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Does the Environmental Supervision System Improve Air Quality in China? An Empirical Study using the Difference-in-Differences Model

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Abstract: To effectively solve the problem of environmental pollution, the Chinese government has implemented an environmental supervision system since 2002. The environmental supervision system mainly uses the four functions of supervision, investigation, coordination, and emergency response to strengthen environmental protection supervision and law enforcement, respond to environmental emergencies, and coordinate cross-regional pollution disputes. As an important system design for China to control environmental pollution and promote the ecological transformation of economic development, the policy effect of the environmental supervision system deserves attention. This paper uses the difference-in-differences method to investigate the impact of the top-down environmental supervision system on air quality based on the 2000–2016 data for 285 prefecture-level cities in China. The results indicate that the annual average concentration of $PM_{2.5}$ decreased significantly after the implementation of the environmental supervision system. The dynamic analysis shows that $PM_{2.5}$ decreased most markedly in the first year after the implementation of the policy, and then the effect gradually weakened. Mechanism analysis suggests that the environmental supervision system can break the collusion between government and enterprise, encourage enterprises to carry out technological innovation, change pollutant discharge behavior and push local governments to adjust the industrial structure, enhance environmental protection awareness to reduce the $PM_{2.5}$ concentration, and improve air quality. Comparing different regions, the $PM_{2.5}$ in East China, North China and Northeast China are relatively high, and the pressure for air pollution control is great. Meanwhile, we find that the environmental supervision system has a significant station effect. Compared with other cities, the cities where the environmental supervision centers are located are more deterred by the environmental supervision, and their air quality has improved to a significantly greater degree. In the future, we should further strengthen the environmental supervision of high-pollution areas and non-station cities, and pay more attention to improving the long-term effect of the environmental supervision system.

Key words: environmental supervision system; air quality; $PM_{2.5}$; difference-in-differences model

1 Introduction

Air quality is related to the quality of human life. While enjoying the progress brought about by globalization and industrialization, humans are suffering from the negative effects of air pollution. Air pollution can readily cause a variety of respiratory diseases and have negative effects on people's mental health (Levinson, 2012). According to World Health Organization (WHO), some 3.8 million premature deaths annually are attributed to outdoor air pollution. About 80% of those deaths are due to heart disease and stroke, while another 20% are from respiratory illnesses and cancers related to exposure to $PM_{2.5}$. Only 20% of the urban population lives in areas that comply with WHO air quality guideline levels for $PM_{2.5}$. Many developing cities are at

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risk of long-term health problems (WHO, 2020). Effective control of air pollution and improvement of air quality are important issues that the world needs to face. With the rapid development of China's economy, the problem of air pollution has become more serious, and sudden air pollution accidents occur frequently. The continuous occurrence of haze in many cities has had a huge impact on businesses and on residents' health. To improve air quality, the Chinese government has adopted a series of regulatory measures, which include revising a number of laws and regulations, setting stricter energy-saving and emission-reduction targets, and using the completion of target goals for reducing air pollution as the basis for rewarding and punishing local officials. Despite these various measures, the effective implementation of the policies by local governments is the key to improving air pollution control (Zhou et al., 2013).

For multi-level governments, whether the environmental supervision responsibility should be borne by the central government or local governments is an unavoidable issue in environmental governance. Western countries mostly adopt environmental federalism, but the effect of this decentralized environmental governance system is controversial (Revesz, 2001). China adopts a system that combines central vertical supervision and local decentralized environmental governance. The central government formulates environmental policies and local governments are responsible for implementation (Zhang et al., 2018). This kind of environmental governance system seems to be managed uniformly, but due to the excessive management scope, there is an information asymmetry between the central government and local governments, which makes it impossible for the central government to effectively supervise the implementation of environmental policies by the local governments. Especially under the GDP-oriented performance-evaluation system, local governments' focus on strengthening the economy while neglecting environmental protection makes the implementation of environmental regulations the weakest link in environmental protection work (Qi and Zhang, 2014). The problems of emphasizing legislation, neglecting law enforcement, and neglecting supervision are widespread (Shen and Zhou, 2017). There has even been a simultaneous increase in environmental supervision and environmental pollution (He and Pan, 2017). In addition, China's air pollution is increasingly showing a trend of transformation from local pollution to regional pollution. Due to the diffusivity of air, it is difficult for a single local government to effectively control air pollution. Consequently, air pollution control is no longer a problem that a single city can face alone. It requires collaboration both between central and local governments, and across local governments (Cai, 2013).

To ensure the effective implementation of environmental protection policies, the central government began utilizing the environmental supervision system in 2002. The State Environmental Protection Administration (SEPA) set up six environmental protection supervision centers in China, covering all regions of the country. The supervision centers effectively supervise local environmental protection issues on behalf of the central government, break local protectionism, and solve major environmental problems across provincial boundaries. As an institutional innovation in the field of environmental management in China, the environmental supervision system has been in operation for more than ten years. Determining whether or not it has improved China's environment is worthy of attention, so this article uses rigorous empirical research to explore whether or not China's environmental supervision system has helped to improve air quality in Chinese cities, to identify its influence mechanism, and to determine whether there is heterogeneity.

At present, there are two closely related literatures. One focuses on the characteristics, influencing factors and control measures of air pollution in China. Air pollution in China has obvious temporal and spatial characteristics. The main pollutants such as $PM_{2.5}$ and SO_2 have seasonal differences, characterized as high in winter and low in summer (Bai et al., 2018). The main pollutants have strong regional characteristics in space, with obvious spatial spillover effects (Zhang et al., 2014; Feng et al., 2020). Xiao et al. (2020) measured the haze control level in North China, and found that economic growth had a negative effect on the haze control level and efficiency, while industrial structure had a positive effect on the haze control level and efficiency. Urban economic growth, urban expansion, population agglomeration, industrial production, and sulfur dioxide emissions are the main factors affecting changes in air pollutants (Lin et al., 2014; Yang et al., 2021). In addition, many studies focus on the impacts of various regulatory tools on air pollution. Li and Wen (2016) found that emission rights trading policies have a significant policy effect on the intensity of industrial sulfur dioxide emissions. However, Zhang and Zhang (2019) suggested that emissions trading have no significant emission-reduction effect in the pilot areas. In 1987, China promulgated the Law of the People's Republic of China on the Prevention and Control of Air Pollution, which has been revised several times since then. Although it governs air pollution through government administrative powers, environmental protection legislation alone cannot significantly inhibit local pollution emissions. Only in provinces with strict environmental protection law enforcement, or relatively serious local pollution, can legislation have a significant effect on improving the environment (Bao et al., 2013).

The other line of research focuses on the policy effects of environmental supervision. Han (2016) proposed that the regional environmental supervision system is a beneficial supplement to China's environmental protection governance system, which can break through administrative regional restrictions and solve environmental problems through cross-regional cooperation. Liu and Zhang (2018) put forward suggestions regarding the legalities, authority, and working mechanism of China's environmental supervision system through comparative analysis. Chen (2017) suggested that environmental protection supervision and accountability procedures should be standardized. Shen and Li (2018) stated that the environmental supervision system can effectively avoid local protectionism by concentrating the supervision power and realizing the "centralization" of governance rights, thereby helping to improve the efficiency of environmental governance. Chen et al. (2020) found that the environmental supervision system encourages enterprises to actively disclose environmental information and carry out energy conservation and emission reduction to avoid negative impacts in environmental regulation as much as possible. Liu and Wu (2019) showed through a study of 75 cities that the net effect of the central environmental protection inspection is not significant. Shi et al. (2017) conducted a study on 25 cities that were interviewed by the environmental protection department, and found that if the city interviewed because of air pollution, the air quality improved significantly after the interview, otherwise, there was no impact. Tan and Mao (2020) conducted a study on the first round of central environmental protection inspections from 2015 to 2017, and found that their impact on air pollution was a significant reduction immediately after the "on-site" inspection, so it is necessary to establish a continuous and dynamic routine environmental inspection mechanism.

Existing studies mostly focus on the theoretical analysis of the environmental inspection system, using descriptive statistical methods to analyze the temporal and spatial characteristics of air pollutants, and the empirical analysis only has a small sample size and a limited time span. To overcome these limitations, this paper selects 285 prefecture-level cities in China, covering 30 provincial-level autonomous regions and municipalities across the country, and a sample period from 2000 to 2016. It then uses a multi-period double difference method to empirically analyze the impact of environmental supervision systems on air quality and their internal mechanisms, and also analyzes its heterogeneity. This study aims to systematically analyze the impact of China's environmental supervision system on air quality, and to provide empirical evidence and policy references for other developing countries to improve their environmental governance systems.

The remainder of this paper is organized as follows. Section 2 provides an analysis and explanation of the policy background. Section 3 introduces the empirical methods and data processing. Section 4 presents the main empirical results and robustness tests. Section 5 investigates and analyzes the transmission mechanism of the environmental supervision system on air quality. Section 6 discusses the heterogeneity of the data. Finally, Section 7 outlines the final conclusions.

2 Environmental supervision system

Various problems in China's environmental protection urge the central government to implement the environmental supervision system. First, environmental violations continue to increase, and air pollution is becoming more serious. At the beginning of this century, the Chinese government and the public did not realize the serious harmful effects of smog. It was not until the smog had swept through most cities in China that the Chinese government began to include $PM_{2.5}$ as a key target for prevention and control. At this time, China's air pollution control is already facing tremendous pressure.

Second, the environmental protection management system is divided into administrative regions, and each region has its own governance, which makes it difficult to define responsibilities for environmental violations in cross-regional environmental disputes, and regional coordination is urgently needed for effective air pollution control.

Third, the problem of environmental violations under separate governance has made China's environmental protection institutional defects more prominent. In the early days of environmental protection in China, the State Environmental Protection Administration (CSEPA) was mainly responsible for the overall planning and formulation of environmental protection plans, policies, and standards, and the environmental protection departments of local governments were responsible for implementation. Under the framework of the principal–agent theoretical analysis (Fig. 1), local governments play the role of "middleman" between the central government and enterprises, but there are conflicts and games between the central and local governments regarding the environmental protection goals. Information asymmetry often makes the principal–agent relationship insufficiently binding, which leads to the incomplete implementation of the national environmental regulation policies by local governments (Zhang, 2016), alternative implementation (Zhong, 2017), and free-riding (Cai et al., 2016). The profit-seeking nature of enterprises and the dual consideration of political and economic interests by local government officials have led to conspiracies between governments and enterprises (Long and Hu, 2014), which has intensified local environmental pollution and increased regional pollution transfer (Li and Zhang, 2018). Enforcement of environmental protection is difficult, and local governments' low awareness of environmental protection prevents the national environmental protection policy from being effectively implemented. To develop a short-term economy, some local governments approve industrial projects that are profitable, but severely pollute the air, aggravating the air pollution.

To avoid the risks caused by conflicts of interest and information asymmetry between the central and local governments, and strengthen the management and supervision of local environmental protection departments, SEPA has set up additional dispatched agencies on a regional basis and established an environmental supervision system. In June

2002, SEPA first set up two regional environmental supervision centers in East China and South China as regional inspection pilot units. Four years later, the environmental supervision centers in Southwest China, Northwest China, and Northeast China were established, and the environmental protection supervision center in North China was organized in 2008 to realize the full coverage of environmental protection regional supervision.

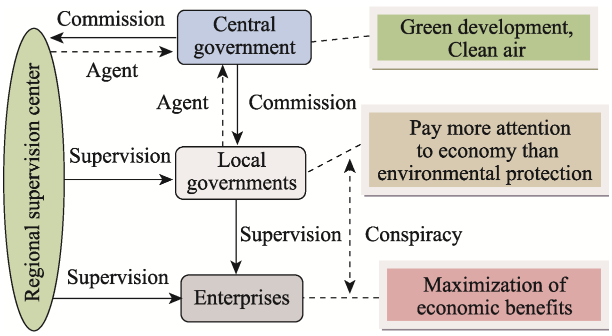

Fig. 1 Principal–agent relation diagram of environmental protection

As a law enforcement supervision agency dispatched by SEPA, the main responsibilities of the regional supervision centers are to supervise the implementation of environmental protection by local governments on behalf of the central government, cooperate with multiple departments to investigate and rectify illegal sewage companies, coordinate cross-regional environmental pollution disputes, and carry out emergency responses to sudden environmental pollution accidents. The regional supervision center reports the environmental protection situation of the local government to SEPA, and interviews the responsible individuals from the relevant departments that have not strictly implemented the environmental protection policy. The inspectors carry out on-site enforcement of the company's environmental protection targets and provide feedback on enforcement results to the local environmental supervision bureau, and then the local environmental supervision department imposes administrative penalties.

3 Empirical framework

3.1 Data and variables

We obtained information about the environmental supervision system from the official website of the Ministry of Ecology and Environmental Protection of the People's Republic of China. Table 1 shows the relevant content.

To quantitatively represent China's air pollution, we used the annual average concentration of $PM_{2.5}$ as a proxy variable. China's urban areas use smog as a catastrophic weather forecast. The country's smog pollution has shown the characteristics of high frequency, wide impact, long duration, normalization, and difficulty in governance (Shao et al., 2019). To deal with haze pollution and improve air quality, the primary task is to control the level of $PM_{2.5}$. The $PM_{2.5}$ data come from the global annual $PM_{2.5}$ satellite raster data calculated by Donkelaar et al. (2016). The data are based on the raster data for the average concentration of $PM_{2.5}$ as monitored by remote sensing satellites released by the Social Economic Data and Application Center of Columbia University. The satellite monitoring data are relatively more objective and accurate than ground monitoring data and can avoid measurement errors caused by human factors (Ghanem and Zhang, 2014). This paper further uses ArcGIS to transform this raster data into $PM_{2.5}$ concentration data for each of the 285 prefecture-level cities in China from 2000 to 2016.

Table 1 Establishment of environmental supervision centers in China

Region	Establishment year	Coverage area
East	2002	Shanghai, Jiangsu*, Zhejiang, Anhui, Fujian, Jiangxi, Shandong
South	2002	Hubei, Hunan, Guangdong*, Guangxi, Hainan
Northwest	2006	Shaanxi*, Gansu, Qinghai, Ningxia, Xinjiang
Southwest	2006	Chongqing, Sichuan*, Guizhou, Yunnan, Tibet
Northeast	2006	Liaoning*, Jilin, Heilongjiang
North	2008	Beijing*, Tianjin, Hebei, Shanxi, Inner Mongolia, Henan

Note: * indicates the provinces where the environmental supervision centers are located.

Figure 2 compares the annual average concentrations of $PM_{2.5}$ of the cities in 2000, 2008 and 2016. In 2000, $PM_{2.5}$ concentrations were relatively low. In 2008, high-pollution areas increased significantly. In 2016, the air quality in most areas improved, but air pollution levels in Tianjin, Hebei, Shandong and Jiangsu were still severe. According to the $PM_{2.5}$ secondary standard of 35 μg m^{-3} in the "Ambient Air Quality Standard" GB3095-2012, we divided the cities into high-pollution ($>$35 μg m^{-3}) and low-pollution ($\leqslant$35 μg m^{-3}) cities. Figure 3 shows the percentages of these two types of cities in different regions. It can be seen that from 2000 to 2016, the average concentrations of $PM_{2.5}$ in more than half of the cities in East and South China exceeded 35 μg m^{-3}, while in most cities in Southwest and Northwest China it was below 35 μg m^{-3}. It is worth noting that, after the environmental supervision system was fully implemented in 2008, the average annual $PM_{2.5}$ concentrations in East China, South China, and Southwest China dropped significantly, while that in Northeast China fluctuated after a short period of decline.

Since the $PM_{2.5}$ is closely related to urban economic development, industrial production, and residents' lives, this article controls for a series of related variables based on previous research and data availability. These variables include: 1) The size of the population, which represents the

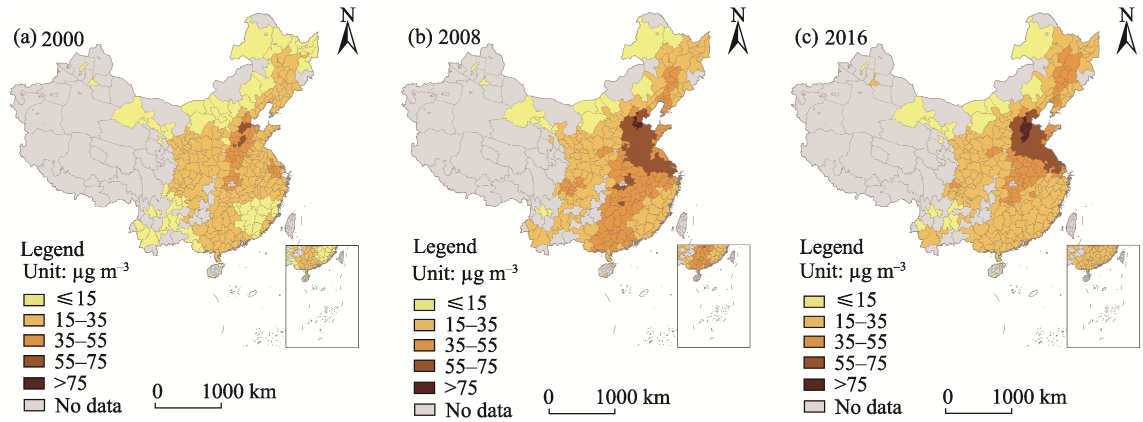

Fig. 2 $PM_{2.5}$ in 2000, 2008 and 2016.

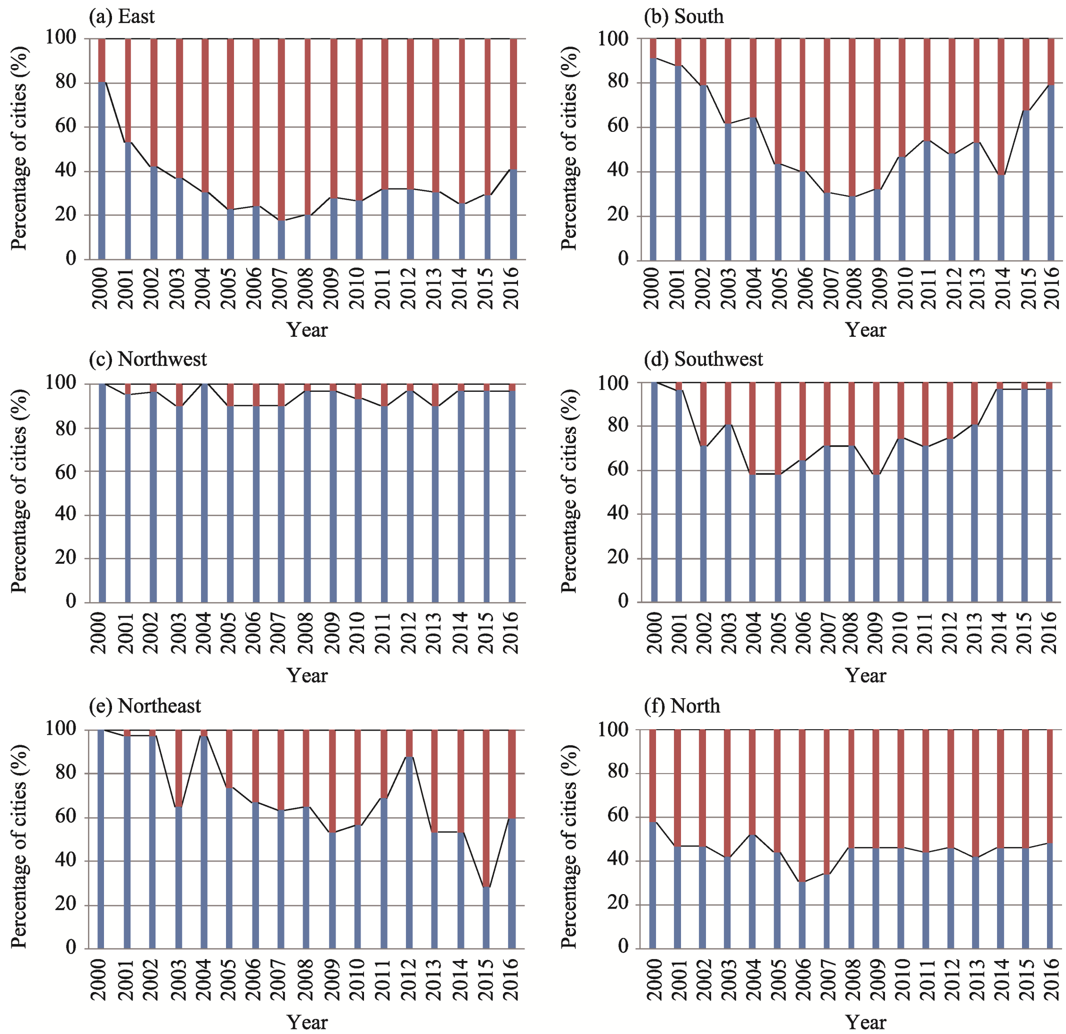

Fig. 3 The percentages of the high-pollution and low-pollution cities in different regions from 2000 to 2016

impact of differences in the scale of urban population activities; 2) The industrial structure, measured by the proportion of the added value of the secondary industry in the regional GDP, which represents the characteristics of the overall industrial structure; 3) The GDP per capita, representing the level of economic development; 4) The degree of market openness, measured by the ratio of foreign direct investment (FDI) to GDP, to examine the degree of regional openness; 5) Fiscal dependence, measured as the proportion of fiscal revenue to GDP, to represent the level of fiscal burden in a region; 6) The level of urbanization, measured by the ratio of the urban non-agricultural population to the total population. To control for the nominal price effect, all currency variables were deflated using the GDP of each province based on the year 2000. The above data were from the 2001–2017 editions of the *China City Statistical Yearbook*. Eliminating the cities which had missing data, the final data set included 285 cities.

In addition, to solve the endogeneity problem, referring to Hering and Poncet (2014), we used the ventilation coefficient as an instrumental variable. The ERA-Interim database of the European Center for Medium-Range Weather Forcasts provides data on wind speed at 10 m height and boundary layer height for a global grid of 0.75° × 0.75° (about 83 km^2). We first calculated the ventilation coefficient of each grid corresponding to the year; then we matched each grid with the sample city according to its latitude and longitude to obtain the ventilation coefficients of the 285 cities from 2000 to 2016. The industrial sulfur dioxide data per unit of GDP was used to measure the pollution behavior of enterprises. These data came from the *China City Statistical Yearbook*. The total number of authorized invention patents was used to measure the innovation behavior of enterprises. These data come from the official website of the State Intellectual Property Office of China. The number of urban environmental pollution accidents and the investment completed in the treatment of waste gas were used as proxy variables for the local government's environmental awareness. These data came from the 2001–2017 editions of the *China Environment Yearbook*. To facilitate the calculation and reduce the volatility of the data, this paper carried out logarithmic processing on the variables of population size, per capita GDP, ventilation coefficient, number of authorized invention patents and the in.0vestment completed in the treatment of waste gas. Table 2 shows the descriptive statistics for each variable.

Table 2 Summary statistics and descriptions of variables

Variable name	Mean	S.D.	Description
$PM_{2.5}$	35.111	16.130	Average annual concentration of $PM_{2.5}$ (μg m^{-3})
ln (population)	5.843	0.695	Logarithm of total population (×10^4 person)
Industry structure	47.853	11.197	The share of secondary industry in GDP
ln (PGDP)	15.512	1.053	Per capita GDP
FDI	0.004	0.004	Ratio of FDI to GDP
Fiscal dependence	0.081	0.045	Ratio of fiscal revenue to GDP
Urbanization	0.352	0.190	Ratio of non-agricultural population in total population
ln (VC)	7.353	0.294	Average annual air flow coefficient
SO_2	0.031	0.120	Industrial sulfur dioxide emissions per unit of GDP (t (×10^4 yuan)$^{-1}$)
ln (patent)	5.821	1.838	Number of invention patents authorized (pieces)
ln (investment)	6.279	1.723	Investment completed in the treatment of waste gas
Accidents	37.960	65.562	Number of environmental pollution accidents

3.2 Empirical strategy

The main objective of our empirical analysis was to investigate the impact of the environmental supervision system on air pollution, and we used the difference-in-differences (DID) method to obtain this estimate. The basic principle of the DID method is to divide the sample into a "treatment group" affected by the policy and a "control group" not affected by the policy. Likewise, it controls for other related factors to examine the differences between the two groups before and after the policy is implemented. Detecting policy effects and the double difference method can solve the endogeneity problems caused by the omission of dependent variables, and can effectively improve the accuracy of the policy evaluation. Due to the inconsistent times when the environmental supervision systems were set up in various cities, the multi-period DID method is used, and the measurement model is set as follows, with reference to Thorsten et al. (2010):

$$Y_{it} = \alpha + \beta ESS_{it} + \delta X_{it} + \gamma_i + \sigma_t + \varepsilon_{it} \qquad (1)$$

In Equation (1), Y_{it} measures the air pollution in city i in year t. ESS_{it} is a dummy variable. When city i has established an environmental supervision system in year t, ESS_{it} is set to 1 in each year, all others are set to 0, and X_{it} represents the relevant control variable. γ_i and σ_t represent city fixed effects and time fixed effects, respectively, and ε_{it} is the error term. α, β, δ are coefficients and β is the estimated amount of the difference method, which measures the treatment effect of the environmental supervision system on air pollution. When β is negative and significant, the environmental supervision system has reduced air pollution and improved air quality.

4 Empirical findings

4.1 Baseline estimation results

Table 3 provides the DID regression results. Model 1 shows that the policy variable is –1.629 at 1% significance, which indicates that the environmental supervision system significantly reduced $PM_{2.5}$. As this paper adopts panel data, to eliminate the influences of time and individual differences on the explained variables, Model 2 controls the city fixed effects and year fixed effects, and Model 3 further controls the city characteristic variables. The results show that the policy variable is –1.024 (Model 2) and –1.192 (Model 3), respectively, under 1% significance. Whether or not the control variables are included, the regression coefficients for $PM_{2.5}$ are all significant and negative, which indicates that the establishment of an environmental supervision system can significantly reduce the degree of air pollution in the city. In addition, the data also show that the higher the proportion of the secondary industry, the higher the level of urbanization, and the more serious the air pollution. This also shows that China has indeed reduced the air quality in cities in the process of rapid industrialization and urbanization. A city with a stronger financial strength will have a significant decrease in its $PM_{2.5}$ concentration. It may be that the cities with a stronger financial strength have a greater ability to invest in scientific research and innovation, which is conducive to improving air quality.

Table 3 The effect of the environmental supervision system on $PM_{2.5}$

Variables	Model 1	Model 2	Model 3
ESS	−1.629*** (0.266)	−1.024*** (0.317)	−1.192*** (0.317)
ln (population)			3.825 (1.981)
Industry structure			0.117*** (0.024)
ln (PGDP)			−4.383*** (0.792)
Fiscal dependence			−19.412*** (4.762)
Urbanization			4.929** (2.091)
FDI			42.851 (29.486)
City fixed effects	NO	YES	YES
Year fixed effects	NO	YES	YES
Observations	4793	4793	4793
R^2	0.934	0.950	0.951

Note: ** and *** indicate the statistical significance levels of 5% and 1%, respectively. The numbers in brackets are the city-level cluster standard errors. "YES" and "NO" indicate controlling or not controlling city fixed effects and year fixed effects, respectively. Control variables include ln (population), Industry structure, ln (PGDP), Fiscal dependence, Urbanization and FDI.

4.2 Parallel trend hypothesis testing and dynamic analysis

An important requirement of the DID method is that the parallel trend assumption must be met; that is, before the implementation of the environmental supervision system, there should be no significant differences in the trends of air pollution between the pilot cities and the other cities. In this regard, this article draws on the method of Thorsten et al. (2010) and uses the following equation:

$$Y_{it} = \alpha + \sum_{k=-4}^{6} \beta P_{it}^{k} + \delta X_{it} + \gamma_i + \sigma_t + \varepsilon_{it} \tag{2}$$

In Equation (2), P_{it}^{k} is a dummy variable representing the "k" year of the environmental supervision system pilot. For example, k = 1 indicates the first year of the implementation of the environmental protection supervision system in city i, and $k = -1$ indicates the year before the implementation of the policy. This article mainly examines the policy effects in the four years before and six years after the implementation of the system. The coefficient "β" indicates the difference in air pollution between pilot cities and non-pilot cities in the "k" year of the environmental supervision system policy. If "β" is not significant in the period $k < 0$, then the difference in air pollution between the pilot cities and the non-pilot cities is caused by the environmental protection supervision system. On the contrary, if "β" is significant in the period $k < 0$, then the difference in air pollution between the pilot cities and non-pilot cities is not caused by the environmental protection supervision system, which does not conform to the parallel trend hypothesis. The data in Fig. 4 show that "β" was not significant before the implementation of the environmental protection supervision system, but it became significant after the implementation of the policy, indicating that the parallel trend test was passed. We can also see that the environmental supervision system has significantly reduced the air pollution levels of the pilot cities in the first year of its establishment, but the follow-up effect was weaker, which indicates that the short-term effect of environmental protection supervision is obvious, but the long-term effect is not ideal. This may be due to the fact that although the regional supervision center carries out environmental supervision on behalf of the central government, it only has the power of law enforcement and no power of punishment, which leads to a limited deterrent capacity of supervision.

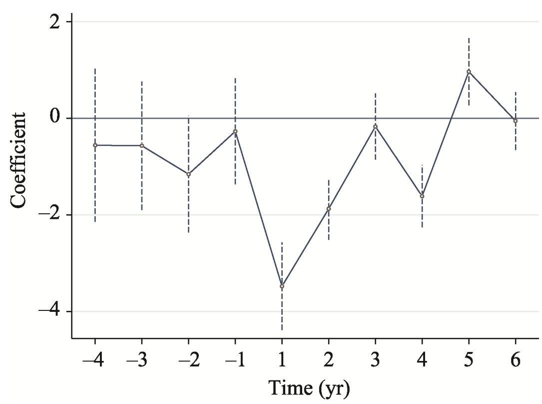

Fig. 4 Dynamic impact of the environmental supervision system on air pollution

4.3 Robustness checks

4.3.1 Excluding other policy influences

When China implemented the environmental supervision system it also adopted other environmental regulations to reduce air pollution. For example, at nearly the same time, China implemented the emission trading system. Under the conditions determined by the total emission control index of pollutants, a market mechanism is used to trade emission rights to reduce pollutant emissions and improve air quality. China started the emission trading project in 2001 and selected 11 provinces, including Tianjin, Hebei, Shanxi, Inner Mongolia, Jiangsu, Zhejiang, Henan, Hunan, Hubei, Chongqing, and Shaanxi, to carry out the pilot system of emission trading in 2007. For this paper, we removed the prefecture-level cities under the jurisdiction of these 11 provinces to eliminate their impact on the levels of air pollution. The estimated results are shown in Model 1 and Model 2 of Table 4. After controlling for the impact of the emission trading system, the environmental supervision system still significantly reduced the average annual concentration of $PM_{2.5}$. This means the conclusion that the environmental supervision system has a significant negative effect on air pollution is robust.

4.3.2 The PSM-DID estimation

Since the environmental supervision system is a quasi- natural experiment, the pilot cities and non-pilot cities may not be randomly selected, and the cities which have a high pressure of environmental pollution and a high proportion of industry are more likely to be included in the pilot group. For example, East China and South China have better economic development and a high proportion of industry, so they were the first regions to carry out the environmental supervision pilot. In addition, the sample used in this study includes 285 prefecture-level cities across the country, and there are individual differences between cities, so there may be selection bias.

To further control for this systematic bias, this paper adopts the Propensity Score Matching–Difference in Difference (PSM-DID) model as a robustness test. First, we selected a series of city-level variables, including urban population size, industry structure, per capita GDP, fiscal dependence, urbanization, and FDI, as the matching criteria. We then used the nearest-neighbor matching method and bootstrap technology to repeat the sampling calculations and run the test 500 times in order to obtain the standard error. The scores were determined for the control group that matched the treatment group, and then the matched results were further regressed using the DID method. The regression results for the PSM-DID are shown in Model 3 and Model 4 of Table 4. The effectiveness of the environmental supervision system is still significant, so the reduction of $PM_{2.5}$ indicates that the conclusions obtained in this paper are robust.

Table 4 The results excluding other policy influences (Model 1 and 2) and PSM-DID estimates (Model 3 and 4).

Variables	Model 1	Model 2	Model 3	Model 4
ESS	-1.719^{***} (0.342)	-2.171^{***} (0.350)	-1.596^{***} (0.273)	-1.769^{***} (0.273)
Control variables	NO	YES	NO	YES
City fixed effects	NO	YES	NO	YES
Year fixed effects	NO	YES	NO	YES
Observations	2952	2952	4392	4392
R^2	0.920	0.922	0.931	0.932

Note: *** indicates the statistical significance level of 1%. The numbers in brackets are the city-level cluster standard errors. "YES" and "NO" indicate controlling or not controlling city fixed effects, year fixed effects and control variables, respectively. Control variables are the same as in Table 3.

4.3.3 Instrumental variable method

To investigate the accuracy of the estimation results of the DID method, the instrumental variable method was used to overcome the impact of endogeneity (Cai et al., 2016). This method requires that the selected variables should be related to the endogenous variables but not to random disturbance terms. In this paper, the ventilation coefficient was selected as the instrumental variable. This selection was made because when the total emission of air pollutants is fixed, then the smaller the ventilation coefficient, the higher the concentration of air pollutants, and more stringent environmental supervision measures are more likely to be implemented. The ventilation coefficient is determined by meteorological and geographical conditions and cannot be artificially controlled, so it meets the exogenous condition hypothesis of the instrumental variable method. The estimation results for the instrumental variables are shown in Table 5.

In the first stage, the explanatory variables and instrumental variables are regressed to obtain the fit values of the explanatory variables. The F statistic in the regression results is greater than 10 and is at 1% significance level. The

Table 5 Instrumental variable estimations

Variables	First step regression	Second step regression
	ESS	$PM_{2.5}$
ln (VC)×post	0.135^{***} (0.000)	
ESS		−1.748*** (0.265)
Control variables	YES	YES
City fixed effects	YES	YES
Year fixed effects	YES	YES
Observations	4793	4793
R^2	0.964	0.546
F value	33.12	

Note: *** indicates the statistical significance level of 1%. The numbers in brackets are the city-level cluster standard errors. Post is a time processing variable. "YES" indicates controlling city fixed effects, year fixed effects and control variables, respectively. Control variables are the same as in Table 3.

ventilation coefficient is not a weak instrumental variable, and it can be used as an instrumental variable. In the second stage, the fitting value of the explanatory variables was used to regress the explained variables. The regression estimation results show that the environmental supervision system still has a significant negative effect on $PM_{2.5}$ with controlling the related variables and fixed effects. After eliminating the endogeneity problem, the environmental supervision system can still significantly reduce $PM_{2.5}$, which shows the robustness of the regression results.

5 Potential mechanisms

This study's main empirical finding is that the environmental supervision system can significantly reduce $PM_{2.5}$. In this section, we discuss several potential channels or mechanisms of how the environmental supervision system affects air pollution.

5.1 Environmental supervision system and enterprise emission behavior

Enterprises are the key objects of environmental supervision. Through the regulation of illegal pollutant discharge and the verification of total emission reduction of the main pollutants, the pollutant discharge behavior of enterprises is restricted and managed. Enterprises with a pollutant discharge which fails to meet the standard are punished, rectification measures are put forward, and the rectification task is completed within a limited time. As a result of the pressure from external authorities, enterprises are encouraged to carry out cleaner production and reduce the emission of air pollutants through technological innovation. To verify this mechanism, this paper uses industrial sulfur dioxide emissions (SO_2) per unit GDP and the logarithm of the total number of urban invention patents as the proxy variables of enterprise emission behavior and innovation ability. Table 6 shows the estimated results. It can be seen that the environmental supervision system significantly reduces sulfur dioxide emissions per unit GDP and improves the innovation ability of enterprises, both of which indicate that the environmental supervision system can reduce enterprise emission behavior, thus improving the urban air quality.

5.2 Environmental supervision system and local government industrial policies

China's heavy industry-led industrialization process has led to large amounts of fossil fuel consumption and air pollutant emissions. In the face of severe air pollution, environmental protection supervision focuses on the heavy-pollution industries, which puts pressure on the environmental governance of local governments. Thus, the local governments have made adjustments to urban industrial structure, closing and transferring heavy-polluting industrial enterprises and promoting urban industrial upgrades to reduce the air pollutant emissions. Based on this, this article adopts the proportion of the secondary industry in GDP as the proxy variable for industrial structure. It can be seen from Table 6 that the environmental supervision system has indeed significantly reduced the proportion of the city's secondary industry and improved the city's air quality through industrial restructuring.

5.3 Environmental supervision system and local government environmental awareness

Under the information asymmetry and "GDP-only" assessment system, it is necessary to break the channel of government-enterprise collusion to change the local government's awareness of valuing economy over environmental protection. The environmental supervision team, on behalf of the central environmental protection department, supervises the implementation of environmental protection by local governments, such as administrative accountability to the responsible persons and relevant staff at all levels according to the severity of environmental pollution accidents. This undoubtedly motivates local governments to strengthen environmental supervision. With the central government's increasing attention to air quality, the balance between economic growth and environmental protection by local governments is also changing. The pressure of environmental supervision has broken the collusion between governments and enterprises. Through accountability, local governments can curb perfunctory rectification, superficial rectification, and the violation of laws and regulations. This is conducive to the local government improving the awareness of environmental protection, and taking more effective environmental governance measures to improve the air quality. Through research on coal mine safety governance, Nie et al. (2020) found that the collusion of government and enterprise will bring about rapid economic growth, but it will also bring about a large number of safety production accidents. Drawing on their ideas, this paper takes the number of urban environmental pollution accidents as the proxy variable of government-enterprise collusion, and the investment completed in the treatment of waste gas as the proxy variable of local government environmental protection behavior to investigate the impact of the environmental supervision system on local government environmental protection awareness. The regression results are shown in Table 6. The environmental supervision system has indeed reduced the number of environmental pollution accidents and increased the amount of local government investment in pollution control, which show that the environmental supervision system is conducive to breaking the government-enterprise collusion and improving the local government's awareness of environmental protection, all of which are conducive to improving air quality.

6 Heterogeneity analysis

So far, we have estimated the average impact of the envi-

Table 6 Analysis of potential mechanisms

Variables	ln (patent)	SO_2	Industry structure	Accidents	ln (investment)
ESS	1.125*** (0.037)	–0.005*** (0.001)	–0.596* (0.322)	–17.557*** (0.021)	0.052** (0.021)
Control variables	YES	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES
Observations	4793	4793	4793	4793	4793
R^2	0.252	0.721	0.868	0.012	0.912

Note: *, **, and *** indicate the statistical significance levels of 10%, 5%, and 1%, respectively. The numbers in brackets are the city-level cluster standard errors. "YES" indicates controlling city fixed effects, year fixed effects and control variables. The control variables in the regression analysis of industry structure include ln (population), ln (PGDP), Fiscal dependence, Urbanization and FDI, and the other analysis of potential mechanisms includes the same control variables as in Table 3.

ronmental supervision system on air pollution. Here we further explore possible heterogeneity. Geographical distance is important in government decision-making (Huang et al., 2017). Campante and Do (2014) found that the farther a city is from the state's center, the weaker the government's ability to supervise the city officials and hold them accountable. We further explore whether the government station effect exists. The environmental supervision center is a central agency that represents the power of the central government. Therefore, the closer a city is to the environmental supervision center, the stricter the environmental supervision may be, and the stronger the deterrence of the local government will be. Does this mean that the city where the environmental supervision center is located would have a better policy effect than other cities? The central government has established environmental supervision centers in Jiangsu, Guangdong, Shaanxi, Sichuan, Liaoning, and Beijing, each of which supervises several regions (Table 1). We divided the sample cities into two groups: one group includes 77 prefecture-level cities in the province where the environmental supervision center is located and the other group includes 208 prefecture-level cities in the province where the environmental supervision center is not located. According to this grouping study (Table 7), the air pollution levels of the two groups of cities both declined after the implementation of the environmental protection supervision system, but the air quality improvement of the provinces where the environmental protection supervision center is located was more obvious. This shows that, compared with the cities without supervision centers, the station cities do indeed benefit from greater environmental supervision deterrence.

Table 7 Heterogeneity analysis

Variables	Station city	Non-station city
ESS	–1.593*** (0.489)	–1.349*** (0.318)
Control variables	YES	YES
City fixed effects	YES	YES
Year fixed effects	YES	YES
Observations	1308	3485
R^2	0.898	0.944

Note: *** indicates the statistical significance level of 1%. The numbers in brackets are the city-level cluster standard errors. "YES" indicates controlling city fixed effects, year fixed effects and control variables, respectively. Control variables are the same as in Table 3. "Station city" indicates the cities in the province where the environmental supervision center is located, and "Non-station city" indicates the cities in the province where the environmental supervision center is not located.

7 Conclusions

This paper studies the effects of the environmental supervision system on air quality using the DID method and data from 285 prefecture-level cities in China from 2000 to 2016. Empirical analyses show that after the implementation of the environmental supervision system, China's $PM_{2.5}$ has dropped significantly, indicating that air quality has been effectively improved, and a variety of robustness testing methods have proven this conclusion.

This paper further discusses the transmission mechanism of the environmental supervision system on air quality and finds that, on the one hand, the environmental supervision system exerts external pressure on enterprises to promote technological innovation, clean production, and to reduce the emission of air pollutants. On the other hand, by exerting pressure on local governments, the latter can change the industrial structure and upgrade the industry in their region to reduce air pollution. At the same time, the accountability system can increase the deterrence to local government leaders, break the collusion between government and enterprises, enhance the environmental protection awareness of local governments, reduce the occurrence of pollution accidents, and improve the air quality.

The analysis of the trends in the average annual concentration of $PM_{2.5}$ in different regions shows that the $PM_{2.5}$ levels in East China, North China and Northeast China are relatively high, and the pressure for air pollution control is great. Environmental supervision in these regions should be strengthened to improve the air quality.

In addition, the $PM_{2.5}$ levels of the cities where the environmental supervision centers are located have dropped more significantly than in other cities. Therefore, it is necessary to strengthen environmental supervision in non-station areas, increase the coverage and deterrence of the environmental supervision system, and effectively improve the air quality in all cities.

Through dynamic analysis, this paper finds that the short-term effect of the environmental supervision system is significant, but in the long run, the effect on air quality improvement is not ideal. Future research should more deeply analyze the existing problems and mechanisms to enrich the existing research.

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环保督查制度改善了中国的空气质量吗？—基于双重差分模型的实证分析

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摘　要：为有效解决环境污染问题，中国政府从 2002 年开始实践环保督查制度，环保督查制度主要通过监督、调查、协调、应急四大职能，加强环保监督执法、应对突发环境事件以及协调跨区域污染纠纷。环保督查制度作为中国治理环境污染问题、促进经济发展生态化转型的重要制度设计，其政策成效值得关注。本文基于中国 285 个地级城市 2000–2016 年数据，采用双重差分法考察这种自上而下的环境监管制度对空气质量的影响。结果表明，环保督查制度实施后，中国 $PM_{2.5}$ 年均浓度显著下降。动态分析显示政策实施后第一年 $PM_{2.5}$ 下降最为明显，随后效果逐渐减弱。机制分析发现环保督查制度通过督企和督政打破政企合谋，促使企业进行技术创新，改变污染物排放行为，推动地方政府调整产业结构，增强环保意识，降低 $PM_{2.5}$ 浓度，改善空气质量。不同区域对比显示，华东、华北和东北地区的 $PM_{2.5}$ 相对较高，空气污染治理压力大。同时，我们发现环保督查制度具有显著的驻地效应，与其他城市相比，环保督查中心所在城市受到环境监管的威慑更大，空气质量改善更为明显。未来应该进一步加强高污染区域及非驻地城市的环境监管力度，并且关注环保督查制度长期效应的提升。

关键词：环保督查制度；空气质量；$PM_{2.5}$；双重差分模型