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Emissions trading system (ETS) implementation and its collaborative governance effects on air pollution: The China story

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ABSTRACT

The study aims to employ the difference-in-differences method and mediating effect model to assess panel data of 267 prefectural-level cities in Chinese 30 provinces from 2003 to 2016 and empirically examines whether the Emissions Trading System pilot has realized collaborative governance effects upon air pollution. This study verifies the rationality of the element design of China's Emissions Trading System pilot from the perspective of environmental effects. The results indicate that the China's Emissions Trading System pilot does have a significant 'reduction effect' on haze pollution concentration level, which is probably achieved by 'boosting the application and transformation of green technologies among enterprises' and 'transferring heavily polluted industries'. Moreover, the total quota allocation, total number of incorporated enterprises and the entry of institutional and individual investors were not the significant influencing factors for reducing haze pollution, while the transaction volume of China Certified Emission Reduction and the total penalty amounts incurred play significant roles. The heterogeneity test shows that only Guangdong province's policy has a significantly negative effect on haze pollution concentration. This study provides a new way of thinking for the coordinated governance mode by combining environmental governance and carbon trading scheme. The experiential evidence strongly supports the establishment and improvement of China's Emissions Trading System pilots and the implementation of a unified national carbon market.

1. Introduction

Air pollution and climate change are two vital issues that threaten the sustainable development of humankind. Gas emissions and other energy consumption activities not only pollute the air but also have a negative impact on the global climate change. So far, these two issues have been managed separately, failing to achieve an expected coordinated governance results, and raising the total social cost (Harlan and Ruddell, 2011; Rao et al., 2013). Chinese government's management and control measures for air pollution mainly focus on administrative governance, while market-based mechanisms have been relatively underused. In terms of administrative governance, the measures are primarily temporal in nature, involving an odd-even rationing policy, suspending the operations of factories and construction projects, etc. However, the overuse of mandatory administrative measures tends to discourage emitters' emission reduction initiatives as well as distorting the market (Mulder, 2011). Since 2013, the intense and extensive prevalence of haze and its frequent occurrence has accelerated the moves towards a Chinese carbon-trading scheme. On October 29, 2011, the National Development and Reform Commission proposed piloting carbon emission trading in seven provinces and cities, comprising Beijing, Shanghai, Tianjin, Chongqing, Hubei province, Guangdong province, and Shenzhen – the scheme being initiated in June 2013.

As a market incentive enabler, the emission trading system (ETS) pilot not only could promote the development of energy saving and the emission reduction process, and enhances sustainable growth, but also offers new capital bonus for sustainable development and stimulates environmental and ecological governance (Zhang, 2015; Tao and Duan,

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2015). As it is well known, air pollutants and carbon dioxide are all primarily derived from the combustion of coal, petroleum, and natural gas, which arise from the same source. By reducing carbon dioxide emissions in the carbon trade market, Sulphur dioxide, nitrogen dioxide, and other air pollutants can also be reduced. Therefore, establishing a carbon trade market can not only reduce carbon emissions but also collaboratively curb air pollution and improve the quality of the atmosphere. Moreover, the China Certified Emission Reduction (CCER) carbon trade system has become a new approach for air pollution governance, in which emitters can obtain certified emission reduction issued by the National Development and Reform Commission by developing CCER projects. On the one hand, the emitters can use the certified emission reduction amounts to trade on the carbon market. On the other hand, Government could “monetize” carbon and haze pollution by initiating social capital and making full use of carbon trading (Wang et al., 2014). Therefore, investigating the impact of the carbon market on environment quality will be an effective supplement research for the collaborative governance of China’s Emissions Trading System pilot.

Difference between China’s Emissions Trading System pilot and EU ETS are mainly reflected in four aspects: market size and coverage, total amount setting and quota allocation, flexible mechanism, and enforcement and punishment mechanism. Firstly, in terms of market size and coverage, China covers more than 20 industries and nearly 3000 key emission units. EU ETS covers about 45% of greenhouse gas emissions in the region and 11,000 high energy consuming enterprises in 31 countries. Secondly, in terms of total amount setting and quota allocation, China carbon pilots have set a target of reducing carbon emission intensity by more than 17% by 2015. The EU has set a target of reducing carbon emissions by 40% in 2030 by 1990. Thirdly, in terms of flexible mechanisms, the maximum CCER ceiling for each pilot in China could not higher than 10%, while EU carbon market could not reserve and borrowing in the first and second phases until the third phase. Fourthly, in terms of enforcement and punishment mechanisms, most of China carbon pilots regulate that enterprises will be punished 1–3 times more than the market price if excess emissions happens, while EU enterprises will be fined 40 euros per ton in the first phase and 100 euros per ton in the second phase if excess emissions happens.

This study intends to use the difference-in-differences (DID) method and mediating effect model to assess panel data of Chinese prefectural-level cities from 2003 to 2016 and empirically examines whether the ETS pilots has realized collaborative governance effects upon air pollution. Compared to previous work, the contribution of this study is shown below:

(1) This is the first empirical study to investigate the collaborative governance effects of China’s ETS pilot schemes upon air pollution. The previous literatures concerning emission reduction and the environmental effect of carbon trade policy generally revolves upon carbon emissions and its intensity (Li and Zhang, 2017), rather than looking at the collaborative governance effects between ETS and air pollution.
(2) Due to data availability, most studies on emissions trading have been limited at provincial or industrial level. In order to fully evaluate and compare the different atmospheric environments of carbon pilot and non-pilot cities before and after the pilot scheme, this study intends to comprehensively investigate the air pollutants indices (e.g., haze concentration, industrial smog, and industrial SO_2 emissions) at the prefectural city level. DID model is used as a quasi-experiment tool to empirically test the collaborative governance effects between China’s ETS pilots upon air pollution, which could offer direct experiential evidence and provide a scientific basis for incorporating air pollution effects into carbon trading scheme design.
(3) Existing studies often use an interaction term to study the effect of technological progress and industrial structure upon the environment quality rather than fully investigate their mediating role. In this context, this study examines both the mediator/adjustment effect of the mechanism influencing Greentech progress and the industrial structure on environment quality due to carbon trading. This is also followed by the internal carbon market policy & system design and investigates its environmental effect by using the fixed effects model.

The study also examines such different content in the carbon market as the total allocation quota, number of emitters admitted to the market, CCER transaction volume, range of participants, and the punishment mechanism in the fixed effects model to examine their influence on the environment. Finally, the paper offers experiential support and a scientific basis for China to establish and improve its carbon emission trade system and implement a unified carbon trade transaction market nationwide.

2. Literature review

A number of studies outside China have examined the environment effect of ETS pilot. For instance, Dales (1968) was the first to introduce the concept of property right to research into environment regulation to curb pollution, laying a solid theoretical foundation for emission trade studies. Schleich and Betz (2004) employed simulation to reveal that the EU ETS helps reduce emissions. Anderson and Di Maria (2010) empirical studies showed that the EU emission trading system significantly lowered the carbon emissions of the manufacturing industry. Moreover, compared to those not participating in the carbon trade market, emitters admitted to the market have a greater potential for emission reduction. On this basis, a number of current publications argue that China’s ETS has yet to save energy and reduce emission. For instance, Wang and Wheeler (2000) argue that, in many developing countries, the implementation of environmental protection is significantly endogenous. Moreover, Li et al. (2019) use empirical examination to find that the ETS pilots in some parts of China had not brought about emission reductions. Shin (2013) points out that there is not an institutionalized Sulphur dioxide (SO_2) emission transaction in place in the ETS pilots and the system is a failure in China. Cheng et al. (2016) CGE model simulations of Guangdong province found the ETS lowers SO_2 and nitrogen oxide emissions in Guangdong province by 33% and 31% respectively by 2020 from the 2010 level. Tu and Shen (2015) argue that the reasons of low market liquidity in SO_2 emission trading system, as it does not attract as much attention as China’s ETS pilots. All the above demonstrate that the best practices outside China show that emission trading produces remarkable emission reductions.

In terms of non-market policies and factors relating to the coordinated control of haze pollution, many studies find that directive environmental policies, spatial network structures, and energy efficiency improvement have an important impact on the coordinated control of haze pollution in China. Zhang et al. (2019) study the indirect impact of environmental regulation on haze pollution governance using the GMM method, they argue that China’s current environmental regulation has effectively inhibited haze pollution. Li et al. (2019) find that the increase in network density, decline in network grade, and decrease in network efficiency are important influencing factors of the collaborative governance of haze concentration in China. Zhang et al. (2019) estimate that the increase in energy efficiency of China’s steel industry 1% will decrease both raw material input and SO_2 emissions by 14%, but increase $PM_{2.5}$ emissions by 20%.

In terms of emission reductions from emission trading, a common practice is to simulate the data to analyze and compare the difference between the carbon emissions of the ETS and non-ETS. For instance, Ellerman et al. (1998) forecast the carbon emissions from 2005 to 2006, and found that Europe would cut carbon emission by around 5,000,0000 tons (around 2.4%) in 2005. From 2005 to 2006, the total emission reduction is around 100 million tons (around 4.7%). Their study also analyzed the relationship between the price of carbon and the price of coal and gas in the first two stages of EU ETS and compared both stages. They found that the shift from coal-fired power generation to gas power generation in European power generation enterprises had become the main motivation for emission reduction. Murray et al. (2015) employed an econometric model to analyze the emission reductions from RGGI, finding that economic recession contributes to 1% of emission reduction, while gas contributes to over one third of total volume of emission reduction because of the conversion from coal-fired power generation to the combination of coal-fired and gas power generation. When the above variables are controlled, RGGI is the main contributor to lowered emission in the regulated areas. Due to the short existence of the ETS pilots in China, most studies employ forecast and simulation models to analyze their emission reductions. For instance, Zhao et al. (2016) simulated nationwide carbon transactions in China indicate that, under the dual limitations of economic growth and environmental protection, inter-provincial carbon emission transactions could reduce carbon emission to 7 billion tons, representing a decrease of 27.27%.

The carbon market involves different elements and aspects of system design. Most studies focus on the influence of a scientific and rational system design of the carbon market on market efficiency, market liquidity, and carbon price. In terms of market efficiency, Munnings et al. (2016) believe that other supplementary climate policies reduce the need for carbon transactions, and participants are not familiar with carbon trade, which increases transaction cost. In terms of market liquidity, Zhao et al. (2016) conclude that the total amount of quota, distribution method, the range of industry covered, transaction rules, transaction cost, monitoring, report and inspection, contract fulfilment mechanism, market transparency, and policy and regulations all contribute to the liquidity of the carbon market. In terms of carbon price, Seifert et al. (2008) establish a dynamic computable general equilibrium (CGE) model to investigate the influencing factors of the carbon prices of EU ETS, finding that carbon price does not vary seasonally. In terms of China's carbon trading market, Fu et al. (2017) argue that inconsistencies between the trade mechanisms of the seven ETS pilots are an important factor influencing carbon price stability. From the perspective of different elements of system design, the influence of the scientific of carbon emission reduction targets, rationality of carbon quota allocation, and proportion of CCER offset credits on emission reduction are widely discussed. In terms of emission reduction targets, many studies (e.g., Egenhofer, 2007) conclude that the total quota amount is an important factor influencing emission reductions, and argue that the EU ETS relinquish the power of setting greenhouse gas emission reduction targets to member countries in order to solicit their support (leading to a serious deficiency in demand in the carbon trading market), which is an important reason behind their failure to realize emission reduction targets. Ellerman et al. (1998) and De Perthuis and Trotignon (2014) believe that the "grandfather method" of allocating quota can harm the interests of emitters dedicated to emission reduction and discourage any innovation. Judging from the construction experience of carbon markets in developed countries, the fairness and effectiveness of the carbon emissions trading system are the vital factors responsible for the environmental effects. EU ETS, as the largest and most mature carbon emissions trading market in the world, has made many achievements since its establishment. EU ETS not only encourages enterprises to reduce their emissions by creating a highly liquid carbon trading market, but also greatly promotes the development of Europe's low-carbon industry and the transition of the entire economy to low carbon (Betz et al., 2006; Twomey et al., 2012). However, despite its many achievements in its phased development, many studies have found impediments in the EU ETS's design of carbon market elements from the perspective of environmental effects, emission reduction efficiency, and emission reduction technologies, such as excessive quota allocation (e.g., Flachsland et al., 2009; De Perthuis and Trotignon, 2014). As EU ETS sets its total carbon emissions based on self-reporting by enterprises and for the protection of domestic enterprises, most tend to adopt loose standards in data accounting, resulting excess quotas. The EU ETS quota license was over-allocated by 7.8% and 7.4% in the first and second stages respectively (McAllister, 2009). The excessive supply of carbon quotas leads to inefficient emission reduction measures, which is not conducive to the progress of emission reduction technology.

As a market incentive, a rational ETS scheme could not only promote the development of energy saving and emission reduction, but also serves as an important grab in the collaborative governance of environment. Although existing studies have discussed the influence of the ETS pilots on carbon dioxide emissions and carbon intensity, there is still little discussion of the collaborative influence of air pollutants and the associated influence mechanism. Due to the short existence of China's ETS pilot schemes, there are only a few *ex post* studies on their environmental effect, and most studies use simulation to forecast the emission reduction results. However, with mathematical models, the parameters are largely hypothesized, which does not satisfy the need to plan and evaluate a nationwide ETS implementation policy by 2020.

Moreover, existing studies of the environment effect of carbon trading pilots are often concentrated on such ETS in developed countries as EU ETS and the US SO_2 cap and trade program. Still, there is a lack of studies discussing and examining the collaborative influence of China's ETS air pollution pilots and their influencing mechanism for different areas and scales.

3. Samples and data

3.1. Air pollution index

(1) Prefecture-level samples from 2003 to 2016 are used for the study. Haze ($PM_{2.5}$) data at this level employs satellite and ground survey data from Columbia University's Socioeconomic Data and Application Center. Global $PM_{2.5}$ raster data is obtained by virtue of the GEOS-Chem chemical transmission model; this is matched to the location of each province and prefecture with the precise latitude and longitude values. The annual average $PM_{2.5}$ concentration of each province and prefecture from 2003 to 2016 is extracted by means of the ArcGIS software. After analyzing the raster data, a spatial distribution map of the cold and hot spots (Fig. 1) is plotted by means of spatial analysis technology in order to understand the spatial distribution and temporal trends of the air pollutants in a visual way. This shows that severe haze pollution occurred in eastern coastal areas and central inland areas in 2003, but began to shrink in 2016, and a trend of extending to such western areas as Sinkiang and Tibet. The average haze concentration of the treatment (pilot province/ prefecture-level city) group was consistently higher than the control (non-pilot province/prefecture-level city) group in 2014 prior to the emission trade piloting, but that of the treatment group began to decrease at the beginning of 2015 to 0.86 mcg/m^3 lower than the control group (see Fig. 2).

(2) Other pollutant indices used in this study include the emission volume of smog and SO_2 in Chinese cities from 2003 to 2016. The statistics at the prefecture level are from the China City Statistical Yearbook. In order to examine the overall trend of smog and SO_2 emissions, comprehensive indices are established by the entropy weight method to plot the spatial distribution of the cold and hot spots (Fig. 3). This shows that, from 2003 to 2016, the smog and SO_2 emissions were greatly reduced. The average emissions of the treatment group did not differ much from the control group before and after the implementation of the ETS pilots, with both continuously declining from 2010 to 2016 (Fig. 4). Therefore, how much the ETS pilots play a part still needs further examination.

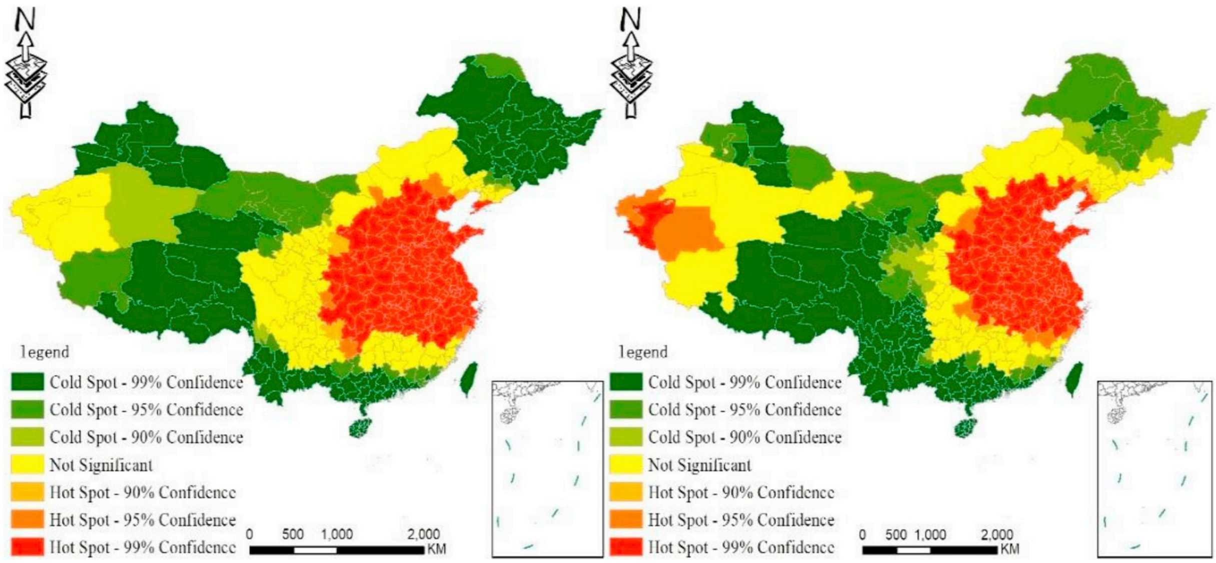

Fig. 1. Spatial distribution map of the cold and hot spots of China's haze ($PM_{2.5}$) pollution in 2003 (on the left) and 2016 (on the right).

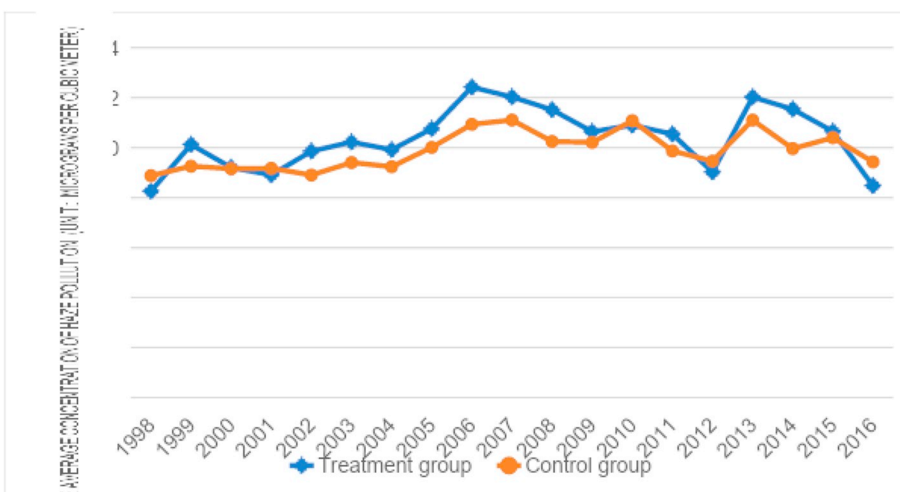

Fig. 2. Changes in average haze concentration of the treatment and control groups over time.

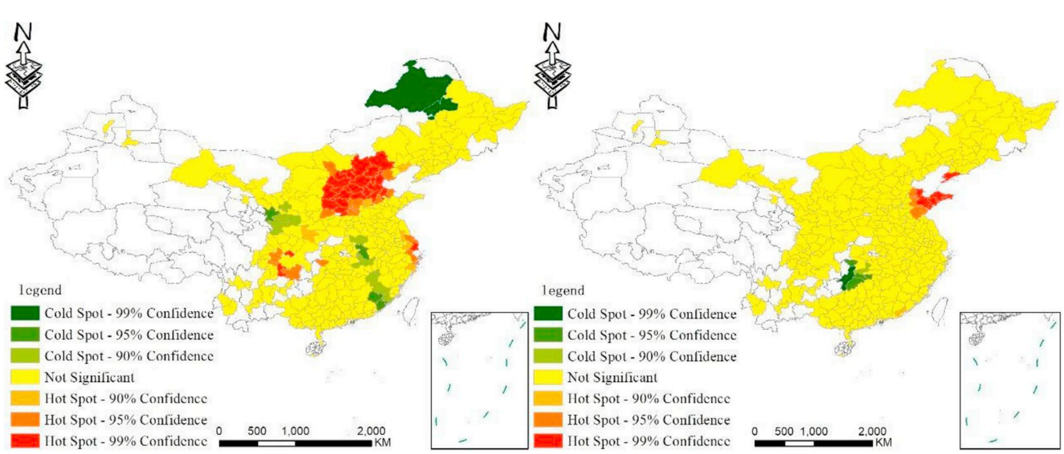

Fig. 3. Spatial distribution map of the cold and hot spots of SO_2 and smog in China in 2003 (on the left) and 2016 (on the right).

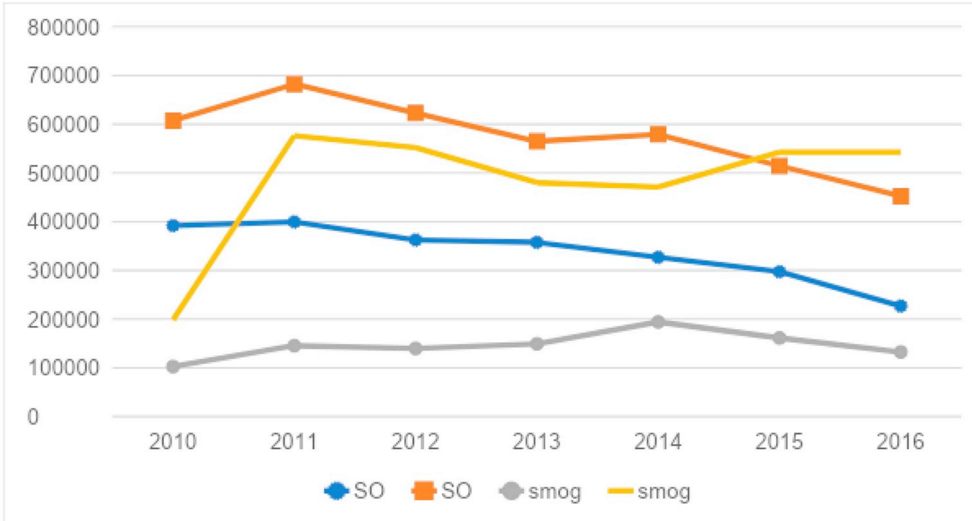

Fig. 4. Average SO_2 and smog levels of treatment and control groups over time.

3.2. The explanatory variables

(1) Emission trading pilot policy. A dummy variable denotes whether a city/province is piloted or not; piloted cities/provinces being assigned a value of 1 or 0 otherwise. The provincial level panel data contains 6 pilot provinces/cities (Shenzhen is part of Guangdong province) and 24 non-pilot provinces/cities, while the prefecture level panel data contains 35 cities and 232 non-pilot cities.

(2) Greentech. Data development analysis (DEA) is used as the primary parameter method, i.e., the Malmquist index of changes in green total factor productivity is calculated, and then decomposed into changes in Green efficiency and Greentech. Green total factor productivity considers pollutants in the environment as undesirable output and thus overcomes the lack of consideration of environmental factors in traditional total factor productivity. In the measurement, regional GDP serves as desirable output; three industrial wastes serve as undesirable output; and labor input, capital stock, and energy input serve as input factors. Of these, the three industrial wastes are used as the degree of pollution in calculating the environmental pollution index by the entropy weight method; labor input refers to the urban employment population, energy input is given by total electricity consumption, and the capital input index is denoted by urban capital stock. Following Zhang et al. (2018), the price index of investment in fixed assets is used, with the year as base period to deflate gross fixed capital formation. Subsequently, capital stock in 2003 is used as the initial value, with the rate of depreciation of each city at around 9.6%.

(3) Proportion of second industry. The proportion of second industry to total GDP is used. As is well known, second industry is the biggest consumer of non-fossil fuel. As a result, the higher its proportion in the industrial structure, the more difficulties it creates for regulating air pollution. Statistics at the provincial level are derived from the China Statistical Yearbook on Environment and statistics at the prefecture level are from the China City Statistical Yearbook.

3.3. Control variables

The control variables are examined from both provincial and prefectural perspectives. In terms of the provincial panel, the control variables comprise *per capita* gross domestic product (pgdp), urbanization level (Urb), energy consumption structure (ES), openness (Open), environment regulation (Reg), and marketization level (Market). For the prefectural panel, the control variables comprise Prefectural GDP growth (PGDP), energy consumption (EC), environment regulation (Reg), added value of the second industry, energy efficiency (EE), annual average temperature (Tem), and annual average rainfall capacity (Rain). Except for annual average temperature and the rainfall capacity, all the prefecture data are derived from past records of the China City Statistical Yearbook, China Energy Statistical Yearbook, Statistical Yearbook of the Chinese Investment in Fixed Assets, and China Population and Employment Statistics Yearbook. The source data for the annual average temperature and the rainfall capacity is from the University of East Anglia's Climatic Research Unit. Based on internal calibration and data integration, the original data is vectorized and the annual average temperature and the rainfall capacity of different prefectures from 2003 to 2016 obtained. The specific implications, calculation methods, and results are shown in Table 1, which contains panel data at the prefectural level and the explained, core explanatory, mediator, and control variables.

4. Model and data

4.1. Validity test: the effects of ETS pilot scheme on air pollutants

The influence of the ETS pilots on air pollutants demonstrates the effects of collaborative governance as a market-oriented environmental regulation policy. Previous studies show that the ETS pilots is remarkably effective in reducing carbon dioxide emissions (Li and Zhang, 2017). Here, we examine whether the policy is effective in controlling the emission of different air pollutants, the air pollutant indices that are significantly affected, and apply to prefectures to deeply examine their robustness and influencing mechanism. Using the Difference-in-differences (DID) model to evaluate the effect on the atmospheric environment serves to control the beforehand difference of the paper object. Separating policy influences from other influencing factors is common in empirical studies of policy evaluation. Accordingly, the DID model is constructed as follows:

$$LnEnv_{it} = \alpha_0 + \alpha_1 Time \times treat_1 + \alpha_2 lnX + \mu_t + \gamma_i + \partial_i + \varepsilon_{it} \quad (1)$$

where the subscript *i* accounts for a province/prefecture-level city and *t* accounts for year. For instance, Env_{it} is the environmental index for province/prefecture-level city *i* in year *t*, including the haze ($PM_{2.5}$) concentration, industrial SO_2, and industrial smog emissions. α_1 refers to the direction and degree of influence of the ETS pilots on haze $PM_{2.5}$

Table 1
Prefecture level panel data.

Variables	Complete sample			Treatment group			Control group			Remarks
	Sample size	Average value	Standard deviation	Sample size	Average value	Standard deviation	Sample size	Average value	Standard deviation	
Haze ($PM_{2.5}$)	3471	37.399	16.35	455	37.86	12.68	3016	37.32	16.838	Unit:mcg/m^3
Prefecture GDP growth (Pgdp)	3471	34320.49	29191.72	455	43805.98	41560.41	3016	33510.3	26456.4	Per capita GDP Unit: yuan
Energy consumption (EC)	3471	753744.9	1298537	455	1722508	2709664	3016	607595.3	819794.6	Total electricity consumption Unit: kilowatt hour
Environment regulation (Reg)	3471	1672560	2652426	455	1611873	4674001	3016	1681715	2192447	Amount of smog reduced Unit: tonne
Structure of second industry (Second)	3471	48.56	11.07	455	47.066	8.59	3016	49.35	10.85	The proportion of added value of second industry to GDP Unit: %
Energy efficiency (EE)	3471	1.011	0.2907	455	1.005	0.292	3016	1.012	0.2904	Green total factor productivity
Temperature (Tem)	3471	14.21	5.325	455	19.41	3.226	3016	13.43	5.13	Annual average temperature Unit: °C
Rainfall capacity (Rain)	3471	1008.13	512.76	455	1501.8	495.79	3016	933.653	472.5	Annual average rainfall capacity Unit: mm
Progress of Greentech (Greentech)	3471	0.9984	0.3852	455	0.993	0.3086	3016	0.9993	0.3955	Green total factor productivity is decomposed into Greentech efficiency and Greentech progress

concentration and three industrial wastes. A negatively significant α_1 indicates that the ETS pilots improved the environment quality, and therefore realizing collaborative governance of the government. A positively significant α_1, on the other hand, indicates that the policy aggravates air pollution. $Time \times treat_1$ refers to whether or not the i province/prefecture-level city was influenced by the ETS pilots in the t period. In other words, if province/prefecture-level city i carries out the emission trade pilot policy in year t, the value is assigned a 1 in year t and the subsequent years, otherwise the value is 0. X denotes the set of control variables. At the prefectural level, these are GDP growth, environment regulation, government R&D investment, industrial structure, annual average temperature, and rainfall capacity. Moreover, equation (1) controls the effects of province/prefecture-level city and time. γ_i is the urban fixed effect, μ_t the time fixing effect, and ε_{it} the error term. In addition, equation (1) controls the province/prefecture-level city and time effect. γ_i is the fixed effect of province, μ_t the fixed effect of year, ∂_i the city effect, and ε_{it} the error term.

In the regression of the prefecture-level city data (shown as Table 2), the ETS pilots significantly influences the $PM_{2.5}$ and SO_2 emissions both at the 1% level as shown in columns (1) to (4). This indicates that the ETS pilots lowered the haze concentration and Sulphur dioxide emissions in the treatment group compared with the control group. In particular, the ETS pilots lowered the haze concentration by 1.136 mcg/m^3 on average, reducing SO_2 emissions by 1.37 tons. As shown in columns (5) and (6), however, the ETS pilots (Time $\times$ $treat_1$) did not significantly influence industrial smog emissions. In short, the ETS pilots significantly reduced haze concentration and SO_2 emissions. According to regression results without the addition of other control variables in columns (1) and (4), the coefficient of the ETS pilots (Time $\times$ $treat_2$) is significantly negative at the 1% level, indicating that, compared to non-pilot cities, the ETS pilots significantly lowers haze concentration and SO_2 emission. In columns (2) and (4), when the control variables are added, the influence coefficient of ETS (Time $\times$ treat) on haze concentration and SO_2 is significantly negative. In column (6), after the addition of the other control variables, the influence coefficient of ETS (Time $\times$ treat) on industrial smog is not significant, indicating that, at the city level, the ETS pilots significantly reduced haze concentration and SO_2 emissions. The ETS pilots lowered haze concentration and SO_2 emissions by 0.933 mcg/m^3 and 0.7452 tons, respectively.

Table 2
Influence of the carbon pilot policy on haze concentration and industrial sulphur dioxide emissions.

	$PM_{2.5}$		Industrial SO_2		Industrial Smog	
	(1)	(2)	(3)	(4)	(5)	(6)
Time $\times$ $treat_2$	−0.0717*** (0.01)	−0.0713*** (0.0111)	−0.4567*** (0.075)	−0.307*** (0.0667)	0.1828 (0.1386)	0.1423 (0.1384)
lnpgdp		−1.126* (0.592)		3.164 (3.539)		4.704 (4.28)
lnpgdp2		0.1467** (0.0775)		−0.2859 (0.457)		−0.6021 (0.5604)
lnml		- 0.0172 (0.0086)		−0.0388 (0.0405)		−0.508*** (0.1088)
lnenergycon		−0.0026 (0.0046)		0.0875 (0.0236)		−0.0227 (0.0329)
lnregulation		−0.0125*** (0.0022)		0.1419*** (0.0204)		0.1102*** (0.0274)
lnsecond		0.0087*** (0.0018)		−0.1133*** (0.0136)		0.0135 (0.0204)
lntem		0.1069*** (0.0279)		0.1101 (0.0739)		0.131 (0.1029)
lnrain		−0.0657 (0.0137)		−0.3622*** (0.0652)		−0.1284 (0.0869)
Constants	3.599*** (0.029)	−0.7059 (0.689)	10.58 (0.0606)	2.844*** (6.564)	10.123 (0.0463)	0.1943 (8.1551)
Time effect	N	Y	N	Y	N	Y
Urban effect	N	Y	N	Y	N	Y
R-squared	0.0078	0.0664	0.0181	0.1392	0.0006	0.0484
N	3471	3471	3471	3471	3383	3383

Note: **and *** denote significance at the 10%, 5%, and 1% levels. The robust standard deviation of clustering at the cities level is given in parenthesis.

4.2. Parallel trend and dynamic analysis

To further verify whether the ETS pilots achieved collaborative governance on the environment, we examine whether the control and treatment groups have the same trends before the DID test. On the hypothesis that prior to the ETS pilots, pilot cities and non-pilot cities have an identical trend, the following regression model is adopted

$$lnEnv_{it} = \beta_0 + \beta_1 Time \times treat_{it} + \sum_{t=2010}^{2013} \beta_t T_{it} + \beta_2 \cdot X + \alpha_i + \gamma_t + \varepsilon_{it} \qquad (2)$$

where Env_{it} denotes the air pollutant emissions – haze concentration (Lnpm) and SO_2 emissions in this context. Dummy variable $Time \times treat_{it}$ refers to whether province/prefecture-level city *i* is affected by the ETS pilots in period *t* (i.e., if province/prefecture-level city *i* carries out the emission trade pilot policy in year *t*, a value of 1 is assigned in year *t* and subsequent years, otherwise the value is 0). Thus, when the year is *t* and it is a pilot province/prefecture-level city, $T_{it} = 1$, otherwise $T_{it} = 0$; when *t* falls in the range of 2014–2016 and *i* is a pilot province/prefecture-level city, the variable value is 1, otherwise it is 0. Accordingly, it is hypothesized that, when ETS is implemented from 2010 to 2013, the coefficients from β_{2010} to β_{2013} are the corresponding policy effect. The hypothesis is supported if the coefficients from β_{2010} to β_{2013} are not significant. Moreover, the coefficients β_{2014}, β_{2015}, and β_{2016} reflect the dynamic effects of ETS over the three years.

The regression results are shown in Table 3. The results in column (1) show the dummy variable coefficients from 2010-2013 are not significant, supporting the hypothesis that using the DID method for evaluation is both reasonable and feasible. The results in column (1) also show that, from 2015, when the ETS pilots began, the ETS pilots had continuous but gradually declining negative effect on haze concentration. From 2015 to 2016, the coefficients stabilize at −0.1%. Since the ETS pilots began in 2014 and the regression coefficient is not significant until 2015, this indicates that there is a phase lag in the influence of the ETS pilots on haze concentration. Meanwhile the results for SO_2 in column (2) are that the coefficients from 2010 to 2016 are not significant, indicating that the influence of ETS on SO_2 emissions does not have a dynamic effect.

The above results indicate that ETS pilots significantly reduces haze concentration and the results are demonstrated by parallel trend and dynamic analysis as reliable and robust. There are three reasons that may be behind this. Firstly, the benchmark regression has significant result on SO_2 while the parallel trend and dynamic effect test does not, which implies that the SO_2 emission trading pilot policy played a more significant role in SO_2 reduction since 2007 (Ren et al., 2019).

Secondly, as well as completing the emission reduction target at a low cost, ETS serves to encourage enterprises to invest in low-carbon technology following the quota price signals implied in the ETS pilots. As a result, the "chain effect" of continuous input of high-carbon technology can be avoided and the enterprises' initiative to upgrade and transform production technology is strengthened. Upgraded and transformed production technology lowers $PM_{2.5}$ concentrations.

Thirdly, since the ETS pilots increases the pressure on emitters to survive, when emitters lack the initiative or ability to invest in the environmental transformation of production technology, some may transfer to another industry. In particular, they might transfer to an industry with an outdated capacity and intense pollution, or from pilot areas to non-pilot areas, which in turn lowers the pollutant emissions of pilot areas. The above empirical results show that the ETS pilots significantly reduced haze concentration. But what is the underlying mechanism involved? Combining the above analysis, the next section continues with a deep discussion of Greentech technology and changes in industrial structure.

Table 3
Trend test and dynamic effect of haze and industrial sulphur dioxide emissions.

Variables	$PM_{2.5}$	SO_2
	(1)	(2)
$Reform_i$, 2010	−0.0484 (0.0402)	−0.5323 (0.5764)
$Reform_i$, 2011	−0.0201 (0.0311)	−0.0626 (0.4477)
$Reform_i$, 2012	−0.0108 (0.02847)	−0.1667 (0.4113)
$Reform_i$, 2013	−0.0259 (0.0233)	−2.184 (0.1028)
$Reform_i$, 2014	−0.1225 (0.0269)	0.0483 (0.4119)
$Reform_i$, 2015	−0.1052*** (0.0397)	0.0481 (0.6836)
$Reform_i$, 2016	−0.1026*** (0.0266)	−0.0856 (0.4068)
Constant term	Y	Y
Control variables	Y	Y
Time Effect	Y	Y
Urban Effect	Y	Y
R-squared	0.233	0.352
N	1251	1251

4.3. Robustness and endogenous tests

(1) The logit double difference method. The logit double difference method can be used as a robustness test after the parallel trend and dynamic effects test. The results in Table 4 show that the carbon emissions in the pilot cities significantly reduced the haze concentration by 1.212 μg/m^3. The estimated results do not differ significantly from the benchmark results. However, the impact of carbon pilot policies on sulphur dioxide emissions is not robust. Hence, we focus on the impact of carbon pilot policies on haze concentration in the later section.

(2) The time window width test. In the robustness test, the focus is on the impact of the ETS pilots on haze concentrations. To further illustrate the robustness of the results, the time window width is changed. In Table 5, we examine the impact of the changes on haze concentration after the implementation of the ETS pilots during the years 2013–2015, 2012–2016, and 2011–2016. The regression coefficients are all negatively significant at the 1% level, which means the implementation of the policy did reduce haze concentration. With the enlargement of the time window width, the regression coefficient decreased from −12.31% to −15.76%, indicating the longer the time distance, the stronger the reducing effect of the ETS pilots on haze pollution concentration.

(3) The multi-temporal DID test. The implementation of the carbon pilot policies of Beijing, Shanghai, Tianjin, and Guangdong started in 2013, while those of Shenzhen, Hubei, and Chongqing began in 2014. To improve the accuracy of the research and solve the endogeneity problem caused by the multi-period execution time in the carbon pilot areas, a multi-time DID model is needed. Table 6 gives the results of using OLS, the Individual Fixed Effect Model, Time Fixed Effect Model, and Multidimensional Fixed Effect Model to solve the time heterogeneity problem, showing that the multi-time DID test results are consistent with the results of the benchmark regression model.

(4) The PSM-DID test. As the chosen of carbon pilots may not be exogenous, there may exist a problem of self-selection. Therefore, the PSM method could help alleviate the deviation caused by the self-selection issue of the carbon market by creating a new sample after obtaining the propensity value. Firstly, we use three different methods to construct different matching samples: nearest neighbor matching, caliper matching, and Mahalanobis distance matching. Secondly, the "Bootstrap" (50 iterations) is used to obtain the standard errors of the statistics to overcome the influence of potential small sample errors. Table 7 shows the estimation results of the average difference in haze pollution between carbon pilot areas and non-pilot areas. The negative average treatment effect (ATE) indicates that the haze pollution concentration in carbon pilot areas is 0.117–0.1691 lower than non-pilot areas.

Table 4
Carbon emission trading policy and haze pollution and sulphur dioxide: Logit double difference results.

Variables	$PM_{2.5}$			SO_2		
	Before Policy	After policy	Double difference result	Before Policy	After policy	Double difference result
Difference	−0.353***	−0.162***	−0.192***	0.087	−0.039	−0.126
Standard error	0.096	0.046	0.105	0.169	0.080	0.185
T value	−3.68	3.55	1.82	0.51	0.49	0.68
P value	0.000	0.000	0.068	0.608	0.626	0.496

Note: **and *** denote significance at the 10%, 5%, and 1% levels. The standard deviation is given in parenthesis.

Table 5
Change the time window width test.

Variable	One year before and after	Two years before and after	Two years before and Three years after
Time × $treat_{it}$	−0.1232**	−0.1485**	−0.1576***
	(0.0589)	(0.0959)	(0.0464)
Control Variable	Yes	Yes	Yes
Sample	801	1335	1602
R-squared	0.3053	0.2901	0.2559

Note: **and *** denote significance at the 10%, 5%, and 1% levels. The standard deviation is given in parenthesis.

5. Discussion

5.1. Analysis: the influencing mechanism

(1) Mediating effect model

The mediating effect model can serve to analyze the process and mechanism between variables (Baron and Kenny, 1986). In order to verify whether Greentech progress and energy efficiency are transmission channels of how ETS influences haze pollution, three observation equations are established. These comprise an observation equation of the explained variable of haze concentration $LnPM_{it}$ to explanatory variable ETS pilot $LnTime \times treat_{it}$ and mediator variable $LnMed_{it}$; an observation equation of explained variable $LnPM_{it}$ to explanatory variable ETS $LnTime \times treat_{it}$; and an observation equation of mediator variable $LnMed_{it}$ to explanatory variable ETS pilot $LnTime \times treat_{it}$ as follows:

$$lnPM_{it} = \beta_0 + s_1 \times \mathrm{Time} \times \mathrm{treat}_{it} + s_2 \times lnX + \partial_i + \theta_t + \varepsilon_t \tag{3}$$

$$lnMed_{it} = \beta_1 + s_3 \times \mathrm{Time} \times \mathrm{treat}_{it} + s_4 \times lnX + \partial_i + \theta_t + \varepsilon_t \tag{4}$$

$$lnPM_{it} = \beta_2 + s_5 \times lnMed_{it} + s_6 \times Time \times treat_{it} + s_7 \times lnX + \partial_i + \theta_t + \varepsilon_t \tag{5}$$

where $lnPM_{it}$ denotes the haze concentration of province/prefecture-level city i in year t, and $LnMed_{it}$ is mediator variable. According to the above analysis, Greentech (lngreentech) progress and the industrial structure are used as the mediator variables to examine its mediating effect. $Time \times treat_{it}$ accounts for whether province/prefecture-level city i is influenced by the ETS pilots in period t. In other words, if province/prefecture-level city i carries out the emission trade pilot policy in year t, the value of 1 is assigned in year t, otherwise the value is 0. s_i refers to the variable coefficient of influence of the explanatory variable on the explained variable. X is the set of control variables, comprising GDP growth, environment regulation, Government R&D investment, industrial structure, annual average temperature, and the precipitation. Moreover, the observation equation of mediating effect also controls the province and time effect to further reduce potential bias due to missing variables. ∂_i is the provincial effect, θ_t the time effect, and ε_{it} the error term.

Therefore, if the regression coefficient S1 of observation equation (3) is significant, the mediating effect argument is established. If the regression coefficient S3 in observation equation (4) and coefficient S3 in observation equation (5) are both significant, the indirect effect is significant. If coefficient S3 in observation equation (5) is not significant, the direct effect is not significant, indicating that only the mediating effect exists. This is called the complete mediating effect (Shao et al., 2019). If the regression coefficient is significant, the direct effect is significant, which is called the partial mediating effect.

The results are provided in Table 8. Column (1) investigates the influence of ETS on haze concentration, with results that suggest the above empirical results are consistent. The influence is still negatively significant at the 1% level, which conforms to the mediating effect argument. Column (2) investigates the influence of the ETS pilots on Greentech progress, which is significantly positive at the 1% level. Moreover, the implementation of ETS increases Greentech progress by 24.72%. Combining the results shown in column (3), the coefficient is still significantly negative, indicating that the indirect effect of mediation is significant. Moreover, the influence of Greentech progress in column (3) on haze concentration is significantly negative, indicating that there is a

Table 7
Estimated average processing effect based on different matching methods.

Matching method	ATE
Nearest neighbor matching	−0.1691*
	(0.102)
Caliper matching	−0.1463*
	(0.086)
Mahalanobis distance matching	−0.117*
	(0.065)

Note: The standard error of the estimated value is obtained by autonomous sampling and is further used to estimate the 95% bootstrap confidence interval of the average processing effect, the confidence interval being obtained by the bias-correction method. ** indicates significant at the 5% level.

Table 6
Multi-temporal DID test.

	OLS	Individual fixed effect model	Time-fixed effect model	Multidimensional fixation effect
Time × $treat_{it}$	−0.05472***	−0.05482***	−0.05431***	−0.05479***
	(0.0129)	(0.0121)	(0.013)	(0.0125)
Control Variable	Yes	Yes	Yes	Yes
Sample	3471	3471	3471	3471
R-squared	0.9593	0.3255	0.9592	0.9592

Note: **and *** denote significance at the 10%, 5%, and 1% levels. The standard deviation is given in parenthesis.

Table 8
Test of the influence mechanism of the ETS pilot on haze pollution: Greentech progress.

Variables	PM2.5	Greentech	PM2.5	PM2.5
Model	(1)	(2)	(3)	(4)
Time × $treat_{it}$	−0.0725*** (0.0117)	0.2472*** (0.0458)	−0.0417*** (0.0145)	–
Lngreentech	–	–	0.0575*** (0.0136)	–
Lngreentech × Time × $treat_{it}$	–	–	–	−0.1499*** (0.0329)
Control variables	–	–	Y	Y
Constant	3.599*** (0.0057)	−0.1316*** (0.0221)	8.2498*** (0.939)	7.7549*** (1.7485)
Time effect	N	N	Y	Y
Provincial effect	N	N	Y	Y
N	455	455	455	455
R-squared	0.0074	0.0588	0.3852	0.3817

Note: **and *** denote significance at the 10%, 5%, and 1% levels. The standard deviation is given in parenthesis.

significant direct effect, i.e., a partial mediating effect. By virtue of the mediating effect test, the results show that Greentech progress is indeed the transmission mechanism between the ETS pilots and haze pollution. It can be inferred from the mediating effect test that the ETS pilots improves haze concentration by improving Greentech progress in China. Nevertheless, to examine the direction and degree of influence requires the further investigation of the mediating effect among the ETS pilots, Greentech progress, and haze concentration. Column (4) of Table 8 provides the interaction item of Greentech progress and ETS. From the results of the interaction item (Lngreentech × Time × $treat_{it}$), it can be seen that the influence of Greentech progress and ETS on haze concentration is significantly negative at the 1% level. The empirical results show that the ETS pilots lowers haze concentration by improving Greentech progress, and that Greentech progress has both a mediating effect and significant adjustment effect.

According to the estimates in column (2) of Table 9, the influence of ETS on urban industrial structure is significantly positive. In column (3), the influence of ETS on haze concentration is significant at the 1% level, indicating a significant direct mediating effect. Moreover, according to column (4) of Table 9, the interaction item of industrial structure and ETS also significantly influences haze concentration. All these results demonstrate that industrial structure not only has a mediating effect but also a significant adjustment effect. It also reduces haze concentration under the collaborative governance of the ETS pilots. This conclusion verifies the previous assumption that ETS achieves collaborative governance of haze concentration through two ways. The first is to motivate the initiative of enterprises to upgrade and transform production technology. Second, the ETS pilots increased the production cost of enterprises and therefore, in order to avoid the pressure of environmental regulation in the pilot cities, some enterprises choose to remove their polluting industries from pilot areas to non-pilot areas.

Table 9
Test of the influence mechanism of the ETS pilot on haze pollution: industrial structure.

Variable	$PM_{2.5}$	Industrial structure	$PM_{2.5}$	$PM_{2.5}$
Model	(1)	(2)	(3)	(4)
Time × $treat_{it}$	−0.2202* (0.0117)	1.42*** (0.1342)	−0.0453*** (0.0149)	–
Lnsecond	–	–	−0.0019*** (0.0048)	–
Lnsecond × Time × $treat_{it}$	–	–	–	−0.0048*** (0.0011)
Control Variable	–	–	Y	Y
Constant	3.599*** (0.0057)	49.137*** (8.39)	7.868*** (1.791)	7.7837*** (1.721)
Time effect	N	N	Y	Y
Provincial effect	N	N	Y	Y
N	455	455	455	455
R-squared	0.0074	0.1487	0.3852	0.3807

Note: **and *** denote significance at the 10%, 5%, and 1% levels. The standard deviation is given in parenthesis.

(2) Analysis of the influence of ETS design on haze concentration

On November 14, 2011, the National Development and Reform Commission held a launch meeting of the ETS pilots in Beijing, Hubei province, Guangdong province, Shanghai, Tianjin, Shenzhen and Chongqing. In these seven pilots, besides their major differences from non-pilot provinces and cities, in terms of economic development, industrial structure and proportion, scientific technology, etc., there are also differences in their coverage, quota allocation, offset mechanism, and punishment system of ETS (Table 10). Different mechanism designs will affect the realization of emission reduction targets, cost of emission reductions, and cost sharing, thus producing different emission reduction and incentivization results. In order to realize the collaborative target of environmental improvement, a scientifically correct, economically reasonable, and politically practical mechanism for ETS is needed. Effective mechanism design serves to ensure the integrity of the emission trading market and minimize cost and risk. The emission market is formed by human-imposed constraints, and its ability to exert practical performance depends on a scientific and reasonable market mechanism design. Due to the great differences in economic development, system design, information transparency, mandatory law requirements, investors' preference for risks, etc., the fixed effects model is more appropriate than the random effects model. Accordingly, the influence of five elements of carbon markets on haze concentration is empirically identified based on data for the 35 pilot cities in China from 2013 to 2016 spanning 4 years. The empirical model is,

$$Lnpm_{it} = \alpha_0 + \alpha_1 lnpe_{it} + \alpha_2 lnqy_{it} + \alpha_3 lnccer_{it} + \alpha_4 lnorg_{it} + \alpha_5 lnpunish_{it} + \alpha_6 lnX + u_i + \gamma_i + b_t + \varepsilon_{it} \tag{6}$$

where $lnpm_{it}$ is the haze concentration of city i in year t, $lnpe_{it}$ is the total amount of quota of city i in year t, and its coefficient α_1 measures the influence of the total amount of quota on haze ($PM_{2.5}$) concentration; $lnqy_{it}$ is the number of emitters admitted to the ETS pilots in city i in year t and its coefficient α_2 measures the influence of the number of emitters admitted to the ETS pilots on haze ($PM_{2.5}$) concentration; $lnccer_{it}$ is the CCER transaction volume of city i in year t and its coefficient α_3 measures the influence of the CCER transaction volume on haze ($PM_{2.5}$) concentration; $lnorg_{it}$ denotes whether or not there is institutional and individual participation in city i in year t and its coefficient α_4 measures whether or not the institutional and individual participation influences haze ($PM_{2.5}$) concentration. $lnpunish_{it}$ denotes whether province i sets a penalty fine in the carbon market in period t (a value of 1 assigned for pilots with a fine in the punishment system, including Beijing, Shanghai, Hubei province, Shenzhen, and Guangdong province, otherwise a value of 0 is assigned pilots with no fine and mandatory rectification in a limited period, open criticism notice, and deprivation of policy incentives, including Tianjin and Chongqing), and its coefficient α_5 measures the influence of the intensity of the punishment mechanism on haze concentration ($PM_{2.5}$); X is the set of control variables, comprising GDP growth, environmental regulation, government R&D investment, industrial structure, annual average temperature, and the precipitation. Also controlled the fixed effect of province and city, and time effect to

Table 10
Comparison of the ETSs of the pilot provinces and cities in China.

	Beijing	Shanghai	Tianjin	Guangdong province	Shenzhen	Hubei province	Chongqing
Emission reduction target (2010 base period)	emission intensity reduced by 18% in 2015	emission intensity reduced by 21% in 2015	emission intensity reduced by 19% in 2015	emission intensity reduced by 19.5% in 2015	emission intensity reduced by 21% in 2015	emission intensity and energy consumption reduced by 17% and 16% in 2015, respectively	emission intensity reduced by 17% in 2015
Gas under emission regulation and types of emission activities	CO_2 direct and indirect emission of energy activity; emission during industrial production	CO_2 direct and indirect emission of energy activity; emission during industrial production	CO_2 direct and indirect emission of energy activity; emission during industrial production	CO_2 direct and indirect emission of energy activity; emission during industrial production	CO_2 direct and indirect emission of energy activity;	CO_2 direct and indirect emission of energy activity; emission during industrial production	CO_2 direct and indirect emission of energy activity; emission during industrial production
Requirements for emitters admitted to ETS	Annual average emission of 10,000 tonnes and above from 2009 to 2011	annual average emission of 20,000 tonnes and above in the industrial sector, 10,000 tonnes and above for other sectors, from 2010 to 2011	Annual emission of 20,000 tonnes and above in a single year from 2009 to 2010	Annual average emission of 10,000 tonnes and above in the industrial sector, 5000 tonnes and above in standard code for other sectors, from 2010 to 2011	Annual emissions of 3000 tonnes and above in a single year from 2009 to 2011. Large public architecture and national office buildings with 10,000 m^2 and above	Annual average energy consumption of over 60,000 standard coal from 2010 to 2011	Annual emissions of over 20,000 tonnes in a single year from 2008 to 2012.
Sectors under emission regulation	Electricity power, heat supply, cement, chemical industry, medicine, banking, and commercial retail	electricity, steel, petroleum refining, chemical industry, nonferrous metal, construction materials, textile, papermaking, rubber, chemical fiber, aviation, port, airport, railway, hotel and financial institutions	Electricity power, heat supply, steel, chemical industry, petrochemical, petroleum and natural gas extraction, mining and civil architecture	Electricity power, cement, steel, petrochemical, hospitality, finance, business, and public institutions, among others	Water supply, electricity supply, heat supply, public architecture, light manufacturing	Electricity power, steel, cement, automobile manufacturing, nonferrous metal, glass, and papermaking	Electrolytic aluminum, ferroalloy, calcium carbide, caustic soda, cement, and steel
Base year	2009–2011	2010–2012	2009–2012	2011–2012	2009–2011	2010–2011	2008–2012
Quota allocation	Grandfather method + benchmark method, allowing for dynamic adjustment	Grandfather method + benchmark method, allowing for dynamic adjustment	Grandfather method + benchmark method, allowing for dynamic adjustment	Grandfather method + benchmark method + auction method, allowing for dynamic adjustment	Grandfather method + benchmark method + auction method, allowing for dynamic adjustment	Grandfather method + benchmark method + auction method, allowing for dynamic adjustment	Grandfather method + benchmark method, allowing for dynamic adjustment
Reservation and advance borrowing	advance borrowing prohibited, and reservation allowed	advance borrowing prohibited, and reservation allowed	advance borrowing prohibited, and reservation allowed	advance borrowing prohibited, and reservation allowed under approval	advance borrowing prohibited, and reservation allowed	advance borrowing and reservation prohibited,	advance borrowing prohibited, and reservation allowed
MRV	Emitters' emission list and third-party certification	Emission auditing and third-party certification	Emitters' emission list and third-party certification	Emission auditing and third-party certification	Emission auditing and third-party certification	Emission auditing and third-party certification	Emission auditing and third-party certification
Offset credit	Maximum upper limit of CCER is 5% and 50% should be projects within the city	Maximum upper limit of CCER is 5% with no geographic limitations	Maximum upper limit of CCER is 10% with no geographic limitations	Maximum upper limit of CCER is 10% and 70% should be projects within the city	Maximum upper limit of CCER is 10% with no geographic limitations	Maximum upper limit of CCER is 10% and 100% should be projects within the city	Maximum upper limit of CCER is 8% with no geographic limitations
Punishment	In the case of unreported certification, a fine of less than 50,000 yuan shall be imposed; in the case of quota not submitted, a fine of 3–5 times of market price shall be imposed	In the case of unreported certification, a fine of 10,000 to 30,000 shall be imposed; in the case of quota not submitted, a fine of 5–10 times of market price shall be imposed	Mandatory rectification in a limited period, open criticism notice, deprivation of the right to incentives	In the case of absent report or certification, a fine of 1–3 times of market price shall be imposed based on average price in recent 6 months	In the case of quota not submitted, a fine of 3 times of market price shall be imposed based on average price in recent 6 months.	In the case of quota not submitted, a fine of 1–3 times of market price shall be imposed with 150,000 yuan top; in the case of absent report, a fine of 10,000 to 30,000 shall be imposed and the right to incentives shall be deprived.	Mandatory rectification in a limited period and deprivation of the right to incentives
Trading platform	China Beijing Environment Exchange	Shanghai Environment and Energy Exchange	Tianjin Climate Exchange	China Emissions Exchange	China Emissions Exchange	China Hubei Emission Exchange	Chongqing Assets and Equity Exchange

Source of data: the authors summarize the data according to the emission trading regulation scheme of all pilots.

further reduce potential bias due to missing variables. u_i is the provincial effect, γ_i the city effect, b_t the time effect and ε_{it} the error term.

Table 11 shows the regression results of the key ETS elements on haze pollution. As shown in column (1), the coefficient is not significant, indicating the total amount of quota allocated fails to have an important effect on haze concentration. This may imply that the pilot ETS needs to moderately reduce the carbon quota to ensure the vitality and creativity of the carbon market. On the other hand, it also indicates that the ETS pilots fail to consider the upper limit of air pollutant concentration when allocating quota would impede its collaborative governance effect.

Column (2) reflects the influence of enterprise quantities included in the carbon trading system on haze concentration, indicating that covered enterprises fail to become an important factor affecting haze concentration. It also demonstrates that the current emitters admitted to the ETS fail to contribute to low-cost emission reduction. In the initial stage of establishment of the ETS, more covered industries and emission sources increase the difficulties for regulation, hinder management efficiency, and are detrimental to emission reduction. According to these results, the influence of the number of emitters admitted to the ETS pilots on haze concentration is not significant, possibly because, in carbon trading, the environmental loss arising from lowered management efficiency offsets the environment dividend for emitters.

Column (3) reflects the influence of the CCER offset credit mechanism on haze concentration, with a significantly negative regression coefficient. This indicates that a greater CCER transaction volume is conducive to lowering haze concentration. When column (6) and other factors are all regressed, the influence of the CCER transaction volumes on reduced haze concentration is still significantly negative, indicating that the results are robust. The offset credit mechanism is a bridge connecting the ETS pilots with voluntary emission transactions, and is a nascent carbon market that produces a great deal of "carbon sink" and environment assets. The CCER offset credit mechanism makes increased environment assets enter the ETS and produces economic returns. The results suggest that a greater CCER transaction amount is conducive to environmental resource utilization and protection, and reduction in haze pollution.

Column (4) reflects the influence of the participants on haze concentration, with a positive correlation between the entry and transactions of organizations and individual investors in the ETS, and haze concentration. This indicates that, although the entry of organizations and individual investors is conducive to the liquidity of the carbon market, speculation in the carbon market does not contribute to the long-term investment of local enterprises. Moreover, it does not help them become dedicated to the robust and continuous management of carbon assets, improved clean production technology, and lower pollution. When column (6) and other factors are wholly regressed, the influence of institutions and individual investors on haze concentration reduction is significantly positive, which means the results are robust.

Column (5) shows that the regression coefficient of the influence of the punish mechanism on haze concentration is not significant. However, when column (6) and other elements of the system are wholly regressed, the evaluation coefficient of the punish mechanism is significantly negative, indicating that harsher punishment improves the overall operation efficiency of the ETS pilots and helps reduce haze concentration. Moreover, only under the synergy of the punish mechanism and other system design elements can its influence on haze concentration be relatively significant. This indicates that, when the cost of compliance is lower than the penalty, emitters naturally opt for the default, which undermines the deterrence of the punishment mechanism. Even when compliance is linked together with credit rating, projects reviews, and government subsidies, it cannot essentially address the lack of motivation for carbon transactions. As a result, transaction motivation and emission reduction initiatives increase only when the penalty is higher than the compliance cost.

5.2. Heterogeneity analysis of the ETS pilots

Since different pilot cities have different combinations of system design elements, as well as differences in the level, speed, capability, structure of economic development, technological absorptive capacity, and policy background, the influence of ETS on the environment of different pilots might not be homogeneous. The environmental effect of seven pilots is therefore compared to obtain the differences in the haze reduction results of different ETS systems. Through the model

$$Lnpm_{it} = \alpha_0 + \alpha_1 lnTime \times treat_{it} + lnX + \gamma_i + b_t + \varepsilon_{it} \tag{7}$$

where $Lnpm_{it}$ indicates the haze ($PM_{2.5}$) concentration of city/province i in year t; and $Time \times treat_{it}$ denotes whether the city/province i is influenced by the ETS pilots in period t. In other words, if city/province i carries out the emission trade pilot policy in year t, a value of 1 is assigned in year t and subsequent years, otherwise the value is 0. X is the set of control variables, comprising GDP growth, environment regulation, government R&D investment, industrial structure, annual average temperature and the precipitation. Moreover, equation (7) also controls effects of province and time, γ_i is the fixed effect of province, μ_t the fixed effect of year, and ε_{it} the error term. From the estimates in Table 8, it can be seen that a significantly negative "reduction effect" of haze concentration occurs only in Guangdong province. Moreover, the influence coefficient of Guangdong province is significant at the 1% level, with the haze concentration of Guangdong province being lowered by 1.01 mcg/m^3.

The above results indicate that the Guangdong province ETS pilot has a significant positive influence in reducing haze concentration compared to the other pilots. In addition, the results further show that a reasonable and effective ETS scheme can make an important contribution to realizing environmental targets. Combined with the regression estimates of Table 12, the reasons why Guangdong province's ETS is conducive to reducing haze concentration are, firstly, the province's

Table 11
Analysis of the influence of ETS design on haze pollution.

Variable	PM2.5					
Model	(1)	(2)	(3)	(4)	(5)	(6)
Lnpe	0.1343 (0.0954)	–	–	–	–	0.0697 (0.1176)
Lnqy	–	0.019 (0.022)	–	–	–	0.0729 (0.047)
LnCCER	–	–	−0.034*** (0.018)	–	–	−0.032*** (0.0059)
Organization	–	–	–	0.5476 (0.4498)	–	−0.4037 (0.5428)
Punish	–	–	–	–	0.0232 (0.3076)	−0.9106*** (0.144)
Control Variable	Y	Y	Y	Y	Y	Y
Constant	14.73 (4.004)	13.762 (3.62)	14.477 (5.747)	16.992 (4.311)	13.894 (3.266)	15.48 (8.94)
Time effect	Y	Y	Y	Y	Y	Y
City effect	Y	Y	Y	Y	Y	Y
N	128	127	102	140	100	100
R-squared	0.611	0.5941	0.72	0.462	0.138	0.4059

Note: **and *** denote significance at the 10%, 5%, and 1% levels. The robust standard deviation of clustering at the cities level is given in parenthesis.

emissions under emission control accounts for around 60% of its total emissions. The management of ETS therefore makes a substantial contribution to the province's twelfth five-year plan emission reduction target. Meanwhile, there relatively fewer types of sectors covered by the ETS pilots, the coverage mostly spanning the electric power, cement, petrochemicals, and steel industries. The number of major emitters is also limited, with less than 200 exceeding 20,000 tons of emissions. As a result, the technology and management costs are lower, boasting salient advantages in implementation efficiency. Secondly, Guangdong province is the first to initiate a carbon emission quota management system, with the target of lowering carbon intensity. The system adopts the principle of separating the accounting/carbon budget of stock projects and new projects, with stringent control of the emission of new projects. In addition, the system separates the time of the free and paid quota allocation, and delegates the power to dole out the paid quota to the industry authority department. In this way, emitters under emission regulation and the owners of new projects need to bid for carbon emission quota. Moreover, the system establishes emission data across the province at the level of installation, with installation as a unit to regulate the emissions of the whole province in an orderly way. Thirdly, Guangdong province has a professional business environment and market mechanism, in which emitters are more sensitive to the ETS pilots and with stronger inner management of their carbon assets. How to make efficient use of the carbon quota has become an important factor influencing emitters' production decisions. Under the constraints of the ETS pilots and driver of transaction interests, the pilots has accelerated the pace of the automatic phasing-out and industry transfer of emitters.

6. Conclusion and policy implications

With the rapid development of industrialization and urbanization, and under the premise of the rigid growth of energy demand, China's resources environment is becoming increasingly constrained. Adhering to market-driven growth and establishing an emission trading market nationwide to control greenhouse gas emissions and achieve the collaborative governance of atmospheric environment represents the future trend. The collaborative control of the environment by virtue of ETS is both a system innovation and new market-based environment regulation instrument, raising the question of whether the ETS pilots produce the desired air pollution governance results in practice. The answer from this study is a clear affirmative.

Building upon the 2003 to 2016 panel data of 30 provinces and 267 prefectural-level cities, the ETS pilots are considered as a quasi-natural environment and a DID model is used to empirically examine the influence of ETS pilots on air pollutants. The results show that the ETS pilots significantly reduced haze concentration and SO_2 emissions. The ETS pilots lowered the haze concentration and SO_2 emission by 0.933 mcg/m^3 and 0.7452 tons, respectively. Moreover, the dynamic effect test indicates there to be a delay in this influence. When the time period was longer, the effect of the ETS pilots were more significant and the reduction in haze concentration was greater, which also indicates that the ETS pilots had a significant cumulative dynamic effect in curbing haze pollution. In the impact mechanism test, the study reveals that the ETS pilots reduced haze concentration by stimulating some emitters to upgrade and transform their green technology while encouraging others to transfer their polluting industry to other areas. In testing the element design of the ETS pilots and haze concentration, it is found that the total amount of quota allocated and the number of emitters admitted to the ETS pilots were not important factors influencing haze concentration. On the premise of ensuring the effectiveness of the carbon quota, a greater CCER transaction volume and greater fines contributed to reducing haze concentration. Moreover, transactions of institutionalized and individual investors in the market did not contribute to reducing haze concentration. In the heterogeneity test of the seven pilots, it emerges that only the Guangdong pilot caused a significant reduction in haze concentration. Under the ETS pilots, the province's haze concentration was lowered by 1.01 mcg/m^3, which is more than the average level across the country. The implications of these results for policy making are as follows:

- The empirical results of the study indicate that the ETS pilots can not only serve as an important market-based environment regulation instrument for ameliorating climate change but also effectively lowers haze concentration and maximizes the collaborative governance efficiency of climate change and air pollution. It also realizes the collaborative governance of CO_2 and $PM_{2.5}$ in the physical environment as well as ensuring that resources are saved with no waste in economic level. It manages to coordinate greenhouse gas emission control, pollution, and emission reduction to guarantee the efficient implementation and economic efficiency of collaborative governance. Therefore, in encouraging ETS pilots to explore innovation, China should advance the top-level design of a unified carbon market nationwide for formation as soon as possible, since a unified carbon market may not only reduce the probability of policy abuse by local governments but also increase the probability of strengthen the environmental performance.
- So far as the energy saving and emission reduction is concerned, China's targets involve the reduction of energy consumption intensity, carbon intensity, and haze concentration. Moreover, there is a substantial policy investment each year on energy saving technology. These administrative instruments change how emitters choose their emission reduction technologies. Building upon the empirical findings of the study, a carbon market nationwide which could compatible with the emission reduction and environment effect to further expand collaborative governance performance. Meanwhile, to avoid overlaps in management and failure in assessment that might occur between the current energy saving, emission reduction policy and carbon market policy, there is a need to strengthen overall planning studies and the connection management between energy saving and emission reduction policy and carbon market policy.
- In terms of the internal design of the system, the findings concerning quota allocation suggest that the amount of quota allocated currently in China is not an important factor influencing haze pollution, and that failing to regulate the upper limit of $PM_{2.5}$ concentration is not conducive to improvement of collaborative governance of carbon

Table 12
Heterogeneity test of the influence of the ETS pilots on haze concentration.

Variable	Hubei	Guangdong	Shenzhen	Chongqing	Beijing	Tianjin	Shanghai
Time × $treat_{it}$	−0.0117 (0.0288)	−0.0106*** (0.0058)	0.0073 (0.0155)	−0.0834 (0.0835)	−0.0412 (0.075)	0.0166 (0.0331)	−0.081 (0.031)
Control Variable	Y	Y	Y	Y	Y	Y	Y
Time effect	Y	Y	Y	Y	Y	Y	Y
Urban effect	Y	Y	Y	Y	Y	Y	Y
Constant	13.01*** (3.37)	12.92*** (3.48)	13.11*** (3.35)	12.135*** (3.28)	14.174*** (4.831)	13.17*** (3.311)	12.57*** (3.13)
R-squared	0.4038	0.4046	0.3854	0.2982	0.5133	0.5143	0.3901
N	455	455	455	455	455	455	455

Note: **and *** denote significance at the 10%, 5%, and 1% levels. The robust standard deviation of clustering at the cities level is given in parenthesis.

market. There are two advantages with including an upper $PM_{2.5}$ limit in the national carbon trading quota allocation scheme. On the one hand, this can expand the collaborative governance of ETS on air pollution while, on the other hand, it can incentivize emitters to upgrade and transform their green technology, thus contributing to lowering $PM_{2.5}$ concentration levels. The results of heterogeneity test of the influence of the ETS pilots on haze concentration suggest that the national carbon market system design can reference the quota allocation of Guangdong province in separating the peak free quota allocation from the paid quota allocation, with new emission projects strictly regulated by the benchmark method prioritized over the historical method. In terms of the CCER offset credit mechanism, on the premise of ensuring the effectiveness of the carbon quota, restriction proportion of CCER should be moderately increased in the design of the national carbon market system, as it is also conducive to the collaborative governance of air pollutants. On the premise of ensuring liquidity of the carbon market, moderately lowering the proportion of institutionalized and individual investors entering into the market is conducive to adhering to the long-term investment of local enterprises; it also helps them invest in continuous carbon asset management and improve clean production energy. All these practices contribute to orderly management of carbon quota. The empirical results for the punishment measures suggest that specific and effective punishment is the key to the high efficiency of overall operations and a key solution to emission reduction and pollution regulation. In terms of the design of punishment measures for the national carbon market, a certain amount of fines should be imposed on emitters that fail to fulfil their emission reduction obligations, so that energy saving and the collaborative governance of pollution can be a “rigid constraint” to ensure the effective operation of the ETS pilots.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Yaxue Yan: Conceptualization, Data curation, Formal analysis, Validation, Visualization, Writing - original draft. **Xiaoling Zhang:** Writing - review & editing, Funding acquisition, Resources, Project administration. **Jihong Zhang:** Investigation. **Kai Li:** Software, Methodology, Supervision.

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