4385
HC	0.3708***	3.3809
Cons.	- 0.0707***	- 6.1718
R-squared	0.6944	

From Table 3, the regression coefficient is 0.0196. The p-value is less than 0.01 for the interaction term, indicating a significant impact of the ETS policy on the green innovation of provinces in the pilot area. In summary, ETS promotes the development of green technology innovation in the entire region, including renewable energy utilization, green technology R&D investment, and construction of a clean energy system, thereby realizing carbon emission reduction. Furthermore, the p-values of IS, UR, HC, and EI are also less than 0.01, implying a significant impact of the ETS policy on the green innovation of provinces. Among them, IS, UR, and HC refer to economic level, knowledge level, and technical level, which all positively impact green innovation. But EI has a significantly negative effect on green innovation.

Table 4： ETS and green innovation in different regions



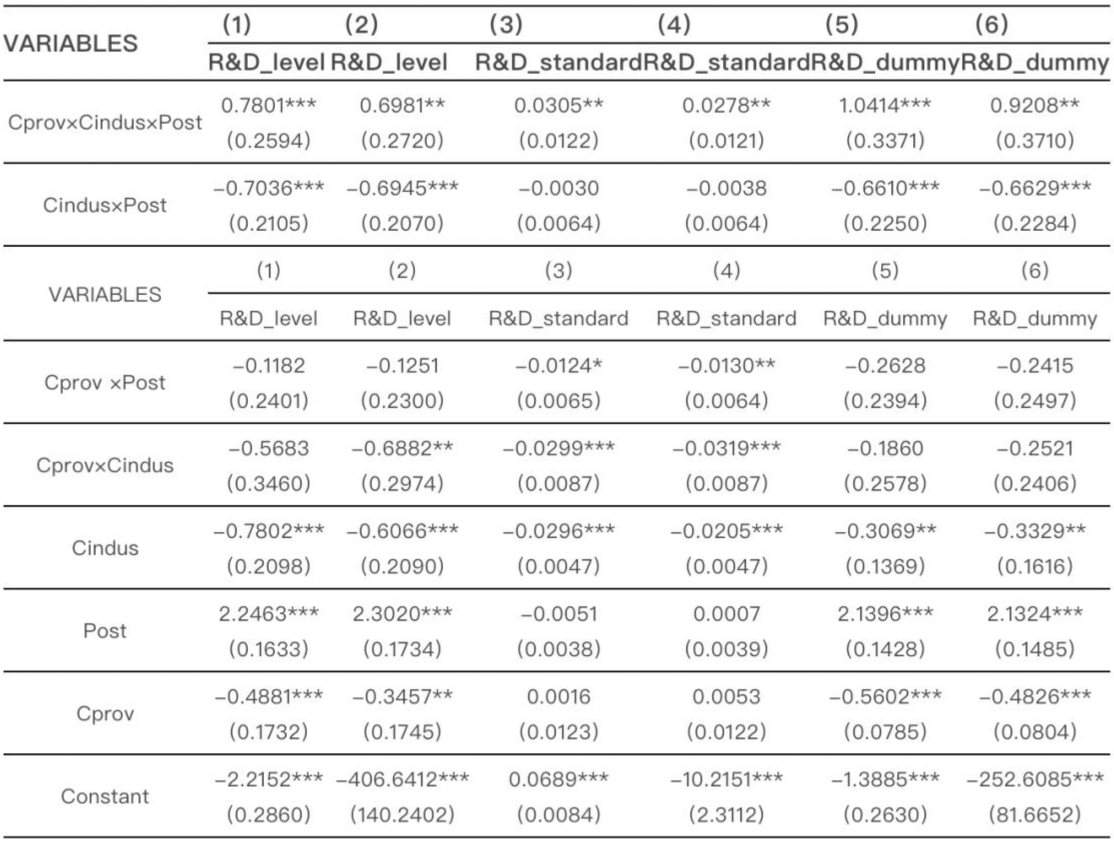
Variables	BTIP		SIP		GIP		HCIP	
	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic
TP	0.0836***	4.9915	- 0.0771***	-3.2592	0.0235	1.1318	-0.0086	-0.7029
Control variables	Control		Control		Control		Control	
R-squared	0.9862		0.9827		0.9780		0.7693	
Time fixed	YES		YES		YES		YES	
Province fixed	YES		YES		YES		YES	

The pilot provinces fall into four regions: Beijing-Tianjin (BTIP), Shanghai (SIP), Guangdong (GIP), and Hubei-Chongqing (HCIP). Among them, the ETS policy has a significantly positive effect on the region of Beijing-Tianjin. Markets in this region are more willing to alleviate pressure from emissions quota constraints through green innovation, which enhances innovation motivation. As for the area of Shanghai, the ETS policy shows a significantly negative effect on green innovation, which can be attributed to two possible reasons. Firstly, in response to the increased cost burden of the ETS policy, enterprises have chosen the reduction in production rather than green innovation, as the latter takes a long time to satisfy results. Secondly, there is the lowest entry threshold of China Registered Emissions Reduction policies in Shanghai, which results in an active carbon trading market in Shanghai (Wen and Xu, 2018). In this context, enterprises are more inclined to buy carbon emission permits than engage in green innovation. The ETS policy reveals an insignificant impact on regions of Guangdong and Hubei-Chongqing, but for different possible reasons. For the area of Guangdong, it has already been the leader in China's green technology innovation. It has achieved the goal of green and sustainable development before the arrival of the policy (Peng et al., 2021). Therefore, the ETS policy does not play a significant role in Guangdong. As for the region of Hubei-Chongqing, it still heavily relies on high-energy-consuming industries. Enterprises in this region tend to take a negative attitude, thus posing obstacles to implementing the policy. In this case, the carbon trading markets face a slack season.

The effect of ETS on green innovation in the R&D investment aspect

In the third study, Liu divided the sample enterprises into three groups, namely, enterprises of pilot industries in pilot provinces (treatment group), enterprises of non-pilot industries in pilot provinces (control group 1), and enterprises in non-pilot provinces (control group 2) (2017). In addition, the element of R&D investment is used to measure enterprises' green innovation. R&D_level indicates the R&D investment intensity, that is, R&D expenditure/total sales revenue*100%. R&D_standard refers to the standardized R&D intensity, which is obtained after the standardization of the R&D intensity of the industry to which the company belongs. R&D_dummy indicates whether the enterprise engaged inR&D investment that year.

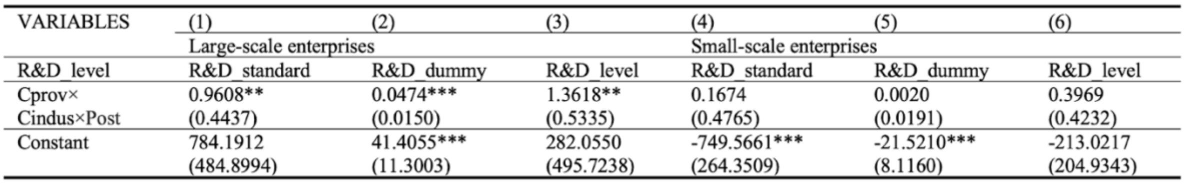
Table 5: The effect of ETS on enterprises’ green innovation (R&D investment)



VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	R&D_level	R&D_level	R&D_standard	R&D_standard	R&D_dummy	R&D_dummy
Cprov×Cindus×Post	0.7801*** (0.2594)	0.6981** (0.2720)	0.0305** (0.0122)	0.0278** (0.0121)	1.0414*** (0.3371)	0.9208** (0.3710)
Cindus×Post	−0.7036*** (0.2105)	−0.6945*** (0.2070)	−0.0030 (0.0064)	−0.0038 (0.0064)	−0.6610*** (0.2250)	−0.6629*** (0.2284)
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	R&D_level	R&D_level	R&D_standard	R&D_standard	R&D_dummy	R&D_dummy
Cprov ×Post	−0.1182 (0.2401)	−0.1251 (0.2300)	−0.0124* (0.0065)	−0.0130** (0.0064)	−0.2628 (0.2394)	−0.2415 (0.2497)
Cprov×Cindus	−0.5683 (0.3460)	−0.6882** (0.2974)	−0.0299*** (0.0087)	−0.0319*** (0.0087)	−0.1860 (0.2578)	−0.2521 (0.2406)
Cindus	−0.7802*** (0.2098)	−0.6066*** (0.2090)	−0.0296*** (0.0047)	−0.0205*** (0.0047)	−0.3069** (0.1369)	−0.3329** (0.1616)
Post	2.2463*** (0.1633)	2.3020*** (0.1734)	−0.0051 (0.0038)	0.0007 (0.0039)	2.1396*** (0.1428)	2.1324*** (0.1485)
Cprov	−0.4881*** (0.1732)	−0.3457** (0.1745)	0.0016 (0.0123)	0.0053 (0.0122)	−0.5602*** (0.0785)	−0.4826*** (0.0804)
Constant	−2.2152*** (0.2860)	−406.6412*** (140.2402)	0.0689*** (0.0084)	−10.2151*** (2.3112)	−1.3885*** (0.2630)	−252.6085*** (81.6652)

Columns 1, 3, and 5 in Table 5 represent the regression results without adding other control variables. Columns 2, 4, and 6 refer to those adding other control variables such as total year-end assets, enterprise net profit rate, and asset-liability ratio. The original interaction term is expanded to include three items in this study; Cprov indicates whether it is a pilot province or city covered by the policy; Cindus indicates whether the enterprise falls into policy-influenced industries; Post means whether the ETS policy pilot covers the enterprise. The estimated coefficient of Cprov×Cindus×Post is significantly positive, indicating that the ETS policy helps promote more R&D investment activities and encourage technology innovation. According to the results in Columns 5 and 6, few enterprises of the treatment group tend to engage in R&D investment before the implementation of the ETS policy, which is opposite to the situation after the arrival of the policy. Therefore, all the empirical results in Table 5 prove that the ETS policy in China has a significantly positive effect on the R&D and innovation of enterprises.

Table 6: Green innovation effect of ETS and enterprises scales



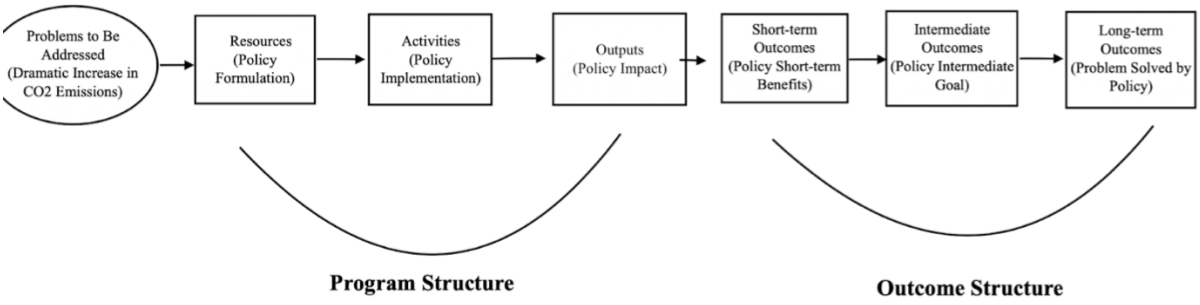
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Large-scale enterprises			Small-scale enterprises		
R&D_level	R&D_standard	R&D_dummy	R&D_level	R&D_standard	R&D_dummy	R&D_level
Cprov× Cindus×Post	0.9608** (0.4437)	0.0474*** (0.0150)	1.3618** (0.5335)	0.1674 (0.4765)	0.0020 (0.0191)	0.3969 (0.4232)
Constant	784.1912 (484.8994)	41.4055*** (11.3003)	282.0550 (495.7238)	-749.5661*** (264.3509)	-21.5210*** (8.1160)	-213.0217 (204.9343)

The ETS policy shows the quality of industrial heterogeneity. Since the size of an enterprise may relate to its marginal emission reduction cost, it may further affect its innovation choices under the ETS policy. In this study, those larger than the industry average enterprise-scale companies are considered large-scale enterprises. In contrast, those more minor than the average scale is taken as small-scale enterprises. From Table 6, it can be drawn that for the large-scale enterprises, their estimated coefficient of the interaction term Cprov×Cindus×Post is significantly positive at the 5% significance level. For small-scale enterprises, the coefficient is positive but not significant. Such a result implies that the ETS policy exerts a positive impact only on the innovation choices of large-scale enterprises, which is not the case for small-scale enterprises.

Policy Evaluation Based on the Logic Model

In evaluating whether carbon trading policies can effectively control carbon dioxide emissions, stimulate green technological innovation, and promote energy use and sustainability enterprises, the logic model, a rational model of how a program will work under certain environmental conditions to solve identified problems, can be used as the basis for China's carbon emissions trading policy performance, telling stakeholders how it is qualified to solve the problem (Newcomer et al., 2015). The elements of the logic model are resources, activities, outputs, short-term outcomes, intermediate outcomes, and long-term outcomes (Newcomer et al., 2015).

Logic Model of Carbon Trading Policy on Green Innovation of Enterprises



As for the resources part, ETS is based on a Quasi-experimental design, with 71 pilot cities selected. The statistically significant result provides evidence for the national carbon accounting system and nationwide policy application. Before the policy was released, many experts conducted research and endorsements, which laid a solid foundation for the formation of the carbon emission trading policy.

For the activity structure in the logic model, we can analyze that the effectiveness of the carbon trading system is insufficient and still needs to be improved during the implementation of carbon trading policies. The Chinese government has issued regulations, documents, implementation rules, and guideline standards based on the National Development and Reform Commission to make carbon trading policy operable implementation (IEA, 2020). However, implementing the carbon trading policy generally faces the problem of weak compulsory and binding. Only a few regions in China have issued decisions with high legal effects. Most regions' regulations on carbon trading are of limited effectiveness, and penalties for non-compliant enterprises are not strong enough to form a sufficient binding force, which brings challenges for law enforcement (Zheng, 2019).

At the same time, during the activity structure we also can see that the supervision and verification system are not well developed. China has set carbon emission measurement, reporting, and compliance registers systems to lay a solid foundation for implementing the carbon trading system (Zheng, 2019). However, China's carbon trading verification system is still in its early stages. Most regions lack well-established supervision institutions, making the system somewhat flawed. The quality and accuracy of data resources is a vital aspect. In the absence of government monitoring, data on carbon emissions may be not accurately self-reported by companies (Zhang et al., 2019) . The uncertainty of data quality affects the determination of carbon quota and limits the policy application to more industry, thus reducing the efficiency of policy operation. Moreover, most regions set the total amount of quotas more lenient to reduce the resistance to implementation but no enforcement of control over these unauthorized operations by supervision and verification agencies. Notably, the economic downturn in 2014-2015 led to a further surplus of carbon quotas, resulting in a significant drop in the price of carbon quotas in 2015, which has a negative impact on the effects of the policy (Zheng, 2019).

Then, for the outputs structure in the logic model, we examine the policy impact on green innovation based on the impact evaluation and data analysis. In summary, the main policy impacts are as follows.

Firstly, the impact of carbon emission trading policy on technological innovation shows significant industry heterogeneity. Notably, implementing the carbon emission trading policy contributed to an increase in technological innovation of 0.35% and 0.48%, respectively, for enterprises in the electric power and aviation industries (Zhang et al., 2020). However, carbon emission trading policy has no significant impact on the technological innovation of enterprises in the steel, chemical, building materials, petrochemical, non-ferrous, and paper industries. This heterogeneity exists between the different sectors of enterprise innovation (Zhang et al., 2020). The reason may be that environmental regulation is associated with environmental industry sectors. More severe association impact is, the stronger willingness to improve technological innovation and reduce costs is.

Secondly, there is a regional heterogeneity of the impact of carbon emission trading policy. The policy in Beijing and Tianjin was found to stimulate green innovation, thus contributing to carbon emission reduction (Liu et al., 2022). However, the carbon emissions trading policy in Shanghai, Guangdong, Hubei and Chongqing does not promote green innovation (Liu et al., 2022). These outputs may facilitate the policy's continuous improvement and targeted implementation, making the nation's carbon emission policy orientation for different regions and areas.

Thirdly, the carbon emission trading policy has a significant positive effect on promoting enterprise' green technology innovation. Implementing the carbon emission trading policy can promote enterprises to carry out more research and development investment activities, encourage enterprise technological innovation, and positively affect research and development of green innovation (Liu et al., 2017). Although the carbon emission trading policy has a significant positive effect on the innovation input of large enterprises, it is not significant on the technological innovation of small and medium enterprises (Liu et al., 2017). The reason should be mainly due to the different marginal abatement costs faced by enterprises of various sizes, leading to different emission reduction strategies under the carbon trading mechanism.

Finally, as for outcome structure in the logic model, short-term policy benefit, intermediate goal, and problem solved by policy, three sequential outcomes are included. Currently, policy significantly impacts the energy and electric power industry and improves carbon emission enterprise performance (Zheng et al., 2021). Secondly, the intermediate outcome is the intermediate outcomes, which are expected to result from the short-term outcomes. The ETS policy will apply to seven more industries and allow individuals to enter the carbon trading market. Meanwhile, achieve financialization of China's carbon trading market and transfer mechanism from "output-based" to "volume-based" with more reliable data access. The long-run outcome, as a solution to the environment and economics transformation challenge, ETS policy will promote enterprise green innovation and energy transition. Moreover, as a supportive policy, it enables the realization of reaching the peak of CO2 emissions by 2030 and achieving carbon neutrality by 2060.

Conclusions

Over the past decades, the rapid development of the national industry and manufacturing (such as steel, coal, petrochemical, and power industries), stimulated by China's economic growth, has led to a dramatic increase in CO2 emissions. To address the issue, China successfully implements the carbon trading policy, typically representative of China's environmental regulation policy. This paper reviews the agenda-setting, formulation, adoption, implementation, impact analysis, and the logic model evaluation of the carbon emission trading policies. Based on the above review, we have got two main conclusions.

Firstly, the carbon emissions trading policies have a positive impact on the green innovation of enterprises. However, this impact has industries, regions and enterprises' scale heterogeneity. Specifically, the carbon emissions trading policy has a more significant positive impact on enterprises on aviation and energy industries, in Beijing and Tianjin, and for large enterprises than medium and small companies.

Secondly, China's legislation and market mechanisms of the carbon emission trading policies should be strengthened and improved. China's carbon trading policy has achieved remarkable output on the green innovation of enterprises. However, the market mechanism is imperfect, the law is not well-established, and the supervision and verification system is not mature enough. If these problems are not resolved in time, the primary data will not be accurate enough, which will result in unreasonable quotas and carbon prices of enterprises.

Policy Implications

Based on the above two conclusions, some crucial implications are suggested to optimize China's carbon trading policy and green innovation of enterprises. For the industries heterogeneity, the government should consider the different characteristics of each industry and avoid only one principle for all sectors while promoting emissions trading. The carbon trading policy of the Chinese government should focus on the aviation and the power industry as much as possible, which could stimulate the innovation potential of aviation and power companies and fully utilize the advantages of carbon emission trading policies (Zhang et al., 2020). At the same time, enterprises also need to actively participate in the carbon trading market according to the characteristics of enterprises themselves, further promoting their transformation and enhancing the competitiveness in their industry.

Regional heterogeneity suggests that regions' economic development, human capital, and innovation differences must be fully considered when establishing carbon emission trading policies (Liu et al., 2022). More efficient resource allocation is needed to benefit all areas from the carbon emission trading policy and receive higher green innovation overall, avoiding the imbalance of carbon markets. Thus, the government should implement different carbon emission trading policies based on local conditions.

As for the enterprises' scale heterogeneity, the government should provide more financial support and design more incentives for research and development on green innovation, such as tax refunds, environmental subsidies, low-carbon intellectual property protection, and low-carbon financing systems, particularly for medium and small enterprises (Dou, 2017).

Meanwhile, there is a need to accelerate legislation for China's carbon emission trading market. China needs to reasonably set the access conditions for the carbon emission trading market, improve market mechanisms on supervision and verification, enhance the effectiveness of the implementation of carbon emission trading policy, and form a unified national carbon emission trading system. The government also should take advantage of the policy tools of the carbon trading system, such as carbon emission caps and carbon prices, to guide enterprises to invest in low-carbon technologies (Chen, 2021). In addition, the quotas should be adjusted according to the development stage of enterprises.

In summary, to achieve the realization of reaching the peak of $CO2$ emissions by 2030 and achieving carbon neutrality by 2060. The Chinese government should scientifically design and establish a unified, efficient, standardized, and supervised carbon emissions trading system based on the experience of the pilot areas and provide clear policy guidance as soon as possible.

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