Original Research

Does Ecological Compensation Reduce Air Pollutant Emissions? - Evidence from Quasi-Natural Experiments in China

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Abstract

The concept and theory of ecological compensation (EC) have been widely studied in the past 20 years, but its practical effects have not yet been agreed upon. Based on a panel data from 281 prefecture-level cities in China from 2009 to 2018, this paper examines the impact of air ecological compensation (AEC) policy on air pollutant emissions and its mechanism with time-varying DID model. The study found that AEC will reduce the emissions of sulfur dioxide, PM2.5, industrial smoke and dust, which remained significant after a series of robustness test. Mechanism analysis concluded that AEC can reduce air pollutant emissions mainly by promoting green technology innovation, strengthening pollution treatment intensity and improving energy efficiency. The effect of AEC varied with city characteristics, in cities with high proportion of Industrial, low environmental regulation intensity and high fiscal pressure, AEC have significant or better policy effects, while, AEC does not have significant policy effects in cities with high environmental regulations intensity and low financial pressure. China should consider further promoting the pilot scope of AEC, but it also needs to improve the compensation standard and compensation mechanism to achieve better policy effects.

Keywords: ecological compensation mechanism, air pollutant emissions, DID model, Heterogeneous effect

Introduction

With the increase of the total population, the pressure on natural resources such as land, air and water is increasing day by day. The deterioration of the ecological environment has aroused the global consensus to strengthen ecological protection. Ecological protection

and pollution prevention require the joint participation of many subjects such as government, enterprises and individuals. However, due to the externality of pollution prevention and control, environmental participants often choose non-cooperative strategies when they are faced with uncertainties such as willingness and investment of collaborative governance. This requires that the environmental policies should have reasonable incentives and constraints to guide participants to choose cooperative strategies. Ecological compensation

(EC), also known as payments for ecosystem services (PES), is such a kind of instrument that combines both administrative and market measures to solve the problem of environmental externalities [1].

The concept of ecosystem services came into being in the 1970s and sparked public debate about the economic value of ecosystems [2]. Since then, a large number of scholars have discussed and reached a partial agreement with the theoretical mechanism and practical effect of EC [3]. Theoretically, EC is regarded as an incentive mechanism for ecosystem protection, the essence of which is to reflect the economic value of ecosystem services through market mechanism on the basis of clear property rights, thus encouraging resource users to take the initiative to protect the ecological environment by paying fees to providers from beneficiaries of ecosystem services [4, 5]. However, the existing studies in the field of EC are still somewhat divergent. The debate mainly focuses on policy effect, standard of EC, transaction cost in the process of compensation, cost effectiveness, fairness, and sustainability.

For example, due to opportunity cost, heterogeneity of compensation objects and information asymmetry between buyers and sellers, the standard of EC often fails to reflect fairness and efficiency [6,7]. In many developing countries, the lack of a complete institutional framework, clear property rights arrangements and benefit distribution mechanisms are the main problems facing EC [8]. Fisher et al. (2009) pointed out that because of the effects of climate, environment, human disturbance and other aspects, the provision of ecosystem services has strong spatial and temporal heterogeneity, which make it difficult to maintain long-term stability [9]. Moreover, the price of ecosystem services is not determined by the supply and demand of classical economics, but is largely influenced by policy, finance, politics and other aspects [10]. While EC attempts to create a purely market-based mechanism, it has been shown that the effectiveness of EC in practice depends to a large extent on community or state participation [11, 12]. Liu et al. (2018) adopts energy theory to calculate the energy loss of industrial solid waste under different treatment methods and measure the ecological environment loss. Based on the case of a city, the study found that the market-based pollution tax of phosphogypsum is too low and does not match the pollution of the whole city [13].

In spite of the defects mentioned above, some EC policies have achieved good results. Fiorini et al. (2020) assessed the impact of EC on forest cover in a watershed in Rio de Janeiro, the research shows that EC increased forest cover by reducing deforestation [14]. Rudolf (2022) compared the effectiveness of two conditional group payment schemes with Indonesian oil palm farmers as field test subjects, the results showed that both EC schemes were effective [15]. Li et al. (2020) took Xin'an River Basin as the pilot of water EC, the empirical results show that EC not only reduces non-point source pollution but also leads to high level of policy efficiency, especially in scale efficiencies [16]. Using the similar pilot, Zheng et al. (2021) found that EC have a spillover effect on industrial structure upgrading [17].

It can be seen from the literature review that research on EC mainly focus on forests, rivers, oceans and other fields, while there are few theoretical or empirical research on EC for air quality. Due to the different environmental externalities of each ecological element, research conclusions in other fields cannot provide reference for EC in air quality. It means that the linkage between EC and air pollutant emissions has not been proven in practice. In addition, the existing literature has neither analyzed the mechanism of EC policy nor pointed out which factors will affect the effectiveness of EC. The lack of these studies is not conducive to correcting the defects of the ecological compensation system, which greatly limits the use of EC tools to curb air pollutant emissions.

Therefore, based on a panel data of 281 cities from 2009 to 2018, this paper uses time-varying DID model and a series of robustness tests to explore whether China's AEC policies reduce air pollutant emissions. The implication of this study lies in that, on the one hand, it can provide scientific proof for the effectiveness of EC method applied in the field of air pollution prevention and control. On the other hand, the mechanism analysis and heterogeneity test of AEC policy can provide important reference for other provinces and cities in China to establish and improve AEC system, which may help further reduce China's emissions of air pollutants.

Our study makes three main contributions to the literature. First, it is a rare empirical study on the impact of China's AEC policy on air pollutant emissions from the city level. This provides empirical reference for the application of EC in the field of air quality. Second, our study not only analyzes the mechanism of AEC policy from the theoretical level, but also identifies the three influencing channels of green technology innovation, pollution control intensity and energy efficiency by applying the mediation model. Third, we find that there exists varies heterogeneities in the policy effect of AEC. For cities with high environmental regulation intensity or low financial pressure, AEC policy is noneffective. We are the first to indicate that AEC should adjust assessment standard and compensation amount according to the characteristics of city, so that it can be effectively applied to all cities.

The remainder of the paper is as follows: First, we describe the institutional background of AEC policy in China, analyze the theoretical mechanisms of AEC, propose the research design, methodology, and variable measures accordingly. Second, we analyze the empirical results of the benchmark model and the mediating effects model, then discuss the heterogeneous effects of AEC policy. Third, we summarize the main findings of this paper and make policy recommendations.

Material and Methods

Institutional Background of Ecological Compensation for Air Quality

As a public good or public service, ecological environment has obvious cross-regional nature, with both national and regional attributes. China has a large geographical area, national and regional ecological of environmental services coexist. The providers and beneficiaries of ecological and environmental services often belong to different administrative divisions and fiscal levels. In addition, local governments, with their authority and regional advantages, are regarded as the main force in environmental protection, and their behavior choices directly affect the effectiveness of pollution control. In order to meet the complex relationship between supply and demand of ecological services, China has gradually formed an EC model led by central or provincial governments and participated by prefecture-level or county-level cities [18].

The key elements of EC system include compensator, compensation recipient, compensation standard, compensation methods and so on. Specific to research of this paper, AEC system has three main bodies, namely provincial government, compensator city and compensation recipient city. Provincial governments act as inspectors to conduct quarterly assessments of city's major air pollutants emissions such as SO_2, PM2.5, PM10, and NO_2. Funds paid to the provincial government by cities that fail to meet the assessment standards (compensator city) will be incorporated to the provincial AEC fund pool to compensate cities that improve air quality (compensation recipient city). Its essence is the inter-city horizontal financial transfer payment system under the coordination of provincial governments, that is, EC flows from cities with deteriorating air quality to cities with improved air quality [19]. Fig. 1 shows the framework of the AEC policy.

Although AEC is an administrative order from the superior government to the subordinate government, the incentive and punishment of this policy only exist at the fiscal of city and have no influence on the promotion of local officials. For local officials in China, city's economic indicators are still the most important criteria for promotion. Therefore, in the assessment of AEC, prefecture-level municipal governments prefer to reduce local air pollutant emissions per unit economic output, that is, the air pollutant emissions intensity, rather than directly reduce pollutant concentration itself. Based on the above institutional background and realistic factors, this paper proposes the following research hypotheses:

Hypothesis 1: The AEC policy will reduce urban air pollutant emission intensity.

Mechanism Analysis of AEC

As there is no market-oriented part in China's AEC, the policy driving force mainly comes from the administrative means of local governments. This paper proposes that AEC mainly reduce air pollutant emissions intensity through three mechanisms:

1. Green Technology Innovation: In the long term, green transformation of economic development is the core to solve the ecological pollution problem. The fundamental path of green development is to promote green technology innovation. Different from traditional technological innovation, green technological innovation emphasizes the adoption of low-carbon technologies and new green concepts, which can significantly reduce environmental pressure while achieving economic benefits. AEC can encourage local governments to expand various environmental protection spending programs. On the one hand, government green investment can speed
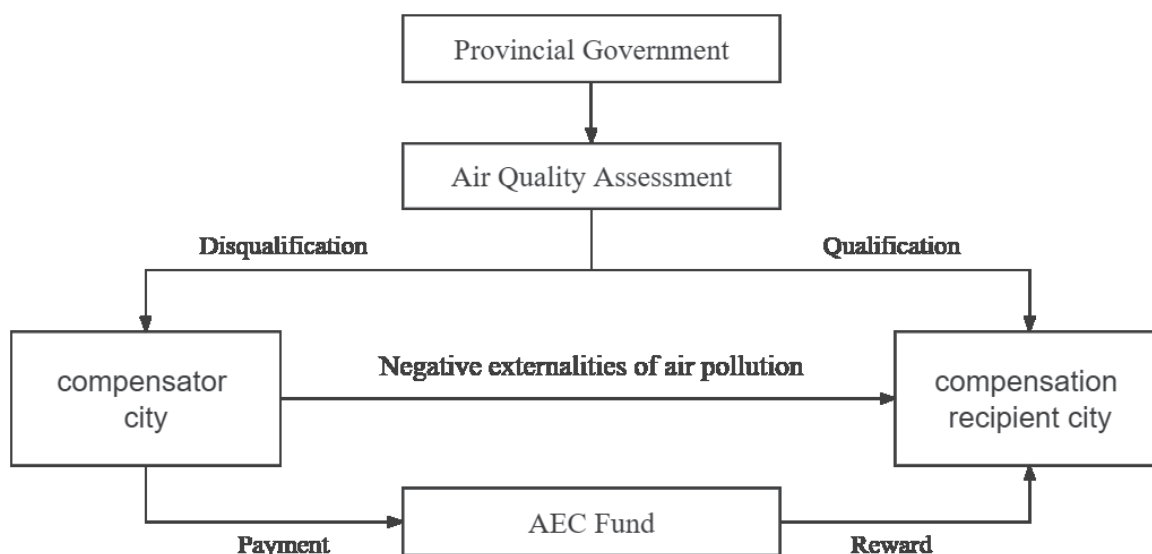

Fig. 1. Framework of the AEC policy.

up the construction of urban environmental infrastructure, provide better hardware infrastructure for local enterprises engaged in green technological innovation activities, and guide social capital and high-quality talents to tilt toward ecological, energy conservation, environmental protection, environmental governance and other green fields [20]. On the other hand, government green subsidy can increase the market demand of local green technology innovation products, stabilize the expectation and confidence of enterprises in green technology innovation, and reduce the market risk of enterprises' green technology innovation. As a result, AEC can strengthen the government's support for green technology innovation, which help to reduce pollutant emissions intensity.

2. Pollution Governance Intensity: Although the environmental regulation can stimulate the environmental protection behavior of enterprises, it also produces pressure on the business activities of enterprises. If the environmental regulation is too strong and deviates from the optimal range, it is not conducive to the improvement of pollutant emissions intensity. At present, China's overall environmental regulation intensity is not high, increasing the intensity of environmental regulation can still reduce pollution emissions without greatly damaging economic output [21]. Therefore, AEC will urge local governments to strengthen environmental governance, increase emission standards for local enterprises with low productivity and high pollution discharge, or increase emission tax and environmental treatment fees to put environmental pressure on enterprises, which force local enterprises to adjust the use of raw materials and production processes, and introducing advanced clean production equipment, and finally reduce the intensity of city's pollutant emissions.

3. Energy Efficiency: Energy efficiency and conservation are considered key means for reducing greenhouse gas emission and achieving other energy policy goals. Consumer decisions about how much energy to consume and whether to invest in more energy-efficient products and equipment will greatly affect regional energy efficiency. Energy conservation technology investment is characterized by long return cycle and high uncertainty. Coupled with technological externalities and credit constraints, investment in energy efficiency and conservation under the market mechanism is often insufficient. AEC policy can encourage local governments to use fiscal incentives to stimulate people to improve energy efficiency projects, such as tax credits to increase the possibility of energy efficiency investment, and the establishment of special government funds to finance energy conservation projects.

Based on the above three theoretical potential path mechanisms, this paper proposes the following hypotheses:

Hypothesis 2: AEC policy reduces air pollutant emissions intensity through promoting green technology innovation, strengthening pollution treatment intensity and improving energy efficiency.

Empirical Model

Since the effective date of AEC policy in different cities are not consistent, based on the practice of mainstream literature [22], we use time-varying difference-in-difference model to estimate the net policy effect. The Cities in Shandong, Hubei, Henan, Anhui and Shaanxi were taken as the treatment group, and the prefecture-level cities in other provinces were taken as the control group. The empirical model is set as follows:

$$Y_{i,t} = \beta_0 + \beta_1 AEC_{i,t} + \Gamma X_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (1)$$

Where subscript i represents the city, subscript t represents the year. $Y_{i,t}$ is the explained variable, which is used to represent various indicators related to air pollutant emissions intensity of city i in year t. The core explanatory variable $AEC_{i,t}$ is set as interaction term of the dummy variables $treat_i$ and $post_t$. When the city implements the AEC policy, Set $treat_i$ to 1, otherwise to 0. If the city implements the AEC policy in year t_0, the value of $post_{t \geq t_0}$ is 1, otherwise 0. The value of β_1 measures the impact of AEC on city pollutant emissions intensity, and the sign of β_1 indicates whether AEC increases or decreases pollutant emissions intensity. $X_{i,t}$ represents a series of control variables at city level. μ_i, λ_t is the fixed effect of city and year, and $\varepsilon_{i,t}$ is the error term.

Variable Selection and Data Source

1. Explained variable. The explained variable in this paper is the air pollutant emissions intensity of city. Referring to the existing literature and the reality of China, we use sulfur dioxide emissions intensity in log (InEQ) to measure air pollutant emissions intensity, that is, sulfur dioxide emissions per unit of industrial added value. The reasons are as follows: first, energy structure in China determines that sulfur dioxide is one of the most important pollutants of industrial output; second, sulfur dioxide concentration is an important factor affecting air quality [23]; third, in China's AEC, sulfur dioxide is one of the main assessment indicators. Sulfur dioxide emissions date and industrial added value date are all from China Urban Statistical Yearbook.

2. Explanatory variables. AEC policy is selected as the core explanatory variable. At present, five provinces have introduced AEC policies, namely Shaanxi, Shandong, Hubei, Henan and Anhui. We set the cities of these provinces as the treatment group and the rest as the control group. The data of AEC are manually collected from the policy documents issued by Provincial Environment Department. It shows that a total of 72 cities in five provinces are participating in the AEC policy.

Table 1. Variable descriptive statistics.

Variable Type	Variable	Observations	Mean	S.D.	Min	Max
Explained variable	lnEQ	2810	10.2401	1.1234	0.8754	12.7124
Explanatory variables	AEC	2810	0.0644	0.2455	0	1
Control variables	$POPD$	2810	0.5376	2.5791	0.0028	128.7371
	lnPCI	2810	5.0469	4.8769	0.0501	50.4561
	ln$PCI2$	2810	2.6602	1.4717	-5.9884	7.8422
	lnSTE	2810	6.8933	1.6256	1.7917	11.8475
	lnFDI	2663	9.9812	1.7649	1.0986	14.1519
	$INDUS$	2810	38.9493	9.2116	9.76	77.54
Policy variables	CES	2810	0.2551	0.4360	0	1
	SC	2810	0.2056	0.4042	0	1

3. Control variables. Referring to the literature of Fu et al. (2018) and Song et al. (2021) [24, 25], variables that have been proven to influence the intensity of air pollutant emissions were selected as control variables, including population density ($POPD_{i,t}$), per capita income ($PCI_{i,t}$), the square of per capita income ($PCI_{i,t}^2$), science and technology expenditure ($STE_{i,t}$), foreign direct investment ($FDI_{i,t}$) and industrial structure ($INDUS_{i,t}$). The population density is calculated by dividing the total urban population by the total area, and the industrial structure is defined as the ratio of industrial industries to all industries. Among them, the population density ($POPD_{i,t}$) is calculated by dividing the total population by the total area, and the industrial structure ($INDUS_{i,t}$) is defined as the ratio of industrial industries output value to all industries output value. The data of population, urban area, industries output value, science and technology expenditure and foreign direct investment are all original data from the China City Statistical Yearbook. Per capita income data for cities are collected from the statistical yearbooks of their provinces.

4. Policy variables. Since 2010, environmental governance has become one of the core tasks of the Chinese government, and a series of environmental policies have been introduced to improve the pollution situation in China. Because the effect of these policies is similar to the AEC policy, therefore, if the impact of other environmental policies is not taken into account, the pollution control effect of implementing AEC may be overestimated. In order to enhance the accuracy and robustness of empirical results, this paper add two other policies dummy variables "Central Environmental Supervision" (CES) and "Smarter City" (SC) as policy control variables. The sources of the above policy data are public documents or reports of Ministry of Ecology and Environment of China.

5. Extra variables. In the mechanism analysis and heterogeneity analysis, we also use green Utility model patents, industrial sulfur dioxide removal, electricity consumption, environmental word frequency, fiscal revenue and fiscal expenditure. Among them, the data of Green Utility model patents, industrial sulfur dioxide removal, electricity consumption, fiscal revenue and fiscal expenditure also come from the China City Statistical Yearbook. Environmental word frequency data were collected manually from public documents of prefecture-level city governments.

Considering the availability and completeness of data, we finally selected the balanced panel data of 281 cities in 10 years from 2009 to 2018. Descriptive statistics of the main variables are reported in Table 1.

Results and Discussion

Benchmark Regression Analysis

Based on the quasi-natural experiment of AEC policy, this paper empirically analyzes the impact of the policy on the air pollutant emissions by using the time-varying DID method. According to the specific assessment scheme of AEC in each province, we studied the impact of AEC on the change of emission intensity of air pollutants in prefecture-level cities. Table 2 reports the corresponding regression results.

In the process of causal identification, the regression results of core explanatory variables will be affected by the control variables, which will adversely affect the empirical results. To enhance the robustness of the empirical results, column (1) and column (2) in Table 2 respectively report the estimation results without and with control variables. It can be found that the estimated coefficients of the core explanatory variables are significantly negative, which preliminarily indicates that the cities selected in the pilot list of AEC policy can significantly reduce sulfur dioxide emissions intensity. However, as mentioned above, there are other policies committed by China government to improving the ecological environment and reducing pollution

Table 2. Benchmark regression results.

	(1)	(2)	(3)	(4)	(5)
AEC	-0.3014*** (-7.47)	-0.3021*** (-7.32)	-0.2965*** (-7.17)	-0.3011*** (-7.29)	-0.2955*** (-7.14)
POPD		0.0118*** (2.98)	0.0118*** (2.98)	0.0120*** (3.02)	0.0119 (3.02)
ln*PCI*		-0.0349*** (-5.37)	-0.0345*** (-5.30)	-0.0350*** (-5.39)	-0.0345*** (-5.32)
ln*PCI2*		0.1709*** (5.43)	0.1706*** (5.42)	0.1742*** (5.53)	0.1730*** (5.52)
ln*STE*		-0.0752*** (-2.81)	-0.0718*** (-2.68)	-0.0771*** (-2.87)	-0.0737*** (-2.75)
ln*FDI*		-0.0221** (-2.05)	-0.0224** (-2.08)	-0.0211** (-1.96)	-0.0214** (-1.99)
INDUS		-0.1444 (-1.24)	-0.1508 (-1.30)	-0.1425 (-1.23)	-0.1489 (-1.28)
CES			-0.0974* (-1.84)		-0.0976* (-1.84)
SC				-0.0553* (-1.68)	-0.0554* (-1.69)
_cons	10.6016*** (435.49)	11.6318*** (24.21)	11.6370*** (24.24)	11.6216*** (24.20)	11.6268*** (24.22)
City fixed effects	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes
N	2810	2810	2810	2810	2810
R^2	0.6518	0.6663	0.6667	0.6667	0.6671

Note: ***, ** and * indicate significant levels at 1%, 5% and 10% respectively, and standard errors are reported in parentheses.

in the time window of the sample data, these policies necessarily reduce the accuracy of the regression results of the benchmark model. To further enhance the accuracy and robustness of the empirical results, this paper draw lessons from Bao et al. (2021), respectively in column (3) and (4), adding "Central Environmental Supervision" and "Smart City" two policy variables to eliminate the interference of other environmental policy [26], and the above two policy virtual variables all add to the benchmark regression in column (5). The results show that the estimated coefficient of the core explanatory variable policy is still significantly negative when considering the impact of other environmental policies. This further indicates that AEC policy has significant pollution control effect without harming regional economic development. Obviously, in order to prove the correctness of hypothesis 1, this paper should be further tested for robustness using other methods.

Although the estimation results reported in Table 1 are relatively robust and show that AEC can significantly improve the pollutant emissions intensity of cities, it still cannot completely exclude the interference of problems such as omitted variables and sample selection bias. Therefore, in order to further improve the reliability of empirical results, robustness tests are carried out in this section from four aspects: parallel trend test, placebo test, PSM-DID and change of explained variables.

Parallel Trend Test

The parallel trend hypothesis is the premise of the application of the time-varying DID method, that is, the experimental group and the control group should have the same trend before the implementation of the policy. This paper refers to the literature of Marcus and Sant'Anna (2021) and uses event study design to perform the parallel trend test [27]. Specifically, we set dummy variables $distance_t$ which calculated as the year distance between the current year and the implementation year of policy, and cross $distance_t$ with policy dummy variables $treat_t$. Then, based on the current year of AEC policy, we put interaction terms into the regression equation for estimation:

$$Y_{i,t} = \beta_0 + \sum_{j=-4}^{j=4} \beta_j treat_i \times distance_{t_0+j} + \Gamma X_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (2)$$

If the interaction term before the policy impact year is significant, it indicates that there is a significant difference in the change trend between the control
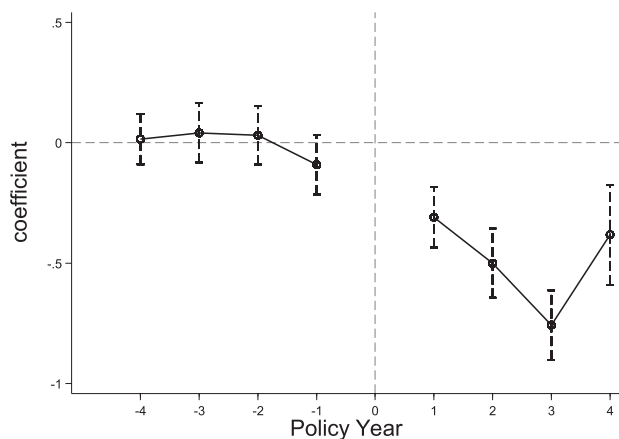
Fig. 2. Parallel trend test.

Fig. 3. Placebo test.

group and the treatment group before the policy impact. Conversely, if the interaction term before the policy impact year is not significant, and the interaction term in the current year or after the policy impact year is statistically significant, it indicates that the parallel trend hypothesis is valid. The estimated coefficients of each interaction term and their 95% confidence intervals are plotted in Fig. 2. The results show that the time-varying DID model in this paper satisfies the parallel trend hypothesis. Moreover, after the implementation of the policy, urban emission intensity drops immediately, indicating that AEC policy has a negative impact on air pollutant emissions intensity. The effect of the AEC policy gets stronger over time, peaking in the third year.

Placebo Test

Although the above analysis excludes the influence of other environmental policies on the results of this paper. At the same time, parallel trend test results also show that the identification of a strategy to satisfy the time-varying DID model assumptions, but we have not completely ruled out the problem such as omitted variables, which constitutes a potential threat to cause the estimation result to be biased [28]. In view of this, we conducted a placebo test by randomly assigning the treatment effect of AEC to cities in the whole sample. Specifically, some cities were randomly selected from 281 cities of the sample as the experimental group, and the other cities were set as the control group. If the estimated coefficient of policy is still significant under this condition, it indicates that the empirical results of this paper are caused by other factors that have not been observed. Otherwise, it means that the policy effect of AEC exists. In placebo test, random sampling was repeated for 500 times. Fig. 3 plots the density distribution of p-values of policies after 500 random sampling. It can be found that the p-values of the policy are concentrated in 0, and there is no estimated result superior to the benchmark regression. Therefore, it can be considered that the empirical results of this paper truly reflect the pollution control effect of AEC policy.
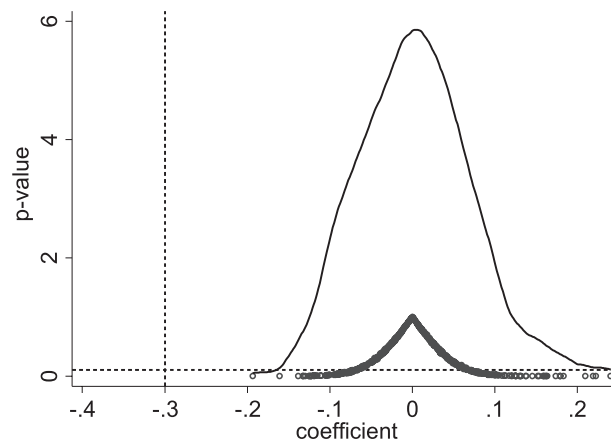
Propensity Score Matching DID Test

Another important prerequisite for using the time-varying DID model is that the experimental and control groups are randomly selected [29]. Intuitively, provinces with higher pollutant emissions intensity are more likely to implement AEC policy. If AEC policy are endogenous, the results of the previous study are still unreliable. Therefore, we further utilized the PSM-DID method proposed by Heckman (1979) to mitigate potential sample selection bias and obtain more accurate causal identification results [30]. Specifically, the control variables in the benchmark regression were used as covariables, and the samples were matched year by year based on the kernel matching method [31]. Finally, with a small amount of sample loss, the matching results of the experimental group and the control group were as similar as possible before the policy impact. Furthermore, the net effect of AEC policy on air pollutant emissions intensity was evaluated by using the benchmark regression model based on matched samples. Columns (1) and (2) in Table 3 also report the estimated results under the two conditions of adding control variables and not adding control variables respectively. The results show that the estimated coefficient of is still significantly negative, which further indicates that the empirical results of this paper should be robust.

Replacing the Explained Variable

Referring to the extensive practices of the existing literature, the above benchmark regression model uses sulfur dioxide emissions intensity as a proxy variable to describe air pollutant emissions intensity, while some literatures use PM2.5, industrial smoke and dust annual average concentration as a proxy variable to measure local emissions intensity [32-34]. The reason is that PM2.5, industrial smoke and dust as major pollutant emissions produced in both production and life, are considered to be the culprit causing haze pollution. Besides, some provinces have adopted PM2.5 as one of the evaluation indexes for AEC policies.

Table 3. Counterfactual test and instrument variable approach

	PSM-DID		PM2.5		Smoke and Dust	
	(1)	(2)	(3)	(4)	(5)	(6)
AEC	-0.2930***	-0.2845***	-0.1456***	-0.1048***	-0.2840***	-0.2054***
	(-7.42)	(-7.53)	(-6.14)	(-5.83)	(-3.97)	(-2.86)
Control variables	No	Yes	No	Yes	No	Yes
City fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
N	2292	2292	2810	2810	2810	2810
R²	0.6980	0.7010	0.6797	0.8276	0.2724	0.3124

Note: ***, ** and * indicate significant levels at 1%, 5% and 10% respectively, and standard errors are reported in parentheses.

Accordingly, this paper replaced the sulfur dioxide emissions intensity in the benchmark regression model with PM2.5 concentration, industrial smoke and dust emissions for robustness test. Columns (3) through (6) in Table 3 respectively report the estimated results in the case of no control variables and the addition of control variables. It can be found that although the absolute values of the estimated coefficients of the core explanatory variables have decreased, they are all significantly negative. In a sense, this indicates that AEC is effective for the improvement of various compound pollutants.

So far, we have reason to believe that the AEC policy will promote the air pollutant emissions intensity. Hypothesis 1 has been verified.

Mechanism Analysis

The above analysis accurately identified the causal relationship between AEC and air pollutant emissions intensity. But what mechanism does AEC take to improve local air pollution? To answer this question, this paper uses the mediating effect model to empirically test it. First, we examine whether AEC policy can promote green technology innovation, pollution treatment intensity and energy efficiency. Then, we further identify whether AEC policies can improve pollutant emissions intensity through the above three channels:

$$M_{i,t} = \alpha_0 + \alpha_1 AEC_{i,t} + \alpha_2 X_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (3)$$

$$Y_{i,t} = \gamma_0 + \gamma_1 AEC_{i,t} + \gamma_2 M_{i,t} + \gamma_3 X_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (4)$$

Where is the intermediary variable, the set of other variables are the same as in model (1). Model (3) tests whether the AEC is effective on the intermediary variables. If the regression result is significant, the mediation variable is added into model (1) to obtain model (4), which test how AEC affects pollutant emissions intensity through the mediation variable.

Next, we test the policy mechanism of AEC according to hypothesis 2 from three aspects: green technology innovation, pollution treatment intensity and energy efficiency.

Green Technology Innovation

The development of clean technology can not only improve the efficiency of the government and enterprises to use environmental funds, but also increase the return of environmental investment. In China, market-oriented environmental regulation is still not perfect. Under the command-based environmental regulation, government and enterprises are less motivated to develop green technology. AEC is an environmental protection policy combining incentives and commands. In order to obtain fiscal subsidies from superior governments, local governments are willing to subsidize and support green patents, which will improve the green technology innovation and reduce pollutant emissions intensity in the city.

We use the number of green utility model patents granted to measure the level of green technology innovation in a city. The results in Table 4, column (1) shows that with green technology innovation (*GTI*) as the explained variable, the coefficient of the core explanatory variable is significantly positive, proving that AEC policy can promote the improvement of the level of green technology innovation in a city. In Table 4, column (2), green technology innovation is added into the benchmark model as an explanatory variable. In this case, the estimated coefficients of and are significantly negative. According to the criterion of the mediation effect model, results of columns (1) and (2) prove that AEC policy can reduce pollutant emissions intensity by increasing urban green technology innovation.

Pollution Treatment Intensity

The central government has issued a series of laws and regulations such as "Law of the People's

Table 4. Mechanism analysis.

	GTI	ln*EQ*	*PTI*	ln*EQ*	*EE*	ln*EQ*
	(1)	(2)	(3)	(4)	(5)	(6)
AEC	0.1031*** (3.45)	-0.2976*** (-7.20)	0.0371* (1.70)	-0.2228*** (-4.20)	0.1083** (2.38)	-0.2468*** (-4.41)
GTI		-0.0356** (-2.05)				
PTI				-0.8016*** (-14.18)		
EE						-0.0533* (-1.87)
_cons	-1.6606*** (-4.74)	11.7083*** (24.14)	-0.0605 (-0.28)	11.3091*** (21.27)	-4.9566*** (-10.87)	11.6224*** (20.14)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
N	2650	2650	2134	2134	2663	2663
R^2	0.0990	0.6678	0.3287	0.4531	0.1748	0.3964

Note: ***, ** and * indicate significant levels at 1%, 5% and 10% respectively, and standard errors are reported in parentheses.

Republic of China on the Prevention and Control of Air Pollution" and "Technical Specifications for Industrial Organic Waste Gas treatment Projects" to regulate the construction and operation management of industrial organic waste gas treatment projects. However, when local governments and companies meet national standards, they have little incentive to further improve pollution treatment efficiency. The incentive mechanism of AEC can solve the above regulation's shortcomings, and local governments will urge local industry to further improve the intensity of waste gas governance.

In this regard, to verify this mechanism, the ratio of industrial sulfur dioxide removal to industrial sulfur dioxide emissions is used to measure pollution treatment intensity (*PTI*). Column (3) in Table 4 shows that *AEC* is significantly positive at the level of 10%, and *AEC* can improve pollution governance intensity. The *PTI* was further put into the benchmark model, column (4) shows that the coefficients of *PTI* and *AEC* were significantly negative at the level of 1%, which prove that AEC reduced the air pollutant emissions intensity by improving the pollution governance intensity.

Energy Efficiency

This paper argues that AEC can not only encourage local governments to improve energy efficiency of local industrial state-owned business, but also promote local governments to establish more efficient and intelligent energy management systems in infrastructure and public services. As for the selection of variables, previous studies have found that energy consumption has output effect, structure effect and density effect.

Therefore, energy consumption is not a good indicator of a city's energy efficiency. In this regard, we use electricity consumption per unit of industrial output to measure energy efficiency.

The results in Table 4, column (5) show that ecological compensation can increase energy efficiency at a significant level of 5%. Column (6) regress the pollutant emissions intensity on the *AEC* and energy efficiency (*EE*) at the same time. The coefficients of *AEC* and *EE* are significantly negative. AEC policy reduce industrial pollutant intensity by improving energy efficiency.

Based on the results in Table 4, we believe that AEC can improve green technology innovation, pollution supervision intensity and energy efficiency of cities, and then reduce air pollutant emissions intensity. So far, Hypothesis 2 is proved.

Heterogeneity Analysis

The influence and transmission mechanism of AEC on air pollutant emissions intensity have been demonstrated. However, for cities with different characteristics, is there heterogeneity in this pollution control effect? Answering this question is helpful to understand the asymmetric impact of AEC and provide useful reference for optimizing and adjusting the system of AEC policy. In view of the above considerations, this section further explores the heterogeneous effects of AEC on air pollutant emissions intensity in terms of three aspects: industrial structure, environmental regulation intensity and fiscal pressure, in conjunction with some of the findings of the previous mechanism analysis.

Heterogeneity of Industrial Structure

Pollution and harmful gases come from a wide range of sources, among which exhaust gas emissions from industrial sectors is a key component. In China, pollution problems in some cities are caused by the agglomeration of massive heavy industry sectors. Intuitively, under the same other conditions, the higher the proportion of industrial cities, the stronger the pollution control effect of AEC. The reason is, the industrial sector, especially heavy industry, is directly managed by the central or local government. Compared with the treatment of domestic waste gas and mobile source waste gas, the treatment technology of industrial sector waste gas is more mature, and the administrative cost of government treatment of industrial enterprises waste gas is lower. Based on this, this paper divides the total sample into two groups of "low proportion of industrial" cities and "high proportion of industrial" cities according to the ratio of industrial industries to GDP in the year before the policy impact. Columns (1) and (2) in Table 5 respectively report the estimated results.

It can be found that although the pollution control effect of AEC policy exists in both high and low industrial cities, the coefficient and significance level of *AEC* indicate that AEC has better pollution control effect in high industrial cities. This shows that the realization of AEC effect not only depends on the policy itself, but also depends on other conditions. Therefore, when the central and provincial governments formulate AEC policies, external factors such as industrial structure should be taken into overall consideration.

Heterogeneity of Environmental Regulation Intensity

With reference to the practice of Zhong et al. (2021), the proportion of word about "environment", "energy", "pollution" and "emissions" in the government's public documents to the total words in the report is taken as a proxy variable of environmental regulation intensity [35]. The higher the frequency of environment-related words, the higher the intensity of local environmental regulation. If a city's environmental regulation intensity is higher than the average level in the year before the policy impact, it will be classified as "city with higher industrial level"; otherwise, it will be classified as "city with lower industrial level".

Columns (3) and (4) in Table 5 respectively report the estimated results of the two groups of samples. It can be seen that AEC can reduce the air pollutant emissions intensity of cities with higher industrial structure level, but has no significant impact on cities with lower industrial structure level. The reason may be that, on the one hand, cities with high environmental regulation intensity pay more attention to air quality and have a relatively low concentration of air pollutants. These cities are very likely to obtain financial subsidies in AEC. On the other hand, the government's environmental expenditure in cities with high environmental regulation intensity is relatively high, and the marginal benefit of further increasing environmental protection expenditure is not high, which is manifested by the insignificant incentive effect of AEC policy on cities with high environmental regulation intensity. On the contrary, cities with low environmental regulation intensity are more motivated to strengthen pollution control so as to avoid becoming payers in AEC.

Heterogeneity of Fiscal Pressure

Fiscal incentives are key to the effectiveness of AEC, and fiscal pressures on cities are highly likely to affect the effectiveness of AEC policy. In this paper, according to the fiscal surplus of the year before the policy impact, cities that are higher than the mean fiscal situation are classified into "abundant group", while cities that are lower than the population mean are classified into "tight group". Fiscal surplus is calculated from fiscal revenue minus fiscal expenditure.

Table 5. Heterogeneity analysis.

	Industrial Structure		Environmental Regulation Intensity		Fiscal Pressure	
	Low	High	Low	High	Low	High
	(1)	(2)	(3)	(4)	(5)	(6)
AEC	-0.1386** (-2.34)	-0.4629*** (-6.65)	-0.5281*** (-8.85)	0.0356 (0.64)	0.0522 (0.59)	-0.2687*** (-5.15)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
N	1302	1361	1496	1167	944	1719
R²	0.6918	0.5478	0.6940	0.6726	0.6817	0.5686

Note: ***, ** and * indicate significant levels at 1%, 5% and 10% respectively, and standard errors are reported in parentheses.

Columns (5) and (6) in Table 5 respectively report the estimated results of the two groups of samples. It can be seen that the pollution control effect of AEC is only obvious in the "tight group", and cities with better fiscal status lack the motivation to further strengthen pollution control. The reason may be that the compensation amount in the current AEC policy is directly determined by the provincial government, and the compensation and penalty amounts are fixed rather than dynamic. Obviously, a fixed amount of compensation or penalty has different attractions for cities with different fiscal situations. If the compensation amount is too large, it is likely to cause a large fiscal shock to the compensation city, although it is an incentive or a threat to most cities. Conversely, when the compensation amount is too small, AEC does not have policy effect for some cities. This again suggests that market-based mechanisms are essential for AEC, and that only compensation amounts approved by the market can influence the environmental behavior of all participants.

The above heterogeneity analysis results show that fixed EC assessment criteria and compensation amounts are not conducive to the effectiveness of EC policies. The EC system should be adjusted accordingly to the characteristics of participating members when establishing the EC system. For cities with high environmental regulation intensity and low financial pressure, the higher level government can consider appropriately increasing the compensation amount to enhance their motivation for further pollutant emission treatment.

Conclusions

Based on the panel data of 281 prefecture-level cities in China from 2009 to 2018, this paper uses the time-varying DID model to analyze the impact of government-led AEC on air pollutant emissions intensity. We get the following results:

First, the implementation of AEC can significantly reduce the intensity of sulfur dioxide emissions, which is still valid after a series of robustness tests including the exclusion of similar policies, parallel trend test, placebo test, PSM-DID test, and change of explained variables. Second, the results of the mediating effects model show that AEC was able to promote green technology innovation, strengthening pollution treatment intensity and improving energy efficiency to reduce sulfur dioxide emissions intensity. Among them, strengthening pollution treatment intensity plays the biggest role. Third, heterogeneity analysis shows that AEC can achieve better policy effects in cities with higher industrial output value. For cities with high environmental regulation intensity and abundant financial funds, AEC's policy effect is not significant.

Based on the above conclusions, this paper puts forward the following policy recommendations:

1. Gradually promote the pilot scope of AEC, and finally establish a unified AEC regulatory system at the national level. Specifically, the Ministry of Environment and Ecology of Central and the Ministry of Finance of Central worked together as censors to formulate the list of participants, assessment period, objects and compensation amount. The assessment criteria and compensation amount should be heterogeneous across provinces. The provinces that fail to pass the assessment shall hand over the compensation to the central Ministry of Finance who will transfer the compensation to the provinces that pass the assessment. Moreover, the central government may consider granting additional fiscal transfers to provinces that implement ecological compensation policies within itself.

2. Expand the participants of AEC and build a multi-subject joint participation mechanism with enterprises as the participants and the government as the supervisor. A considerable part of the sources of air pollutants are industrial enterprises, but the existing AEC model guides enterprises to conduct pollution control through local governments. Therefore, it is hard to avoid the loss of efficiency caused by information asymmetry and moral hazard.

3. The government should focus on green technology innovation, environmental regulation intensity and energy efficiency in the process of promoting pollution control. Higher intensity of environmental regulation will certainly bring higher ecological benefits, but it will also have a negative impact on economic benefits. In the long run, it is necessary to develop clean technology innovation and energy technology innovation to balance ecological and economic development. Introduce a market-based compensation pricing mechanism. The current AEC compensation amount is determined by the government, and the policy incentive only exists at the financial level. The overall result is that AEC has no significant policy effect on some cities. We believe that the establishment of market-based ecological compensation trading center can be considered, and new compensation methods such as emissions trading, technology compensation, industrial compensation and preferential policies can be added to enhance the environmental protecting effect of AEC system.

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Conflict of Interest

The authors declare no conflict of interest.

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