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The effects of environmental inspection on air quality: Evidence from China

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ABSTRACT

To address ecological and environmental issues, central environmental inspection (CEI) coordinated by the Chinese Ministry of Ecology and Environment has been implemented since 2016. This paper aims to comprehensively evaluate how and how much CEI affects air quality. The results of the difference-in-differences models show that CEI improved the air quality and reduced the concentrations of $PM_{2.5}$, PM_{10}, NO_2, and SO_2 by 8.8%, 8.1%, 7.9%, and 2.4%, respectively. Moreover, environmental effectiveness was strengthened over the course of four rounds of inspection. The mediating model results indicate that effectiveness was achieved through active public participation, administrative punishments from the central inspectors, and positive rectification actions from the local governments. The greatest improvement in air quality occurred during the on-site inspection period, after which the effects gradually weakened. A review inspection was carried out to supervise the rectification tasks. The adoption of review inspection made the effects on air quality improvement reappear, which verifies that CEI in China is not just a temporary campaign-style enforcement but a normalized and effective governance of air pollution.

1. Introduction

The rapid development of energy-intensive industries has led to an economic boom as well as severe air pollution (Huang et al., 2014) and enormous health damage (Ebenstein et al., 2017; Vandyck et al., 2018). To curb air pollution, strict environmental regulations have been implemented, such as energy transitions (Shindell et al., 2016; Shen et al., 2019), tighter standards for industrial and vehicle emissions (Karplus et al., 2018; Driscoll et al., 2015; Li et al., 2020a), and technology upgrades (Zhang et al., 2019). These regulations not only reduce air pollution but also increase happiness and prevent deaths. For example, if clean energy policies are adopted in the United States, 175, 000 premature deaths can be prevented, and annual benefits of $250 billion can be obtained (Shindell et al., 2016).

Inspection from the national government can encourage local governments to effectively implement air pollution control regulations through incentives or punishment (Pan et al., 2015; Li et al., 2020b). To curb environmental and ecological problems, central environmental inspection (CEI) was implemented in China. Routine inspection, review inspection, and inspection of special environmental problems are the three main modes of CEI. Four rounds of routine inspections have been implemented in 31 provinces of China, and the first round of inspected regions has undergone review inspections. It is unclear what the effects of CEI will be on air pollution control. In this paper, we comprehensively evaluate the effects of CEI on air quality and examine whether normalized inspection is effective for environmental governance in China.

Environmental inspection in China was previously mainly the responsibility of local environmental protection authorities. The former Ministry of Environmental Protection (MEP) was responsible for the overall planning and formulation of environmental protection plans, policies, and standards. In fact, inspection did not come into play in China under environmental decentralization (Lo et al., 2006; Rooij, 2006; Wang et al., 2003). On the one hand, some polluting enterprises may be protected by local governments because of local economic interests and competitiveness (Dasgupta et al., 1997; Jia and Nie, 2017; Pu and Fu, 2018; Wang et al., 2003). On the other hand, due to the lack of resources and the weak inspection ability of local environmental administrations, it is difficult to ensure the quality and strength of local inspection (Rooij, 2006). Moreover, provincial internal inspection makes it difficult to clarify responsibility in cases of cross-regional environmental violations (Zhang et al., 2018).

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The Environmental Protection Inspection Plan issued in July 2015 pointed out that central environmental inspection is led by the central government instead of the MEP and is centred on the environmental governance of local governments. CEI emphasizes the same division of responsibility between governments. By the end of June 2018, the first round of provinces had been inspected again with the initial normalization of CEI achieved. The detailed introduction to CEI is in the APPENDIX. Air quality improvements are one of the main targets of CEI, although the governance of serious air pollution in China is regarded as an arduous and long-term mission (Sheehan et al., 2014). The 14th-Five-Year Plan for National Economic and Social Development announced by the Chinese government sets a target of 87.5% of days with good air quality. There are still 121 out of 356 cities whose average annual concentration of $PM_{2.5}$ exceeds the level of China's National Ambient Air Quality Standard (National Bureau of Statistics, 2019). The key aims of CEI are to supervise whether the air quality improvement goal has been met and monitor the pollutant discharge of polluting enterprises and other environmental problems. A subsequent feedback report highlights the specific problems of the cities shown to have issues with air pollution. This paper estimates the impacts of CEI on air quality improvements at the city level.

Studies on CEI mainly focus on three aspects. First, from the perspective of the central-local relationship, studies consider CEI to be a mechanism innovation that adjusts the relationship between the central and local governments in environmental governance in the Chinese context (Shen and Dong, 2020; Kostka and Nahm, 2017). It solves local environmental protectionism through negative political incentives (Chen, 2022), a populist approach and normalized inspection (Zhang, 2022). Second, studies analyse the detailed measures of CEI. For example, "talking with local officials about environmental problems" is a typical measure of CEI. If the central inspector finds local environmental problems, the local officials will be held accountable, which may prevent political promotion. This measure promotes the efficiency of the environmental governance of local governments (Wu and Wang, 2019) and improves the environmental performance of enterprises (Shen and Zhou, 2017). Third, from the perspective of policy evaluation, studies at the enterprise level find that CEI significantly decreases chemical oxygen demand (COD) emissions from industrial firms (Zhang et al., 2018; Liu et al., 2017), promotes green innovation (Song et al., 2022; Chen et al., 2019), and increases the environmental investment of polluting enterprises (Du et al., 2020). In general, CEI is an effective regulation for environmental governance.

However, few studies have focused on the impacts of CEI on air quality. Jia and Chen (2019) examine the short-term effects of CEI and prove that the first two rounds of routine inspection improved the AQI, while the CEI implemented four rounds of routine inspection. The comprehensive effects of CEI, including routine inspection, review inspection, and special inspection, on air quality are unclear, and the mechanism of pollution reduction is unknown.

This study developed a comprehensive evaluation of CEI, including the effectiveness of routine inspection, review inspection, and special inspection of environmental problems. We examined the dynamic effects of CEI on air quality with the difference-in-differences (DID) framework and found that CEI significantly improved the air quality index and decreased the concentrations of $PM_{2.5}$, PM_{10}, NO_2, and SO_2. Moreover, environmental effectiveness was strengthened over the course of four rounds of inspection. Furthermore, we identified the mechanism of air quality improvements with a mediating effects model and found that the effectiveness was through active public participation, stringent regulations from the central inspectors and positive rectification actions from the local governments. In addition, although the improvement effects gradually weakened and disappeared after the on-site inspection, they reappeared when the review inspection was implemented. This study enriches the literature by demonstrating that CEI in China is more than just a temporary campaign-style enforcement; it represents a normalized and effective governance of air pollution. The negative political incentives for local officials and the populist approach are effective mechanisms for environmental governance. The empirical findings of this paper can provide crucial information for developing environmental regulations in China and shed light on them for other countries facing pollution issues.

2. Empirical strategy

2.1. Sample and data

To identify the outcomes of environmental inspection, we extracted air pollutant data for 86 cities from January 1st, 2015, to December 31st, 2018, including one year before the first round of routine inspection and one year after the last round of routine inspection. There are 43 cities from 18 provinces that have been inspected for air pollution problems at the city level in the Rectification Plan for Feedback of Central Environmental Inspection (named the Rectification Plan below) for each province or municipality (as shown in Table A1). We selected these 43 cities as the treatment group and 43 other cities that were never inspected for air pollution problems as the control group. The cities in the treatment group and control group were neighbouring cities from the same 18 provinces, as shown in Fig. A1.

Our main datasets included daily air pollution data and meteorological data. The former contains the daily air quality index (AQI), the concentrations of particulate matter less than 2.5 μm ($PM_{2.5}$) and less than 10 μm (PM_{10}), sulfur dioxide (SO_2) and nitrogen dioxide (NO_2). The major sources of PM, SO_2 and NO_x are the power sector (7.8–20.7%), industrial sector (38.6–72.5%) and residential sector (5.6–38.1%) (Li et al., 2017; Zheng et al., 2018). These sectors are also the targeted sectors for environmental governance and environmental inspection (Central Ecology Environment Protection Inspection Office, 2021). The city-level data were obtained from China's National Environmental Monitoring Centre (National Environmental Monitor Center of China, 2019). The meteorological data included the daily average temperature, relative humidity, maximum wind speed, and precipitation and were obtained from the China Meteorological Administration (China Meteorological Administration, 2019). Regulation intensity was also considered in this study, which is reflected by the removal rate of industrial SO_2 and smoke dust (Feng et al., 2020) and was collected from the statistics yearbook of each city. Table 1 shows the descriptive statistics of the variables.

2.2. Model specifications

As an effective method for quantitative policy estimation, the DID method excludes the influence of other exogenous factors and provides empirical evidence on the purely policy-related effects (Fu and Gu, 2017; He et al., 2016; Viard and Fu, 2015). To examine the effectiveness of environmental inspection for air quality improvements, we compared

Table 1
Descriptive statistics.

Variables	Treatment group		Control group	
	Mean	Std. Dev.	Mean	Std. Dev.
Daily AQI level	84.321	56.121	83.067	55.785
Daily $PM_{2.5}$ level (μg/m^3)	49.109	40.325	49.034	40.125
Daily PM_{10} level (μg/m^3)	87.276	58.654	84.479	55.732
Daily SO_2 level (μg/m^3)	24.799	15.762	22.738	14.572
Daily NO_2 level (μg/m^3)	35.227	22.766	31.010	20.741
Daily average temperature (in °C)	15.877	10.325	14.813	10.142
Daily maximum wind speed (in m/s)	4.799	4.981	4.986	5.789
Daily average precipitation (in mm)	3.073	2.125	2.702	1.989
Daily average relative humidity (in %)	67.283	17.514	65.576	17.028
Regulation intensity	0.431	0.412	0.426	0.405

Notes: The observations of the treatment group and control group are 62,823.

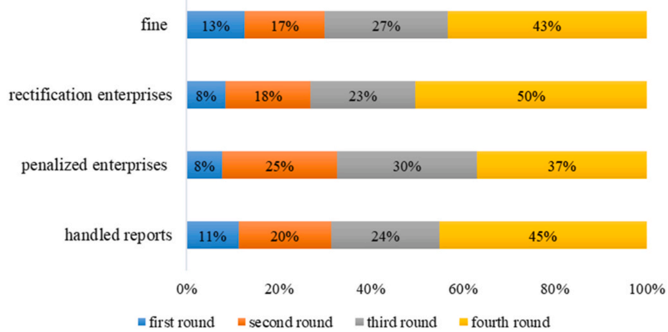

Fig. 1. Penalties and rectifications over four rounds of routine inspections.

the air pollutants of cities in the control group and treatment group from January 2015 to December 2018 with city-level linear difference-in-differences models.

The function of the basic DID model used to evaluate the overall effects of routine inspection is shown in Eq. (1):

$$Pollutant_{ij} = \beta_0 + \beta_1 Post_{ij} \times Inspection_i + \beta_2 X_{ij} + \alpha_i + \gamma_j + \varepsilon_{ij} \quad (1)$$

where the dependent variable $Pollutant_{ij}$ is associated with the air pollutants of city i on date j. We use five different dependent variables in our analysis: the logarithm of the AQI and the concentrations of $PM_{2.5}$, PM_{10}, SO_2, and NO_2. The main independent variables are the interaction terms of $Post_{ij}$ and $Inspection_i$, where the binary variable $Post_{ij}$ indicates whether date j is before or after the inspection period. $Inspection_i$ is another binary indicator and has a value of 1 if city i was inspected by the central environmental inspector and 0 if city i is in the control group. The coefficients for the interaction terms measure the treatment effects of environmental inspection after the inspection was implemented. The control vector X_{ij} contains the average temperature, relative humidity, maximum wind speed, precipitation, weekend, holiday, heating season (from November 15 to March 15 of the following year, which causes serious pollution in northern cities) and regulation intensity. We further included individual fixed effects α_i to flexibly control for city heterogeneity. We did not include dummy variables for whether city i belonged to a treatment group or its social and geographic characteristics. Instead, there was no systematic difference in air quality between the treatment and control groups (Table 1). γ_j reflects the year and month fixed effects. ε_{ij} is a random error term. Standard errors are clustered at the city level (Bertrand et al., 2004).

Central inspectors were stationed in a province and conducted on-site inspections for one month. Inspectors could accept reports from the public regarding environmental protection, inspect polluting enterprises, and supervise the environmental performance of local governments during the inspection month. "Inspection with rectification" is one of the working principles of central environmental inspection. Hence, we further examined the effects of one-month, on-site inspections and post-inspection on air pollution with the difference-in-differences Model (2).

$$Pollutant_{ij} = \beta_0 + \beta_1 During_{ij} \times Inspection_i + \sum_m \lambda_m \left(Month_{ijm} \times \quad Inspection_i\right) + \beta_2 X_{ij} + \alpha_i + \gamma_j + \varepsilon_{ij} \quad (2)$$

where the dependent variables $Pollutant_{ij}$ and $Inspection_i$ and the control vector X_{ij} are the same as those in Eq. (1). $During_{ij}$ indicates whether date j is during the one-month routine inspection period, which is considered part of the post-inspection period. $Month_{ijm}$ indicates whether date j is during the post-inspection month m ($m = 1 \ldots 12$). The coefficients for the interaction terms measure the routine inspection's treatment effects during the one-month inspection period and after the inspection period.

We further examined whether review inspection (RI) of ecological and environmental protection could promote the implementation of rectification strategies and solve environmental problems. To examine the effectiveness of RI for air quality improvements, we compared the air quality of cities under RI with that of cities without inspection or inspection review with a difference-in-differences model (3).

$$Pollutant_{ij} = \beta_0 + \beta_1 During_{ij} \times Review_i + \sum_m \lambda_m \left(Month_{ijm} \times \quad Review_i\right) + \beta_2 X_{ij} + \alpha_i + \gamma_j + \varepsilon_{ij} \quad (3)$$

We selected the period from January 1st, 2018, to December 31st, 2018, as the research period. To examine the impact of review inspection, this paper assumes that the effect of routine inspection gradually weakened after the on-site inspection and had little impact on air quality from January 2018. The period from January 1st, 2018, to the end of May was the prereview period. The other six months of 2018 were during the on-site review period and the postreview period.

The dependent variable $Pollutant_{ij}$ and the control vector X_{ij} are the same as those in Eq. (1). $During_{ij}$ indicates whether date j is during the one-month review period. $Month_{ijm}$ indicates whether date j falls within postmonth m ($m = 1 \ldots 6$). $Review_i$ is the binary indicator and has a value of 1 if city i was reviewed by a central environmental inspector and 0 if city i is in the control group. The coefficients for the interaction terms reflect the review's treatment effects during and after the review period. The sample includes 41 cities, including 18 cities in the treatment group and 23 cities in the control group.

Meeting the common trend hypothesis is the premise of the validity of a DID strategy. Fig. A2 shows the daily AQI and air pollutant concentrations of "inspected cities" and "noninspected cities" over time. Each point plots a daily average across all cities; the blue points refer to the daily AQI of inspected cities, and the red points refer to the AQI of noninspected cities. The vertical line indicates the starting date of the first round of routine inspection. To test the hypothesis of a common trend, we used the raw data with separately smoothed, locally weighted regression and smoothing scatterplot (LOWESS) lines (Cleveland, 1979) for inspected and noninspected cities. We can see that there was similar sharp growth in air pollution in the two groups due to seasonal changes, especially during the winter months. Moreover, we estimate the dynamic effects of routine inspection on the AQI and air pollutant concentrations. The coefficients of each month prove the parallel trend assumption. As shown in Fig. A3, there were no significant differences between the treatment group and the control group before the adoption of routine inspection. After the adoption of on-site inspection, the AQI and air pollutants of the treatment group significantly decreased compared with those of the control group. Hence, the parallel trend assumption is proven. Therefore, routine inspection can be considered a quasi-natural experiment, and the DID model can be used to investigate its impacts.

3. Results and discussion

3.1. Effects of routine inspection on air quality

We employed DID model (1) and used the entire sample to examine the overall effects of four rounds of routine inspection. To prevent a biased estimation of the effects of review and special inspections on air quality, we excluded samples after June 1st, 2018, when the review and special inspections began. As Table 2 shows, the coefficient of the interaction term is significantly negative in column (1), which indicates that routine inspection improved the AQI of inspected cities by 8.4% compared with that of noninspected cities before and after inspection. The concentrations of $PM_{2.5}$, PM_{10}, NO_2 and SO_2 also decreased by 2.4%–8.8%. The declines in $PM_{2.5}$, PM_{10}, and SO_2 were larger. Both $PM_{2.5}$ and PM_{10} were the main air pollutants to be controlled, and they

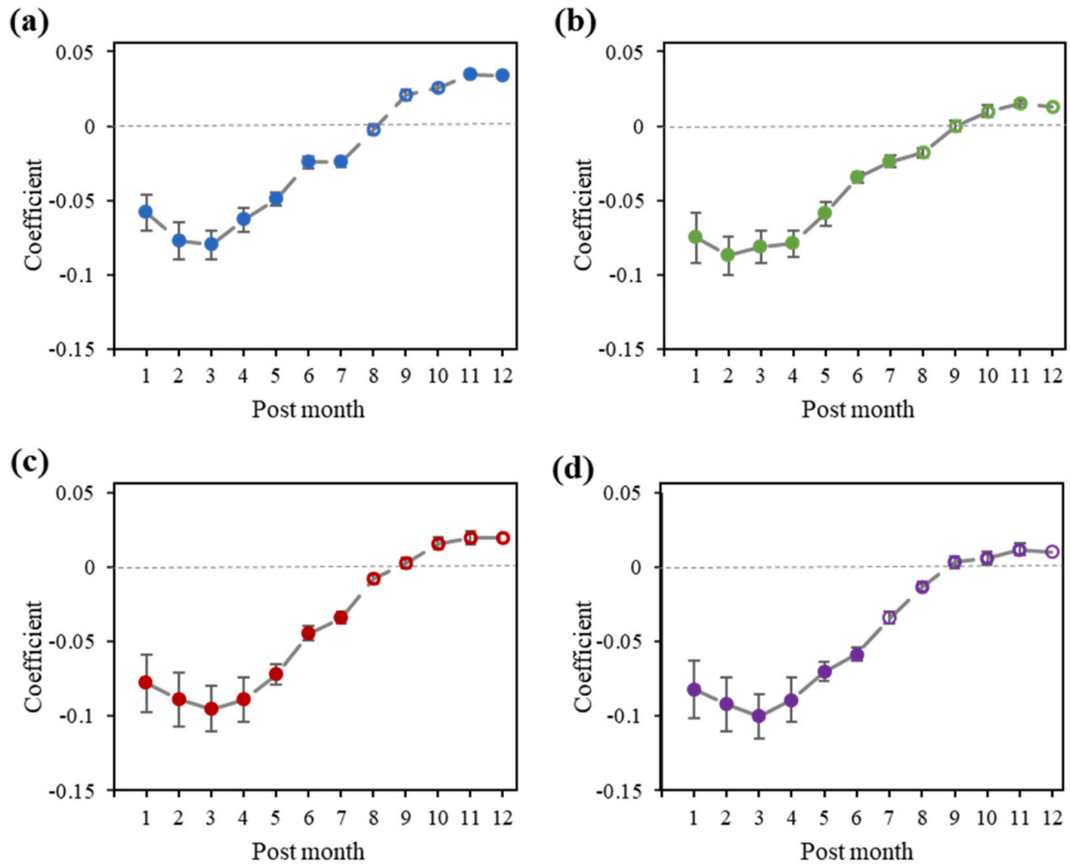

Fig. 2. Coefficient estimates in the AQI for monthly effects of the first round (a), second round (b), third round (c) and fourth round (d) of inspection with 95% CI. *Notes:* Filled circles indicate that the estimation coefficient of inspection is statistically significant, and open circles indicate that the estimation coefficient is not statistically significant.

Table 2
Estimation of the effects of routine inspection on air quality.

Variables	(1)	(2)	(3)	(4)	(5)
	AQI	$PM_{2.5}$	PM_{10}	SO_2	NO_2
Post×Inspection	−0.084***	−0.088***	−0.081***	−0.075***	−0.024***
	(0.018)	(0.022)	(0.021)	(0.031)	(0.027)
Control variables	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	113,050	113,050	113,050	113,050	113,050
R^2	0.103	0.193	0.146	0.300	0.175

Notes: Standard errors are in parentheses. ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

were mentioned in the Rectification Plan. CEI mainly focuses on the treatment of serious air pollution industries, such as thermal power, cement, and bulk coal combustion. In particular, in the thermal power industry, the inspection team implemented the elimination and shutdown of small thermal power units (less than 50 MW) and the capacity reduction of large thermal power units, which contributed greatly to the decline in $PM_{2.5}$ and PM_{10} concentrations (Tang et al., 2019).

We also employed model (1) and evaluated the effects of each round of routine inspection on a city's air quality and air pollutants separately. For each panel, the inspected cities were selected as the treatment group, and the noninspected cities in the same provinces were selected as the control group. Tables A2 and A3 show the city lists for the treatment and control groups, as well as the time span of the four rounds of routine inspection. As shown in Table 3, the changes in all air pollutants in the four rounds were significantly negative, which was similar to the results shown in Table 2. For the 26 cities inspected in the first round, the AQI decreased by 7%, and the concentrations of $PM_{2.5}$, PM_{10}, NO_2, and SO_2 decreased by 2.6–7.7% after the inspection. For the cities inspected in the other three rounds of inspections, the AQI improved significantly, by 8.3–9.6%, and the concentrations of air pollutants declined significantly. In addition, it was found that the improvements in air quality gradually increased with inspections. The reductions in air pollutants in the fourth round were the largest. For example, the declines in the AQI in the inspected cities in the four rounds were 7%, 8.3%, 9.1%, and 9.6%, respectively. The same is true for the four other air pollutants. The higher air quality may have been caused by more stringent inspections.

The central inspectors accepted reports from the public, transferred these environmental cases to local governments, and supervised efforts to rectify problems or penalize polluting enterprises during the on-site inspection period. Fig. 1 shows the increase in the number of reported

Table 3
Effectiveness of four rounds of environmental inspection on air pollution.

Variables	(1)	(2)	(3)	(4)	(5)
	AQI	$PM_{2.5}$	PM_{10}	SO_2	NO_2
***Panel A:** 1st Round of Routine Inspection*					
Post×Inspection	−0.070*** (0.020)	−0.077*** (0.021)	−0.072*** (0.042)	−0.070*** (0.023)	−0.026*** (0.034)
R^2	0.319	0.283	0.349	0.321	0.418
***Panel B:** 2nd Round of Routine Inspection*					
Post×Inspection	−0.083*** (0.071)	−0.085*** (0.075)	−0.077*** (0.054)	−0.081*** (0.111)	−0.023*** (0.045)
R^2	0.136	0.083	0.212	0.139	0.349
***Panel C:**3rd Round of Routine Inspection*					
Post×Inspection	−0.091*** (0.077)	−0.093*** (0.081)	−0.080*** (0.084)	−0.090*** (0.088)	−0.025*** (0.066)
R^2	0.253	0.189	0.251	0.253	0.209
***Panel D:** 4th Round of Routine Inspection*					
Post×Inspection	−0.096*** (0.022)	−0.101*** (0.032)	−0.095*** (0.032)	−0.090*** (0.071)	−0.032*** (0.032)
R^2	0.354	0.333	0.413	0.354	0.533
Control variables	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses. ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

cases over four rounds of inspection. The cases reported by the public were transferred from the central inspectors to the local governments and dealt with by the latter. The rising number of cases reflects that the public has given more attention to environmental problems and has participated more actively in the process of environmental inspection. The rising number of enterprises penalized or required to rectify problems, as well as the heavier fines, reflect the continuous progress of environmental inspection. We also provide direct empirical evidence to prove how CEI affects air quality. Mediating effect models are employed to examine whether active public participation and administrative punishments exert mediating effects. Detailed information about the mediating model settings is shown in the APPENDIX. Table 4 shows the results of the mediating models. As shown in columns (1), (3), (5) and (7), the CEI has significantly increased the number of reports from the public, penalized and rectification enterprises, and the amount of the fine. In columns (2), (4), (6) and (8), the coefficients of the interaction terms are significantly negative and are slightly smaller than those in Eq. (1), and the coefficients of the mediating variables are significant, which indicates that the CEI dropped the AQI through active public participation, administrative punishments from the central inspectors, and positive rectification actions from the local governments.

On-site inspections were conducted for one month in each province by central inspectors. To examine the effects of "on-site inspection with rectification", we employ DID model (2) and compare the effects of the current one-month inspection period and the postinspection months. Taking the first round of inspection as an example, Fig. 2 shows the coefficients of the monthly effects. The first round of inspection was implemented from July 15th, 2015, to June 15th, 2016. The AQI improved by 5.8–7.7% during the on-site inspection. After the first month, the inspectors left, and the improvements in the air quality index were the largest, decreasing by 8%. The results support the effectiveness of on-site inspection with rectification. Inspectors accept reports and address environmental issues or polluting enterprises for the first time during on-site inspection. For example, when stationed in Shandong Province, the inspectors asked the local government in Weifang City to shut down 33 small thermal power units with a total generating capacity of 51,9500 kW, which cut 1.295 million tons of standard coal simultaneously. Most small thermal power plants do not install flue gas desulfurization equipment or do not run the equipment to save production costs; these power plants emit enormous amounts of smoke, the precursor of particulate matter and sulfur dioxide emissions (Ministry of Ecology and Environment, 2012; Tang et al., 2019; Wu et al., 2019; Bo et al., 2021). These stringent regulation measures by inspectors are meaningful for air pollutant reduction and benefit public health.

Fig. 2 also shows that the air quality index continued to improve during the five months postinspection, but the improvement effect gradually weakened. The effect of the inspection on the AQI was no longer significant after 6–8 months of on-site inspection. In other words,

Table 4
The mediating effects of CEI on AQI.

	(1) *Report*	(2) *AQI*	(3) *Punishment*	(4) *AQI*	(5) Rectification	(6) AQI	(7) *Fine*	(8) *AQI*
Post×Inspection	0.112*** (0.022)	−0.071*** (0.016)	0.098*** (0.017)	−0.073*** (0.018)	0.096*** (0.015)	−0.071*** (0.015)	0.158*** (0.092)	−0.069*** (0.021)
Report		−0.125*** (0.096)						
Punishment				−0.122*** (0.102)				
Rectification						−0.146*** (0.115)		
Fine								0.101*** (0.169)
Control variables	Yes	Yes	Yes	Yes			Yes	Yes
City FE	Yes	Yes	Yes	Yes			Yes	Yes
Month FE	Yes	Yes	Yes	Yes			Yes	Yes
Year FE	Yes	Yes	Yes	Yes			Yes	Yes
Observations	113,050	113,050	113,050	113,050			113,050	113,050
R^2	0.121	0.152	0.103	0.161			0.112	0.167

Notes: Standard errors are in parentheses. ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

routine inspections did not impact air quality after January 2018, which confirmed the above hypothesis for equation (3). The impacts on the concentrations of $PM_{2.5}$, PM_{10}, SO_2, and NO_2 are shown to have the same trend (see Fig. A4). There are some reasons for this change. First, some of the environmental issues were addressed by local governments in the previous months, such as cleaning up various polluting enterprises or controlling the direct discharge of pollutants from chemical enterprises. Second, it is difficult to reconcile the pollution problems caused by improper industrial structures in a short time. For example, Xingtai, an industrial city in Hebei Province, has traditional industries that are energy intensive and heavily polluting and have a low output value. The output value of high energy-consumption industries, such as the chemical industry, cement industry, petroleum-processing industry, and smelting industry, accounts for only one-quarter of the city's total industrial output value, while their energy consumption accounts for three-quarters of the energy consumption. The prominent problems with this industrial structure were pointed out by the central inspectors, but they could not be addressed in the short term (The People's Government of Hebei Province, 2016). Third, rectification by local governments is not sufficiently stringent, and some public reporting is not strictly investigated and handled. For the growth of the local economy, some local governments continued to turn a blind eye to the illegal discharge of air pollutants after the inspectors left. To ensure that environmental problems would be addressed, CEI implemented review inspections in May 2018.

3.2. Effects of review inspection on air quality

A review inspection was launched at the end of May 2018 to supervise the implementation of the first round of inspection and the completion of rectification tasks. Six inspection teams were dispatched to revisit nine provinces that had been inspected in the first round of inspections. The inspectors stayed for a month and delivered the first results of the new strict measures. Table A2 shows the inspected regions and the RI period.

We further examine whether the review inspection of ecological and environmental protection, as a supplement to normalized inspection, could promote the implementation of rectification actions and solve environmental problems. We compare the air quality of cities under RI with that of cities without inspection or review inspection with a difference-in-differences model (3). Table 5 reflects the estimation of the effectiveness of RI. In Column (1), the coefficient of the first interaction term is significantly negative, which indicates that the air quality of the reviewed cities improved by 3.8% during the one-month review inspection. The concentrations of $PM_{2.5}$, PM_{10}, NO_2 and SO_2 also decreased by 2.3%–6.8%. The review inspection improved the air quality again after the air quality effects had gradually weakened after the routine inspection. It is necessary and effective for the review inspection to ensure the completion of rectification actions pointed out during the routine inspection period and to supervise the procedures and bureaucracy of local governments. For example, the inspectors found that Jinan's government did not give sufficient attention to or carry out the rectification of the problems pointed out in the feedback during the routine inspection. Instances of "invalid rectification" and "perfunctory rectification" were noted. The review inspection also found that there were still 14 environmental problems mentioned in the list of inspector feedback that were not addressed, for a total of 27 problems.

We also estimated the aftereffects of RI for six months. Taking the AQI as an example, the effects during the first months are similar to the effects during the one-month review period. The improvement in air quality was halved and diminished beginning in the fourth month post-review. The changes in the concentrations of $PM_{2.5}$ and PM_{10} show a similar trend to that of the AQI. For nitrogen dioxide and sulfur dioxide, the greatest improvements occurred in the second month after the review, and then the effects began to weaken. These results show that it is necessary to carry out CEI through regular and normalized governance.

Central inspection is not a temporary campaign of environmental governance. China's CEI has been transformed into a "normalized governance" mode. The achievements of the four rounds of routine inspections and the review inspection reflect that CEI has formed a hierarchical long-term supervision mechanism, formulated operation specifications, and established a professional organization. Review inspection is not only a revisiting of routine inspection but also a post-evaluation of rectification tasks. The number of public reports handled, enterprises rectified, and fines are all much higher than those of the first round of routine inspection (Table A4).

3.3. Special inspection of air pollution problems

Together with the review inspection, a special inspection (SI) on ecological and environmental protection was also launched in nine provinces. Special inspection focuses on curbing special environmental problems in key regions, for example, the air pollution problems in Hebei, Jiangsu, and Henan Provinces; the agricultural and rural pollution problems in Heilongjiang Province; and the water pollution problems of Poyang Lake in Jiangxi Province (as shown in Table A1).

Since SI and RI were carried out at the same time by the same inspectors, Model (3) evaluates the mixed effects of review inspection and special inspection on air quality. We could not clearly separate the effects of each inspection. By comparing the effects in regions with or without special inspection of air pollution problems, we tested whether the special inspection of air pollution problems was helpful for improving air quality in the study regions. Panel A in Table 6 includes Hebei, Henan, and Jiangsu, which were inspected for air pollution problems. The air quality index decreased by 9.8%, and the concentrations of $PM_{2.5}$, PM_{10}, and SO_2 decreased by 10.6%, 8.9% and 7.5%, respectively, which are similar to our general results. The results in Panel B show that the air quality also improved significantly, by 7.5–12.3%, although there was no special inspection of the air pollution problems in these regions. In general, special inspection is effective for dealing with air pollution problems and improving air quality.

The main air pollution problems in Hebei, Henan and Jiangsu cannot

Table 5
Estimation of the effects of review inspection on air quality.

Variables	(1)	(2)	(3)	(4)	(5)
	AQI	$PM_{2.5}$	PM_{10}	SO_2	NO_2
During×Review	−0.058** (0.054)	−0.067*** (0.089)	−0.055*** (0.039)	−0.028*** (0.055)	−0.023*** (0.025)
Postmonth1	−0.055*** (0.044)	−0.067*** (0.069)	−0.052*** (0.037)	−0.033*** (0.059)	−0.028*** (0.031)
Postmonth2	−0.052*** (0.034)	−0.062*** (0.046)	−0.050*** (0.045)	−0.030*** (0.063)	−0.033*** (0.032)
Postmonth3	−0.041*** (0.024)	−0.053*** (0.053)	−0.037*** (0.024)	−0.017*** (0.048)	−0.025*** (0.028)
Postmonth4	−0.029*** (0.025)	−0.018*** (0.032)	−0.019*** (0.038)	−0.014*** (0.054)	−0.018*** (0.027)
Postmonth5	−0.024*** (0.038)	−0.008 (0.043)	0.018 (0.033)	0.014 (0.045)	0.017 (0.042)
Postmonth6	−0.017 (0.029)	−0.010 (0.041)	0.016 (0.038)	0.019* (0.034)	0.011 (0.047)
Observations	14,965	14,965	14,965	14,965	14,965
R^2	0.334	0.344	0.375	0.456	0.443

Notes: Standard errors are in parentheses. ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

Table 6
Estimation of the effects of special inspection of air pollution problems.

Variables	(1)	(2)	(3)	(4)	(5)
	AQI	$PM_{2.5}$	PM_{10}	SO_2	NO_2
***Panel A**: special inspection on air pollution problems*					
Post×Special	−0.097***	−0.105***	−0.089***	−0.075**	−0.018
	(0.028)	(0.058)	(0.028)	(0.027)	(0.069)
Observations	5110	5110	5110	5110	5110
R^2	0.021	0.053	0.068	0.081	0.040
***Panel B**: special inspection on non-air pollution problems*					
Post×Special	−0.116*** (0.035)	−0.122*** (0.053)	−0.081*** (0.051)	−0.075*** (0.026)	−0.027 (0.008)
Observations	9855	9855	9855	9855	9855
R^2	0.026	0.055	0.078	0.059	0.036
Control variables	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses. ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

be solved completely in the short term. For example, all the feedback from the three regions has highlighted the irrational industrial structure and the slow adjustment and transformation. Energy-intensive and heavily polluting industries account for a large share of the total industrial arrangement, such as the cement and coal industries in Hebei and the steel industry in Henan. Table A5 also shows other air pollution problems. Lagging vehicle emission standards and diesel vehicle control lead to dust pollution problems in Hebei and Henan. There is less control of air-polluting industrial enterprises, especially scattered and polluting enterprises with obsolete production technology and a lack of waste gas collection or treatment facilities. In general, air quality improvement is a long-term and arduous task in these regions. Adjustments to the industrial structure and energy structure may not be realized in the short term. To ensure the improvement in air quality and people's health, transportation and polluting enterprises should be strictly regulated by local governments and central inspectors.

4. Robustness checks

We performed a large set of robustness checks to validate our findings. First, we tested whether there were potential effects of group-specific trends before the policy. If the air quality index and air pollutants evolved differently between the treatment group and control group before CEI, our estimation of the effects would be false. To control for the potential effects of pretreatment trends, we conducted two checks, as Bell et al. (1999) did. First, we kept only the samples up to the date before the policy and redefined the *During* dummy variable as a variable taking a value of 1 after June 1st, 2015, or a value of 0 otherwise, which required pretending that the inspection was implemented in June 2015. We chose this date because it was one year before the actual beginning of the policy. Apart from the implementation of the policy, the external environments at these two dates were similar. Second, we kept the entire sample and added the *Post2015*dummy and its interaction with the treatment dummy into model (1).

The coefficients of the interaction between the treatment and *Post2015* dummies could be significantly different from zero during the pretreatment period in the two checks. Panel A in Table 7 presents the results showing that the coefficients of the interaction term were not statistically significant, which proves that there were no trends for group-specific pretreatment. We controlled the pretreatment-specific trends through the interaction between the treatment dummy and the *Post2015* dummy (Panel B in Table 7). The results show that the coefficients of the interaction between the treatment dummy and the *Post2015* dummy were negative but not significant. The coefficients of the interaction between the treatment dummy and the real *Post2015* dummy were significantly negative and comparable in size to the results in Table 2.

Second, the identification of assumptions in the difference-in-differences estimates is more credible when conditioned on a set of control variables. In Table 2, we added the daily average temperature, daily relative humidity, daily precipitation, maximum wind speed, and a heating season dummy. After adding these control variables, our main estimations were not altered (Panel A in Table A6). Moreover, we used the value of the AQI and air pollutants as the dependent variables instead of the logarithmic value for the DID estimation, and the results are consistent with the main results (Panel B in Table A6).

Third, to account for any introduced potential selection bias, we employed propensity score matching (PSM) with a kernel matching algorithm to match the control groups with the treatment groups and then used the difference-in-differences model. Matching estimators supply an alternative estimation strategy and do not require the control of the unobservable variables. Therefore, we regarded PSM as another method of quantifying the impact of inspection. The propensity score was estimated using the daily average temperature, daily relative humidity,

Table 7
Controlling for the existence of group-specific pretreatment trends.

Variables	(1)	(2)	(3)	(4)	(5)
	AQI	*$PM_{2.5}$*	*PM_{10}*	*SO_2*	*NO_2*
***Panel A:** keep the sample before the adoption of CEI*					
Post2015×Inspection	−0.004 (0.016)	−0.021 (0.017)	−0.018 (0.018)	−0.008 (0.014)	0.021 (0.019)
Observations	75,680	75,680	75,680	75,680	75,680
R^2	0.348	0.405	0.409	0.575	0.534
***Panel B:** whole sample*					
Post×Inspection	−0.081*** (0.023)	−0.083*** (0.032)	−0.084** (0.013)	−0.072*** (0.031)	−0.028*** (0.014)
Post2015×Inspection	−0.008 (0.015)	−0.010 (0.015)	−0.011 (0.013)	−0.008 (0.012)	0.002 (0.018)
Observations	113,050	113,050	113,050	113,050	113,050
R^2	0.325	0.369	0.382	0.547	0.513

Notes: Standard errors are in parentheses. ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

daily precipitation, maximum wind speed, and heating season as controls. We ensured that the balancing property was at standard significance levels. The results are presented in Panel C in Table A6 and are very similar to those reported in Table 2. In addition, to prevent the biased selection of samples, we selected different samples. We added three municipalities, Beijing, Tianjin, and Shanghai, to our sample (Panel D in Table A6). We also selected different subsamples and estimated the effects of the central inspection on the air quality in different provinces (Table A7). The results were still consistent with those from the main models.

5. Conclusions and policy implications

Central environmental inspection is a new and unique means of environmental governance in China. It is still unclear how much inspection has contributed to air quality improvement, what mechanisms have led to these results, and whether there are other problems with the inspection mechanism at present. Addressing the above questions is important for the continuous promotion of environmental inspection and the realization of China's goal of sustainable environmental development. In addition, the comprehensive quantitative evaluation of the effects of environmental inspection can provide enlightenment for other developing and highly polluted countries. Therefore, this paper addressed the above questions, and the innovation and significance of this paper concentrated on the following three aspects:

First, this paper provides an overall and quantitative evaluation of the effects of CEI on air quality, including the effects of routine inspection, review inspection, and special inspection. Empirical evidence indicates that the effectiveness of air quality improvements was strengthened with the gradual progress of the inspections. The contributions were primarily the result of active public participation, administrative punishments by central inspectors, and positive rectification actions by local governments. Moreover, the accumulation of early inspection experiences promoted better performance in regions inspected later. The working pattern of on-site inspection with rectification was helpful for inspectors to determine environmental problems and urge local governments to rectify them in a timely manner. The improvement in air quality was greatest during the one-month inspection period. In addition, evaluation of the effects of review inspection verified that CEI in China is not a campaign-style treatment but a normalized and effective governance system for air pollution problems.

Second, we discuss the theoretical mechanism to elaborate the conclusions. The information asymmetry between the central and local governments is an important factor that hinders the central government from achieving the expected effect of air pollution control (Miller and Vela, 2013). According to the revelation principle of incentive theory, the incentive mechanism for governance performance or promotion of local officials, such as adding green GDP or green production to the evaluation index of local government, can effectively reduce the information asymmetry between the central and local governments and encourage local governments to carry out environmental governance (Myerson, 1979; Zabel and Roe, 2009). This study found that central environmental inspection is an effective measure for improving air quality because continuous and normalized inspection can strengthen the central government's preference for air pollution control and stimulate and influence the local government's preference through an incentive mechanism to improve air quality. Moreover, review inspection can further reduce information asymmetry to effectively improve air quality. In addition, governments should recognize that environmental actions can potentially improve economic efficiency. For example, removing pollution from a factory is a reduction in the waste of resources.

Third, the empirical evidence on the effectiveness of environmental inspection at the national level enriches environmental decentralization theory. Previous studies on the effectiveness of environmental decentralization have different views. This study provides empirical evidence on the national effectiveness of environmental inspection at the national level. The mechanism of CEI in China takes the environmental performance of local officials as one of the promotion indicators, which can effectively simulate local government environmental governance. In addition, the normalization mechanism of the inspection ensures the sustainability of the environmental improvements. Therefore, the conclusion of this paper enriches environmental decentralization theory. Evaluation of the effectiveness of normalized environmental inspection can provide crucial information for developing environmental regulations in China and offer enlightenment for other developing and highly polluted countries.

Finally, we also found problems in the current implementation of CEI and provided practical suggestions for future adoption. As the first environmental inspection practice in China, CEI is still in the exploratory stage and has the following problems. First, the improvement effect on air quality in the inspected regions weakened more each month after the central inspectors left. One of the problems to be addressed by inspectors is maintaining long-term and continuous air quality improvement. Second, the phenomena of invalid rectification, perfunctory rectification, and one-size-fits-all regulation were observed. Inadequate rectification could be due to the irresponsibility of the local government. Third, 380 inspection teams and more than 30,000 inspectors were sent to 31 provinces across the country for review inspection. The enormous human resource requirements of this process have caused public doubts. Improving the efficiency of normalized inspection and achieving the maximum benefits are problems to address in the process of central environmental inspection.

To address the above shortcomings, we provide the following policy recommendations. First, a long-term and dynamic evaluation mechanism should be created to realize the real-time and dynamic monitoring of the effects of pollution control in all regions and to ensure the effects of rectification after on-site inspection. For example, the existing database of National Specially Monitored Firms can be connected to the inspection database to realize continuous postevaluation supervision remotely. In addition, the enhanced use of automatic tracking systems (e.g., continuous emission monitors; CEMs) could be considered a long-term and potentially more cost-effective approach.

Second, we should strengthen the responsibilities of multiple levels of government. The problems raised in the inspection should be addressed by a special official to ensure their implementation. Communication and cooperation among local departments should be strengthened to prevent the shirking of responsibilities. In addition, we should resolutely reject one-size-fits-all solutions to problems and create reasonable rectification plans. In particular, for small-scale enterprises, local governments should provide financial subsidies or technical transformation support.

Third, members of the public, as whistle blowers for environmental problems, should be encouraged to participate in multiple phases of environmental inspection, such as providing feedback on its effects. On the one hand, more convenient channels for complaints should be provided for the public, such as a network platform, which could transmit pollution information directly to the inspection team in a timely manner. On the other hand, the public could properly participate in the postevaluation through the inspection information sharing platform and thus realize real-time supervision and feedback even without the on-site inspection team. To reduce the cost and improve the efficiency of inspection, the public should be actively mobilized to become involved in environmental inspection.

This study has the following uncertainties and limitations. First, the air quality improvements contributed by the inspected cities might affect the surrounding areas through atmospheric transportation or spatial spillover effects. Our estimation results may be underestimated due to these potential influences, which is one of the limitations of this study. Second, to examine the impact of review inspection, this paper assumes that the effect of routine inspection gradually weakened after on-site inspection and had little impact on air quality from January

2018. Our results also proved this hypothesis. However, routine inspections may affect the air quality during the review period and post-review period, and our estimation of the effects of review inspection may be overestimated. We cannot completely eliminate the impact of routine inspection, which is another limitation of this study. Third, there are uncertainties in the estimated values of DID models. Table R1 presents the confidence intervals (CI) of the coefficients of interaction term in DID model 1, which estimates the effects of routine inspection on air quality. Results show that routine inspection improved the AQI of inspected cities by 8.4% (95%CI: 7.7%–9.1%) compared with that of noninspected cities before and after inspection. The concentrations of $PM_{2.5}$, PM_{10}, NO_2 and SO_2 decreased by 8.8% (95%CI: 8.3%–9.3%), 8.1% (95%CI: 7.4%–8.8%), 7.5% (95%CI: 6.9%–8.1%), and 2.4% (95% CI: 2.2%–2.6%), respectively. Last, the observed effects of environmental inspection on air quality may be confounded by the anticipation effects. Knowing the policy will be implemented, companies may react in advance and discharge more pollutants. After the policy is implemented, companies may produce less or even shut down, which may cause the results to be underestimated.

CRediT authorship contribution statement

Tong Feng: Methodology, Resources, Writing – original draft, Writing – review & editing. **Huibin Du:** Conceptualization, Resources, Supervision. **Zhifu Mi:** Resources, Writing – review & editing, Supervision. **Zhenni Chen:** Resources, Writing – review & editing. **Nan Wang:** Writing – review & editing.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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