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Organizing regulatory structure and local air quality: Evidence from the environmental vertical management reform in China

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ABSTRACT

The effectiveness of environmental policies is often compromised by weak enforcement due to conflicts between local and national interests. We examine a novel institutional reform in China that centralizes the management authority of grassroots environmental bureaus to address the issue of local capture. By analyzing the staggered roll-out of this reform, we find that the Air Quality Index significantly decreased by 25.1%. We attribute this improvement to a reduction in the capture of front-line environmental regulators by local interest groups, alignment of interests between local regulators and their upper-level administrators, and increased efforts for environmental protection by local governments in a more independent and impartial regulatory environment. These results highlight the effectiveness of distributing management authority to different administrative levels, as it reshapes the incentives for local environmental regulators, strengthens enforcement efficiency, and facilitates the achievement of policy objectives.

1. Introduction

Environmental degradation poses a global challenge to public health and carries significant economic implications, particularly in Emerging Markets and Developing Countries (EMDCs) (Greenstone and Jack, 2015; Ebenstein et al., 2017). Confronted with mounting pressures to contain environmental pollution, the last three decades have witnessed the emergence of environmental regulations as a major activity of governments in EMDCs (Greenstone and Hanna, 2014; Greenstone et al., 2021; Assunção et al., 2023). However, the effectiveness of environmental policies relies not only on their ambition and design but also on enforcement, posing a particular challenge where state capacity is weak and local capture is significant (Kostka, 2014; Duflo et al., 2018; UN, 2019; He et al., 2020c).[1] Aligning the interests among different players in hierarchical governance is a crucial research question for academia, and holds significant importance for policymakers in ensuring environmental protection.

This paper aims to investigate the effectiveness of an institutional reform designed to address the issue of local capture and improve enforcement efficiency in environmental regulation. During China's 13th Five-Year Plan (2016–2020), the central government launched the Environment Vertical Management (EVM) reform. Prior to the reform, environmental governance in China was characterized by a fragmented bureaucratic structure with a dual leadership system. The local Environmental Protection Bureaus (EPBs) were administered by two government bodies: local governments at the same layer and the higher-level EPBs. With the local

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[1] The behavior of front-line government officials is often influenced by local interest groups, resulting in conflicts of interest between top and front-line government officials and compromised environmental protection (Olken and Pande, 2012; Oliva, 2015; Zhang and Cao, 2015).

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government controlling the funding and key personnel decisions of local EPBs, the latter had close relations with the former, who are concerned with economic growth at the cost of environmental protection.[2] After the EVM reform, the county EPB became a branch of the prefectural EPB; that is, the latter assumed full administrative control power over the former including task allocation, funding, and personnel decisions.

To examine the impact of the EVM reform, we manually collect the date when the county EPB hung out its shingle as the branch of the prefectural EPB. Based on the staggered roll-out of the EVM reform, we employ a difference-in-differences (DD) approach to compare the air quality in the reform-pilot counties with those unaffected by this reform before and after the adoption of the reform. To address potential issues related to heterogeneity in treatment effect in the DD analysis,[3] we use the stack-by-event approach in light of the literature (Cengiz et al., 2019; Deshpande and Li, 2019; Fadlon and Nielsen, 2019; Gu et al., 2021; Liao and Kousky, 2022); that is, we reconstruct the sample to mitigate the negative weighting problem in aggregating average treatment effects. In order to establish the validity of our estimation strategy, we offer balance tests to assess the comparability between the treatment and control groups, present evidence of parallel pre-treatment trends between treated and control units, and conduct a series of robustness checks.

We present three sets of analyses to understand the effect of the EVM reform on local air quality. Firstly, we find that the EVM reform significantly improves air quality. Fourteen weeks following the reform, the Air Quality Index (AQI) in treated counties decreases by 8.6% compared to control counties. The improvement in air quality continues to grow over time, leading to a 25.1% increase in air quality after twenty-four weeks.

Secondly, we explore the potential mechanisms. Specifically, we assess the effectiveness of EVM reform in reducing local capture by examining various aspects of local collusion, including social networks, stability of local leaders, preexisting corruption levels, and political connections of pollution enterprises. Our regression analyses consistently show that the EVM reform reduces the capture of county EPBs by local interest groups. Additionally, we investigate behavioral changes in county EPBs and governments. The EVM reform increases the likelihood of county EPBs imposing environmental penalties. Moreover, local governments, constrained by the reform from direct influence over regulators, increase procurement of environmental products and services, signaling a shift towards environmental protection priorities.

Thirdly, we delve into the management costs and potential information loss associated with the EVM reform, aiming to assess its feasibility and trade-offs. The increased span of controls in prefectural EPBs may lead to looser monitoring (Qian, 1994). Using distance between governments as a proxy for management cost, we find that closer proximity between prefecture and county governments expands the pollution control effect of the EVM reform compared to when they are more distant. Centralizing county EPBs under prefectural authority risks losing local informational advantages, but integrating information technology can mitigate this (Zhang et al., 2018; Dal Bó et al., 2021). Our results highlight the reform exerts a larger negative impact on air pollution in prefectures with higher internet coverage, compared to those with lower internet coverage. Policy attention is needed to prepare prefectural EPBs and expedite digital transformation to unlock the reform's full potential.

Our findings contribute to the existing literature in several significant ways. Firstly, we provide empirical evidence on the costs and benefits of delegated decision-making in hierarchical organizations, which has predominantly remained theoretical until now (Tirole, 1986; Laffont and Tirole, 1991; Kofman and Lawarrée, 1993; Mookherjee and Tsumagari, 2004). Arguably, a unique strength of our study is that we trace the impacts of a compelling quasi-experiment designed to tackle endemic problems of weak enforcement all the way through to the key welfare outcome of interest, namely air pollution. Such pollution has been shown to be harmful to labor productivity and health (Chay and Greenstone, 2003; Graff Zivin and Neidell, 2012).

Secondly, our study contributes to the literature on environmental regulations. Whereas much of the literature has focused on the competition and coordination dynamics between horizontal levels of government in addressing environmental issues (Oates, 1999; Oates and Portney, 2003; Sigman, 2005; Kahn et al., 2015; Lipscomb and Mobarak, 2016), our paper analyzes China's recent efforts to counter "local protectionism" by centralizing regulatory bureaucracy up to the prefecture level. Recent work by Greenstone et al. (2022) investigates the impact of automatic air pollution monitoring technology on correcting biased information, emphasizing public responses and investment decisions. In contrast, our research centers on local EPBs and governments' responses, providing insights into how institutional reforms influence environmental law enforcement and air quality improvements. One paper close to ours is Zhang et al. (2018), which studies environmental regulation under the framework of environmental federalism. Specifically, they examine the impact of the enhanced central supervision through real-time monitoring and frequent inspections on firm emissions. Unlike their focal reform without fundamental changes in the central-local governments' relationship, we study an institutional reform (i.e., the EVM reform), which centralizes management authority over county EPBs to enhance the alignment of central-local interests.

Third, this paper is among the first to evaluate the impact of the EVM reform on environmental quality. A closely related study is Chen et al. (2024). The key difference between our work and theirs lies in the unit of analysis and the associated changes in organizational structure. Specifically, our study analyzes the implementation of the EVM reform at the county level, in which the reform made county EPBs into distinct entities separate from county governments. After the reform, county EPBs fall under the full administrative control of the prefectural EPBs, which oversee task allocation, funding, and personnel decisions. In contrast, Chen

[2] It was reported that in May 2010, the government of Guzhen county in Anhui province removed six local environmental protection officials, including the bureau chief, from their positions. The reason for their removal was the three inspections of a rubber factory within a 20-day period conducted by the environmental bureau, which the government argued was detrimental to investment attraction efforts (See DialogueEarth, September 23, 2010).

[3] For example, see De Chaisemartin and d'Haultfoeuille (2020), Callaway and Sant'Anna (2021), Sun and Abraham (2021), Goodman-Bacon (2021) and Borusyak et al. (2024).

et al. (2024) study the EVM reform at the prefecture level, in which the reform only centralized the nominations of prefectural EPB directors and deputy directors from the prefectural governments to provincial EPBs.[4] After the reform, prefectural EPBs continue to operate under dual management by both prefectural governments and provincial EPBs, functioning as working departments of the prefectural governments. Notably, the prefectural governments remains involved in the selection of director candidates, with final personnel decisions requiring consultation with the prefectural governments. These structural differences make the county level the focal point of the reform's implementation, as it represents a more fundamental realignment of management authority (for more details, see Section 2.1). Meanwhile, this paper offers new insights into the mechanisms. We assess whether the EVM reform reduces the local capture of county EPBs by local interest groups, developing six novel variables to measure collusion among governments, EPBs, and firms. By contrast, Chen et al. (2024) focus primarily on the promotion incentives of prefectural EPB directors. Our study moves beyond individual incentives to examine the systemic interactions and collusion among multiple actors, aligning with the reform's goal of curbing local capture.[5]

Finally, our study speaks to the empirical literature on corruption and environmental quality. Notably, Burgess et al. (2012) provide evidence of increased deforestation in Indonesia due to corruption. Duflo et al. (2013) find that restructuring audit markets to mitigate conflicts of interest leads to more accurate reporting of pollution emissions by auditors. Oliva (2015) examine a pollution control policy in Mexico City and uncover extensive corruption in the smog emissions testing program for private vehicles. Building upon these studies, our paper shows that decentralization combined with limited oversight of local-level officials could breed corruption and undermine regulatory quality. Our paper suggests that regulation in large systems requires a delicate balance. Achieving this balance hinges on appropriately allocating regulatory powers to different levels of administration.

The rest of the paper proceeds as follows. Section 2 lays out our research design, including the environmental governance in China, our focal policy reform, and the empirical identification strategy. Data are discussed in Section 3. Baseline results regarding the effectiveness of the reform are presented in Section 4, with the underlying mechanisms discussed in Section 5 and the cost trade-offs in Section 6. The paper concludes with Section 7.

2. Research design

In this section, we provide a comprehensive overview of our research design. Specifically, we first present the reform of the environmental governance structure in China; that is, the introduction of a vertical management system regarding environmental enforcement. We then discuss our estimation strategy (i.e., a DD approach) and its related identification issues.

2.1. Environmental governance in China

China's environmental management system began to take shape in the 1970s and was enshrined in the Environmental Protection Law in 1989. For a long period, since the 1970s, environmental governance in China was characterized by a fragmented bureaucratic structure with limited vertical control.[6] Specifically, environmental management was governed by a so-called dual leadership system with EPBs serving two supervising bodies, the upper-level environmental bureaucrats and local government officials. The left panel in Fig. 1 illustrates this government structure. The dashed lines point to the professional relations between the two bodies, whereas the solid lines represent their leadership relations. For example, a county EPB was responsible for implementing national environmental standards and received guidance from its upper-level prefectural EPB. Meanwhile, the county government controlled the county EPB's funding and key personnel decisions.[7] Due to the personnel and financial constraints on their environmental protection departments, county governments had a far greater practical impact on local environmental management than the upper-level prefectural EPBs.

The two supervisory bodies, the upper-level EPBs and local governments, often had divergent policy objectives. The upper EPBs, burdened with anti-pollution responsibilities, favored strict control policies. In contrast, local governments prioritized economic performance and tended to adopt growth-oriented policies. Under the dual management system, local EPB leaders often maintained close relationships with local government officials, making them susceptible to undue influence (Van Rooij, 2006). By leaving enforcement under the purview of the local government, regulatory independence was compromised as the local government had direct economic, fiscal, social, and employment ties to polluting industries. A typical enforcement problem during this period was the local government intervention in the work of EPBs. Faced with increasingly difficult attainment of green targets, local governments often colluded with EPBs to deceive and cover up their lack of action (Ma and Ortolano, 2000; Kostka and Hobbs, 2012; Ghanem and Zhang, 2014).

[4] Similarly, Kong and Liu (2024) also rely on the staggered turnover of prefectural EPB directors to estimate the effect of centralizing personnel appointment authority on regulatory enforcement.

[5] For comparison, Cao and Wu (2024) examine region-specific, bottom-up reforms initiated in the early 2000s, which vary significantly across regions due to tailored local policies. Our study, however, investigates a nationwide, top-down reform guided by uniform policies, enabling broader generalizability.

[6] This governance structure was based on the interplay between *tiao* (vertical rule) and *kuai* (horizontal rule) within the Chinese government system. *Tiao* means that an agency has the full policy and operational control over all units of organization within its jurisdiction. Commands flow directly down and information comes directly up. *Kuai* signifies control exercised by local governments over any unit, at any level, in any functional setting. Both *tiao* and *kuai* were to rule in a dual control arrangement.

[7] The local government held significant power, including the authority to dismiss local EPB chiefs, reduce funding for key functions, or restrict personnel expansion (Ma and Ortolano, 2000).

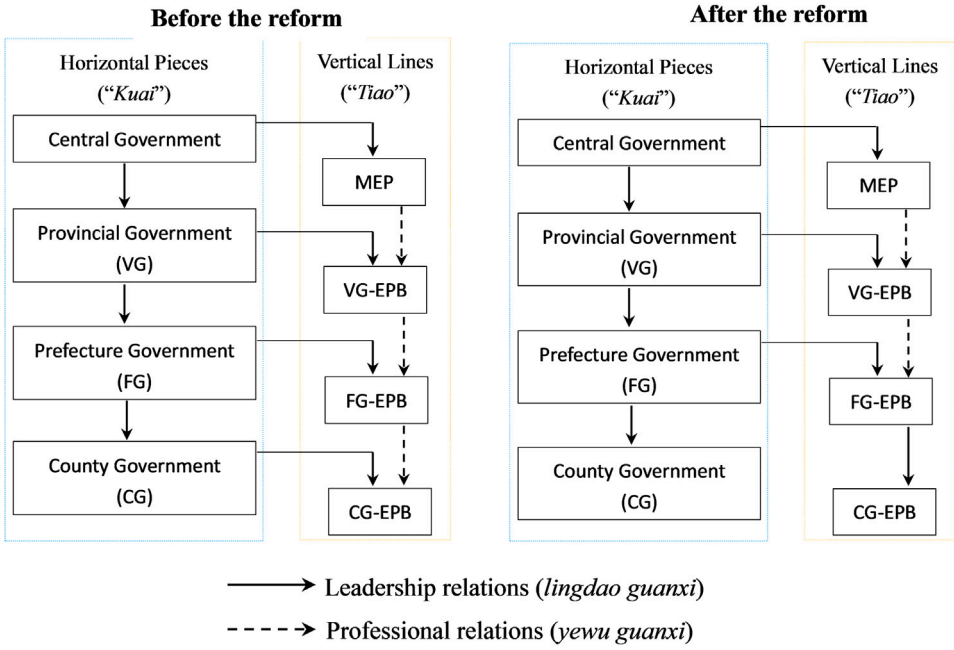


Fig. 1. The environmental governance structure.
Notes: In China, vertical lines of authority ("*tiao*") connect each unit vertically to superior organs of power at the Center, whereas horizontal pieces of authority ("*kuai*") connect them horizontally to local organs of power. It is the "*kuai*" that represents the territorial disciplinary and budgetary controls, thereby as the locus of power.

Over time, demands have arisen for significant steps to tackle endemic problems of weak environmental enforcement. In particular, the rapid and persistent increase in pollution dwarfed the corresponding environmental regulatory enforcement, calling for a comprehensive reform of the governance system. Under the auspices of China's 13th Five-Year Plan (2016–2020), the central government committed to implementing a reform of the environmental management system, specifically through the adoption of an environmental vertical management (EVM) system.[8] The EVM reform recasts the institutional structure in such a way that environmental agencies are no longer beholden to the governments within their geographic jurisdictions. Rather, these agencies are directly controlled by their functional superior agencies. This reform represents the most significant overhaul of China's local environmental management system since the 1980s.

In September 2016, the *Guidelines for the Pilot Program for the Vertical Management Reform of Environmental Monitoring, Inspection and Law Enforcement below the Provincial Level (the 2016 Guideline)* was introduced, outlining the framework for the EVM reform. Fig. 1 illustrates the institutional changes resulted from the EVM reform. The most significant change occurred at the county level. Specifically, after the reform, county EPBs were reorganized as subordinate branches of prefectural EPBs, operating under the direct guidance of the latter. This restructuring means that county EPBs no longer function as dependent entities under county governments but instead operate under the full administrative control of prefectural EPBs, including task allocation, funding, and personnel decisions. This institutional shift strengthened vertical integration between county and prefecture levels, reducing county government influence.

Meanwhile, the EVM reform also involved institutional changes at the city level. After the reform, prefectural EPBs' director and deputy director nominations were transferred to provincial EPBs. However, prefectural EPBs largely maintained dual management from prefectural governments and provincial EPBs, with prefectural EPBs continuing to function as working departments of the prefectural governments. In particular, the organization department of the prefectural CCP committee remained involved in candidate inspections of the prefectural EPBs, with final personnel decisions requiring consultation with the prefectural CCP committee.[9]

This paper focuses on the county-level EVM reform for several considerations. First, the county-level EVM reform involved significant institutional changes, with county EPBs being effectively transited into suboffices of prefectural EPBs. This allows us to

[8] Starting in 1998, China successively embarked on vertical management reforms in various sectors, including banking, taxation, workplace safety, and product quality. However, some of these vertical reforms were subsequently reversed. For instance, the establishment of China's State Drug Administration in 1998 aimed to create a verticalized drug administration supervised by The State Council. The provincial administration exercised vertical control over administrations at the city and county levels to ensure their independence. Nevertheless, by 2008, food and drug regulation had reverted to local administration.

[9] To rule out the potential confounding effects stemming from changes in director nominations at prefectural EPBs, we conduct a robustness check by controlling for city and time fixed effects, in which the identification mainly comes from the comparison of counties with prefectural cities.

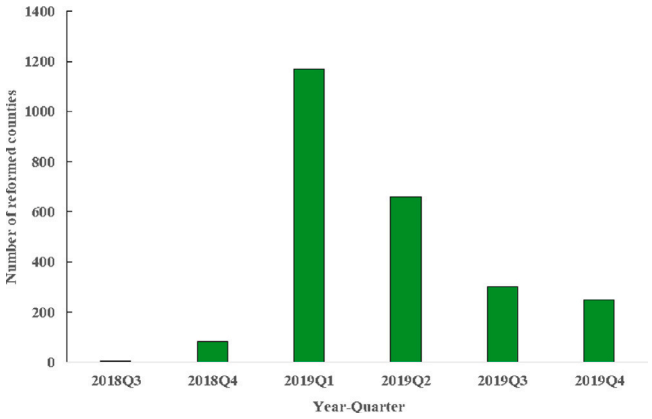


Fig. 2. The timeline of county EPBs' becoming the suboffices of prefectural EPBs.
Notes: This figure illustrates the staggered implementation of the EVM reform across different counties. It depicts the number of counties that adopted the EVM reform during each year-quarter.

investigate pollution control from the institutional hierarchy perspective. Second, as the EVM reform primarily impacts county-level EPB management authority, entering on county-level implementation enables a comprehensive assessment of the reform's impact on environment. Third, the county-level analysis sheds light on grassroots enforcement challenges, as county EPBs act as frontline agencies for environmental governance.

While the *2016 Guideline* provided guidelines, it did not have material and direct effects on county-level implementation, as the central government and the Ministry of Ecology and Environment (MEE) did not directly control county governments and county EPBs. In the meantime, provincial governments were mandated to initiate provincial reform plans following the *2016 Guidelines*. However, delays were common, despite the retoquirement for provinces to commence provincial implementation plans by mid-2017 or 2018. This prompted the MEE to issue a directive, *Notice Regarding Coordinated Advancement for the Vertical Management Reform of Environmental Monitoring, Inspection, and Law Enforcement below the Provincial Level*, in November 2018, aiming to expedite provincial reform completion by March 2019, although some provinces finalized plans by mid-2019 (Chen et al., 2024).

Fig. 2 delineates the staggered implementation of county EPBs' integration as prefectural suboffices, occurring predominantly post-2018. Fig. 3 further illustrates the geographic distribution of the EVM reform across counties equipped with national air quality monitoring stations on an annual basis. Specifically, within our focal sample counties, the EVM reform was implemented on 131 distinct dates. By the end of 2019, more than 86.4% of China's 2846 county-level EPBs had undergone the reform, and a total of 792 counties had installed air monitoring stations. We use these 131 implementation dates for our estimation. The extensive scale of the reform, combined with its roll-out schedule, provides rich variations that can be exploited for the causal identification of the reform's impacts.

2.2. Empirical specification

This paper intends to document the role of the EVM reform in combating local air pollution. To achieve this, we conduct a DD estimation, leveraging the staggered implementation of the EVM reform across counties. Specifically, following the suggestion by Marcus and Sant'Anna (2021), we use policy-never-implemented counties as the counterfactuals for policy-adopted counties, which helps us pin down the average treatment effect of the reform on the latter group.[10]

However, recent studies show that the standard two-way fixed effects model may result in biased staggered DD estimators when the treatment effects vary across regions and over time (De Chaisemartin and d'Haultfoeuille, 2020; Callaway and Sant'Anna, 2021; Sun and Abraham, 2021; Goodman-Bacon, 2021; Borusyak et al., 2024).[11] To address this concern, we apply the stack-by-event approach based on the implementation dates of the EVM reform (Cengiz et al., 2019; Deshpande and Li, 2019; Fadlon and Nielsen, 2019; Gu et al., 2021; Liao and Kousky, 2022). Specifically, for each verticalization event, we create a single-timing DD sample by keeping counties undergoing the verticalization event for the first time and counties never embracing any vertical reform during

[10] Marcus and Sant'Anna (2021) suggest the use of only never-treated units as the control group, which entails a weaker parallel trend assumption than the inclusion of not-yet-treated units in the control. Meanwhile, including not-yet-treated counties as the control group diminishes the size of the control group over the staggered course of treatment, which could lead to decreased precision and complicate the estimation process. Nonetheless, in a robustness check, we incorporate later-treated counties as part of the control group.

[11] This is because the two-way fixed effects model, in essence, generates a weighted average of all possible two-group/two-period DD estimators. When the treatment effects are heterogeneous across groups and over time, the weights of some two-group/two-period cases are negative, due to the use of the earlier-treated units as the control group for the later-treated units. The presence of negative weight results in deviations in the magnitude of the staggered DD estimator and even changes its direction.

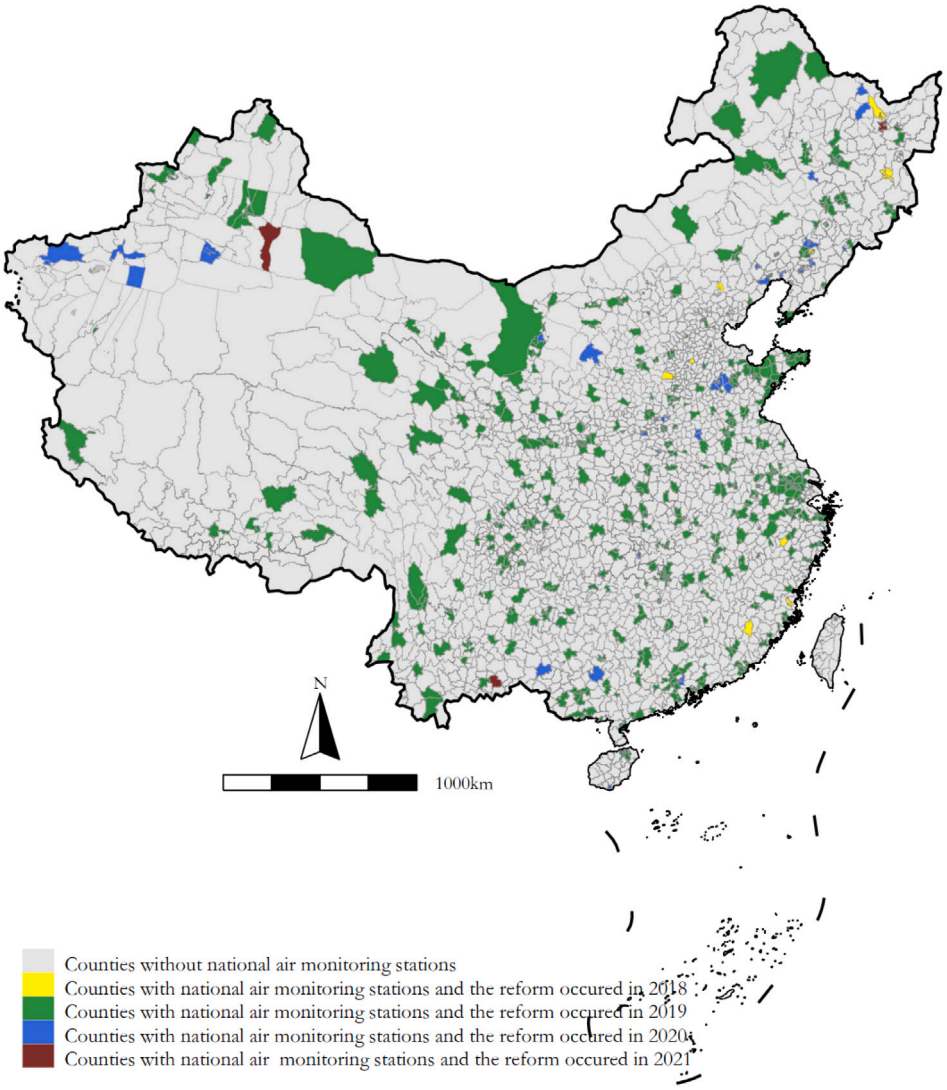


Fig. 3. Geographic rollout of the EVM reform across counties with national air quality monitoring stations.
Notes: This figure illustrates the geographic distribution of the EVM reform across counties equipped with national air quality monitoring stations on an annual basis. Counties without national air quality monitoring stations are depicted in gray. Counties with national air monitoring stations are categorized by the timing of the reform: yellow for implementation in 2018, green for 2019, blue for 2020, and purple for 2021.

the sample period (i.e., 2018–2019). Finally, we append all the constructed samples by rescaling the event timing to 0. The process of our stack-by-event design is illustrated in Online Appendix Figure A1.

There are several alternative robust estimators available to address the issue of heterogeneous effects in the staggered DD (De Chaisemartin and d'Haultfoeuille, 2020; Callaway and Sant'Anna, 2021; Sun and Abraham, 2021; Borusyak et al., 2024). The stack-by-event approach fits our research setting with great flexibility.[12] Moreover, as demonstrated by Baker et al. (2022), the

[12] Firstly, inconsistent data and analysis frames. The stack-by-event approach allows for the use of high-frequency data (daily data in our case) to estimate dynamic effects at a lower frequency (event-study plots for every 14-day intervals). In contrast, the methods proposed by De Chaisemartin and d'Haultfoeuille (2020), Callaway and Sant'Anna (2021), Sun and Abraham (2021) and Borusyak et al. (2024) typically require data and analysis time frames of the same frequency (e.g., using yearly data to estimate yearly effects). Secondly, time-varying covariates. Our model incorporates county-daily weather variables, which are critical for understanding air pollution dynamics, as seen in current literature (Li et al., 2020; Greenstone et al., 2022). Conversely, Callaway and Sant'Anna (2021)'s method assumes static covariates. Thirdly, the stack-by-event approach can incorporate high-frequency panel data. In contrast, when the number of individuals in the sample is relatively small (i.e., a small N and large T), there may not be a sufficient number of 'good control groups' available for imputation-based estimations (Borusyak et al., 2024). Fourthly, the stack-by-event approach explores the dynamic effects of the event, whereas (De Chaisemartin and d'Haultfoeuille, 2020) estimates the instantaneous parameters.

stack-by-event estimator, Callaway and Sant'Anna (2021)'s estimator, and Sun and Abraham (2021)'s estimator yield similar results in terms of effect size, while the stacked regression estimator exhibits greater efficiency compared to the alternative estimators. Nonetheless, we check the robustness of our estimates to the heterogeneity effect issue in the staggered DD setting using alternative estimators, see more details in Section 4.4.

The event-study DD analysis takes the following specification:

$$Y_{skct} = \sum_{\tau=-6,\tau\neq-1}^{12} \beta_\tau Treat_{sc} \times I_{st}^{\tau} + \delta_{sk} + \rho_{st} + \gamma W_{sct} + \epsilon_{skct} \quad (1)$$

where k and c represent the station and county, respectively. Note that there are multiple waves of the EVM reform. Based on the timing of the reform implementation, we construct a corresponding sample for each wave as described above, and denote s as the identifier for each reform event (which is also the identifier for the constructed sample). t is the relative day, defined as the difference between the monitoring day and the day that event s occurred.

Y_{skct} is the logarithm of the AQI at station k in county c on relative day t in event s. δ_{sk} captures the event×station fixed effect, controlling for all time-invariant differences across the monitoring stations that may vary across different verticalization events. ρ_{st} is a set of event×relative day fixed effects, which control for daily macro shocks. W_{sct} is a set of control variables, including county-level weather controls and county-specific seasonalities (to be discussed below). ϵ_{skct} is the error term.

Note that the stack-by-event approach results in multiple occurrences of the same county code within the dataset, thereby increasing the sample size and potentially inflating the statistical inference. Following the common practice in the literature (e.g., Deshpande and Li (2019) and Gu et al. (2021)), we account for this by clustering standard errors at the event level, with county codes nested within these events.[13] Alternatively, one can cluster the standard errors at the county level, which may help address the issue of spatial and temporal correlations. We obtain similar results with standard errors clustered at the county level (available upon request). Meanwhile, similar results are obtained when computing standard errors two-way clustered at the county and event levels (available upon request).

The parameters of interest are β_τ, which capture the effect of EVM on local air pollution over time. We define τ as the number of 14-day cells relative to the outset of the verticalization event (that occurred at $\tau = 0$).[14] I_{st}^{τ} is a binary variable indicating whether the rescaled day t falls within the τ periods relative to the verticalization event s. $Treat_{sc}$ is a dummy variable representing the treatment status, which is equal to 1 if the local EPB in county c initiated the EVM reform at the event time s, and 0 otherwise. We denote the omitted category $\tau = -1$ and thus $\beta_{-1} = 0$. Hence, for $\tau < -1$, the estimated coefficient β_τ allows us to examine whether the treatment and control counties undergo differential trends in air pollution prior to the EVM reform. For $\tau >= 0$, β_τ represents the marginal treatment effect on air pollution during the τ period following the initiation of the EVM reform, corresponding to the reduction at each specific post-reform time .

2.3. Identifying assumption

Our DD identification exploits daily variations among counties. The corresponding identifying assumption is that, in the absence of vertical reform, the daily difference in air pollution between treatment and control groups should not vary over time.

First, the high-frequency data allows us to include a full set of day fixed effects, resulting in the remaining omitted variables only varying at the daily frequency and across counties. While counties may undergo differential changes (that affect air pollution) at longer time intervals, such as on a yearly basis, the likelihood of a dramatic change in air pollution day by day across counties is low. Meanwhile, our identification strategy considers the staggered implementation schedule across 131 dates. Even if dramatic changes at the day level do happen, these changes need to coincide exactly with multiple specific timing slots for the reform's implementation across counties to bias our identification.

Second, to ensure comparability between the treatment and control groups, we conduct comprehensive balance tests following the approach in He et al. (2020c). Specifically, we examine whether prior to the implementation of the EVM reform, the treatment and control groups exhibit significant differences across several crucial variables impacting air quality. Estimation results are shown in Online Appendix Table A1. We find that treatment and control group had similar levels of economic development, approximated by nighttime lights, GDP per capita and fiscal revenue to expenditure ratio. Meanwhile, industrial composition was also balanced across treated and control counties, including ratio of secondary industrial output to total output, ratio of employment in the secondary industry to total employment, and ratio of registered enterprises in polluting industries. Population size, critical for assessing environmental impact, also demonstrated comparability across treatment and control groups. Political status showed no significant differences between the treatment and control groups. Moreover, prior levels of air pollution were balanced between the groups, indicating that the decision to implement the reform was not influenced by pre-existing pollution levels. Geographical factors of counties similarly showed balanced results across the groups.[15] These tests confirm the comparability of the treatment and control groups regarding key determinants of air quality before the implementation of the EVM reform.

[13] When one cluster level is entirely nested within another, appropriate methodology involves clustering at the higher level, leading to more conservative standard errors, as discussed by Cameron et al. (2011).

[14] For example, if the verticalization event took place on December 20, 2018, the time period from December 20, 2018, to January 2, 2019, is considered $\tau = 0$, and the subsequent period from January 3, 2019, to January 16, 2019, is denoted as $\tau = 1$.

[15] While average slope shows marginal significance, the magnitude is small compared to the control mean.

Third, the DD strategy accommodates differences between treatment and control groups, as long as these differences do not systematically vary over time in the absence of the EVM reform. Exploring the panel data, the event-study specification allows us to visually examine whether treated and control counties exhibit parallel trends before the reform, thus providing further support for the validity of our estimation strategy.

Three potential identification issues worth discussing up the front. The first threat is seasonality. Air pollution displays seasonal variations that differ across counties due to geographical and natural factors. If county-specific seasonality is also related to the implementation of vertical reform, our DD estimate on the EVM reform may be biased due to this confounding factor. To address this concern, we include the following variables to capture county seasonality: $year_{st} \times \gamma_c$, where $year_{st}$ = {2018, 2019}; and $month_{st} \times \gamma_c$, where $month_{st}$ = {January, …,December}; and $week\ of\ month_{st} \times \gamma_c$, where $week\ of\ month_{st}$ = {Week 1, …,Week 5}; and $weekday_{st} \times \gamma_c$, where $weekday_{st}$ = {Monday, …,Sunday}. Beyond seasonality, weather factors also play a significant role in influencing air pollution levels. To address this concern, we include a comprehensive set of weather variables observed at county c on relative day t for the event s. Specifically, drawing on the existing literature (Li et al., 2020; Greenstone et al., 2022; Barwick et al., 2024), we control the temperature, wind speed, air pressure, precipitation, sunshine duration, and humidity.

A second identification challenge arises from the potential confounding effect of other policies that coincide with our focal reform. To address this concern, we carefully examined the official government documents issued during the sample period and identified two centralized events related to environmental regulations; specifically, the central environmental inspection (*ducha*) and the environmental talk (*yuetan*). The central environmental inspection is a command-and-control regulatory tool to inspect provincial governments' environmental governance, which was first piloted in Hebei province in 2015 and then spread to the remaining provinces in a staggered manner. The environmental talk holds prefectural officials accountable to environmental targets through direct dialogues conducted by the Ministry of Environmental Protection and prefecture-level officials, which has taken place annually since 2014. We then explicitly control for these two concurrent environmental policies in the analysis to isolate the effect of our focal policy reform.

Third, our analysis centers on the change of air quality, which may raise concerns of spatial contamination. For example, the strong wind may blow air pollutants across county borders, confounding the comparison between treated and control counties. In general, spatial spillover leads to a shortage of identification power issue; that is, one regression estimate and two unknowns (the true policy effect and the spatial spillover effect). To address this issue, we conduct four exercises to examine the potential significance of the spatial spillover effect in our research setting. First, we account for meteorological factors that play crucial roles in influencing the diffusion of air pollution. Specifically, in light of the literature, we control for temperature, wind speed, air pressure, precipitation, sunshine duration and humidity.[16] Second, spillovers are more likely to happen among border monitoring stations than inland county stations. To this end, we check whether our estimated policy effects change significantly after excluding border monitoring stations. Third, spatial contamination largely exists among neighboring counties. Hence, we conduct a robustness check by excluding neighboring control counties adjacent to treated counties. Fourth, to address the potential economic spillovers (such as firm relocation to avoid strict environmental regulations), we examine whether the EVM reform affects firm location that could lead to pollution transfer among counties.

3. Data and variable construction

We describe in details the data and the construction of relevant variables for our analysis of the policy effect of the EVM reform. These include the collection of the implementation date of the reform for each county, and the use of the daily AQI data as well as the controls of other meteorological factors. Meanwhile, to explore the mechanism, we assemble a rich collection of data including the local leaders' characteristics, suspicious money from government auditing, ownership and affiliations of polluting enterprises, environmental administrative penalties, and government procurement of environmental goods and services.

Our baseline focuses on the period from January 1, 2018 to December 31, 2019 to prevent potential influences arising from the COVID-19 shocks that are found to cause unprecedented reductions in economic activity and then air pollution (Chen et al., 2020; He et al., 2020b; Venter et al., 2020). Table 1 presents the descriptive statistics of data and variables used in empirical analysis.

A. The Implementation Date of the Reform

To pin down the precise implementation date of this vertical reform, we manually collect the date when the county EPB hung out its shingle as the branch of the prefectural EPB. The inauguration of environmental protection sub-offices at the county level means that the subordinate relationship of county-level EPBs was officially changed from horizontal pieces of authority (i.e., county governments) to vertical lines of authority (i.e., prefectural EPBs). We present additional evidence to support the use of the inauguration of environmental protection sub-offices as the starting point of the EVM reform at the county level. First, the listing ceremony, typically presided over by the leader of the prefectural EPB, publicly announced the new affiliation of the county-level EPBs. This ceremony served as a means to facilitate cooperation among relevant government departments. Second, we consulted with officials working at local EPBs regarding the implementation of this vertical management reform. They confirmed that the listing ceremony marked the start of the vertical management reform, although certain aspects of the reform, such as financial

[16] Temperature affects chemical reaction rates and atmospheric stability, impacting how pollutants disperse vertically (Kalisa et al., 2018). Wind speed is crucial for horizontal dispersion, rapidly spreading or diluting pollutants across regions (Jones et al., 2010). Air pressure influences air movement patterns, affecting how pollutants spread (Zeng and Zhang, 2017). Precipitation assists in removing pollutants via wet deposition, while sunshine duration affects photochemical reactions that can transform pollutants (Zhang, 2019). Humidity impacts the formation and dispersion of particulate matter (Emekwuru and Ejohwomu, 2023).

Table 1
Variable definitions and descriptive statistics.

Variable	Definition	Mean	SD
Air Pollution Proxy			
AQI	Station daily real mean Air Quality Index (AQI)	72.866	51.185
Log(AQI)	The logarithm of the AQI	4.113	0.575
Weather Control Proxy			
Wind_Speed	County daily real mean wind speed (m/s)	2.560	1.078
Temperature	County daily real mean temperature (° C)	14.447	11.627
Air_Pressure	County daily real mean pressure (hPa)	979.027	43.424
Relative_Humidity	County daily real mean relative humidity (%)	59.244	20.518
Sunshine_Hours	County daily total sunshine hours (hours)	6.447	3.878
Precipitation	County daily total precipitation (mm)	2.336	6.912
Potential Local Capture Proxy			
Mayor_Native	=1 if the county mayor was born in the city where the county is located;=0 otherwise	0.313	0.464
Mayor_Working Time	The time length since the county mayor has worked in the county (months)	47.014	54.456
Mayor_Frequency	The number of county mayors who took office between January 2008 and December 2017	3.749	0.890
Ratio_Suspicious_Money	The ratio of a county's suspicious expenditures turned up by government auditing to total budget expenditures of year 2017	0.282	0.514
Ratio_SOE	The ratio of state-owned polluting enterprises to the total number of polluting enterprises in the county in year 2014	0.073	0.121
Ratio_High	The ratio of polluting enterprises affiliated with the provincial or national administrative divisions to the total number of polluting enterprises in the county in year 2014	0.122	0.170
County EPBs' Regulation Effort Proxy			
Any_EnvPenalty	Whether the county EPBs impose any environmental administrative penalty	0.025	0.157
County Government Fiscal Input Proxy			
Any_EnvProcurement	Whether the county governments make any procurement on environmental goods and services	0.001	0.025
Num_EnvProcurement	The number of environment-related procurement contracts	0.001	0.040
IHS(Num_EnvProcurement)	The inverse hyperbolic sine (IHS) transformation of the number of procurement	0.001	0.026
Exp_EnvProcurement	The sum of environment-related procurement expenditure (10,000 yuan)	0.151	33.111
IHS(Exp_EnvProcurement)	The IHS transformation of the expenditure of procurement	0.003	0.131
Prefectural EPBs' Financial Resource Proxy			
FiscalRev_Percapita	Prefectural EPBs' financial revenue per capita in year 2017 (yuan)	28.273	35.237
FiscalRev_Budget	Prefectural EPBs' financial revenue/financial budget in year 2017	1.184	0.669
Prefectural EPBs' Management Cost Proxy			
Spherical_Distance	The spherical distances between the county government and prefecture government (km)	11.054	21.157
Drive_Distance	The driving distance by car between the county government and prefecture government (km)	15.846	34.179
Prefectural EPBs' Informationization Level Proxy			
Ratio_Internet	Prefecture's ratio of fixed broadband internet users to total population in year 2017	0.289	0.248
Ratio_Phone	Prefecture's ratio of mobile users to total population in year 2017	1.076	0.361

Notes: This table summarizes the variables. Definitions, means, and standard deviations are reported. Detailed descriptions of the data sources can be found in section 3. The air pollution proxy variables are measured at the station level. The weather variables, potential local capture proxy variables, regulation proxy variables, fiscal input proxy variables, and variables related to geographical distance are measured at the county level. Additionally, the variables of financial resource and informatization level are measured at the prefecture level.

settlement and human resources, underwent gradual progress. Third, official news reported that the listing of the county EPBs as sub-bureaus of prefectural EPBs signaled the official implementation of the vertical management system reform (available upon request).

The timeline when county EPBs' being officially centralized as the suboffices of the prefectural EPBs is reported in Fig. 2, which predominantly occurred after 2018. Consequently, this paper primarily examines data from January 1, 2018, onwards.

B. Air Quality Index and Weather

Our study concerns the daily AQI, known for its direct and comprehensive measurement of local air pollution trends. This high-frequency data is widely utilized in the literature (He et al., 2020a; Greenstone et al., 2021; Wang et al., 2022). Specifically, the AQI is determined by considering the concentrations of six atmospheric pollutants: SO_2, NO_2, PM_{10}, $PM_{2.5}$, O_3, and CO. A higher AQI score indicates a greater severity of air pollution.

Since 2015, China has established a nationwide automatic air quality monitoring network and publicly disclosed the hourly data on air pollution.[17] According to the New Ambient Air Quality Standard (GB 3095-2012), each monitoring station monitors six pollutants in the air along with AQI, and reports these data to the China National Environmental Monitoring Centre in real time. For our empirical analysis, we draw on the daily AQI observations from 1074 monitoring stations in 592 counties from January 1, 2018, to December 31, 2019, where daily averages are computed based on hourly counts in the raw data.[18] To ensure significant post-reform periods, our baseline uses stations in 527 counties that implemented the EVM reform before July 18 2019. And our control group constitutes 65 counties never implemented the reform in our sample period. To enhance the size of the control group, we include later-treated counties in the control group in a robustness check, resulting in an analysis with 527 treated counties and 256 control ones.

The station-level daily AQI data is obtained from China's Real-Time Air Quality Reporting and Analysis Platform, which is maintained by the China National Environmental Monitoring Centre.[19] The automatic reporting addresses the concern of data manipulation by local officials as documented by Greenstone et al. (2022). Nonetheless, to further alleviate the concern of data manipulation by local officials, we conduct a robustness check using the Aerosol Optical Depth (AOD)-based $PM_{2.5}$ data, in which the information on air pollution is acquired through remote sensing AOD retrievals that cannot be manipulated by humans.[20]

In addition, as weather elements affect the formation of air pollution, we collect daily meteorological data from the China Meteorological Data Service Center.[21] Consistent with existing literature (Li et al., 2020; Greenstone et al., 2022; Barwick et al., 2024), we include county-level daily meteorological variables in our analysis, which encompass temperature, wind speed, air pressure, relative humidity, sunshine hours, and precipitation amount.

C. The Likelihood of Local Capture

The implementation of the EVM reform is motivated by the aim to curb the potential intervention in the work of local EPBs by local government officials. We combine several unique data sets to assess the likelihood of county EPBs being locally captured.

Mayor Characteristics. As Jia and Nie (2017) demonstrate, with lower transaction costs, native leaders have the natural advantage of making collusion with firms. Furthermore, Persson and Zhuravskaya (2016) find that leaders who have spent their entire careers in one city are more susceptible to implicit contracts with local elites, compared to the leaders who have been rotated across cities. Additionally, Stovel and Savage (2006) and Olken (2007) suggest that the timely replacement of bureaucrats can discourage informal connections and limit potential collusion.

In light of the literature, we gather the biographical notes of all county mayors in our sample to examine the likelihood of county mayors capturing county EPBs. To this end, we manually collect the birthplace and working experience of county mayors who assumed their positions prior to the introduction of vertical reform in this county from the official websites.

Three variables are constructed from the mayor data. We first create an indicator variable to identify whether the county mayor was born in the same city where their working county is located. Local leaders who are natives are more likely to capture bureaucrats to pursue personal interests since their native status grants them a larger net benefit from engaging in local capture.

The second variable is the length of time that the county mayor worked in the county. As interest connections become more entrenched with time, both formal and informal ties, county mayors who have longer working time in a particular county are more capable of capturing county EPBs.

Third, we track the list of county mayors who assumed office between January 2008 and December 2017 and construct a variable—the frequency of changing county mayors. The more frequent the changes in working locations, the more difficult it is for county mayors to establish local ties and intervene in the work of county EPBs.

Governments Auditing. Corruption reduces the stringency of environmental regulations (Fredriksson and Svensson, 2003). A clean political ecology restricts the scope for influence activities, making it challenging for local governments to interfere in environmental

[17] Note that the national air quality monitoring stations do not cover all Chinese counties. The locations of these stations were determined by the central Environmental Protection Bureaus based on local population, and most stations were built before the introduction of the EVM reform. Hence, the missing county AQI information for certain counties is not expected to significantly affect the validity of our estimation. Furthermore, the inclusion of daily fixed effects in our high-frequency data eliminates any sample selection issues generated by factors not varying at the daily level.

[18] In the raw data, there are 1601 air quality monitoring stations across China. Our baseline analysis focuses on 1074 stations due to several practical reasons. First, we exclude 72 stations located in counties administered by the four direct-controlled municipalities, in counties directly under provincial administration and in cities without county administration, as these areas were not subject to our focal county-level EVM reform but to a city-level environmental regulation reform. Second, to mitigate the sample attrition issue and retain high-quality panel data, we exclude 180 stations either having significant missing or irregular data or being newly built (and on trial run). Following these two exclusions, our analysis dataset comprises 1349 monitoring stations in 727 counties. Meanwhile, 135 counties underwent the EVM reform in late 2019, resulting in insufficient post-treatment periods of 24 weeks. Given that only never-treated counties are used as control group in our baseline analysis, we further exclude 275 stations located in these 135 counties. Nonetheless, to examine the sensitivity of our results to the sample construction, we include these 135 counties into our analysis in the robustness checks. After all these procedures, 1074 stations remain in our baseline analysis dataset.

[19] See https://www.cnemc.cn/sssj/.

[20] Compared with the air quality monitoring data (that directly monitor air pollution levels), remote sensing data involve complicated algorithms to infer pollution concentrations indirectly. Meanwhile, remote sensing data typically provide information on air pollution at monthly frequency due to the challenges faced by monitoring satellites at the daily level, whereas our air quality monitoring data are collected at daily level enabling a more credible identification strategy. Hence, following the literature (He et al., 2020c; Greenstone et al., 2021, 2022; Chen et al., 2022; Wang et al., 2022), we use air quality monitoring data in the baseline and the remote sensing air quality data as a robustness check.

[21] See https://www.data.cma.cn.

supervision. In regions with high levels of corruption, polluting enterprises are more likely to provide benefits to local officials in exchange for policy favors and patronage.

Following the approach of Chu et al. (2021), we measure corruption based on irregular behaviors of local governments engaging in accounting practice. Specifically, for all the 592 counties in the baseline analysis, we first collect the number of questionable monies in county governments' auditing for the year 2017 from the China Audit Yearbook.[22] We manually gather data on expenditures in the county government's general budget from County Government Work Reports of 2017 for all 592 counties. We then define a county-level variable by calculating the ratio of questionable monies in county governments' auditing to expenditures in the county government's general budget for the year 2017. A higher value of this variable indicates a higher degree of corruption within the county.

Ownership and Affiliations of Polluting Enterprises. It is well-documented in the literature that the enterprise's political connections are associated with increased patronage and favorable treatment from regulators (Fisman, 2001; Faccio, 2006; Ferguson and Voth, 2008). In China, the government appoints the heads of state-owned enterprises, establishing political ties between these enterprises and the governments. Compared with non-state-owned enterprises, state-owned enterprises can not only transfer the pecuniary interest to local authorities but also capture the political elites through political interests. Consequently, regions with a higher proportion of state-owned polluters are more likely to experience local capture. To materialize this argument, we utilize the available data to construct two relevant variables.

Specifically, we begin by matching the Chinese Industrial Enterprises Data for the year 2014 with the Chinese Enterprises' Pollution Emissions Data for the same year, to compile a list of major polluting enterprises for 592 counties.[23] We then use the information of registered types to identify whether a polluting enterprise is state-owned. Subsequently, we construct a variable by calculating the proportion of state-owned polluting enterprises relative to the total number of polluting enterprises in each county.[24] This variable measures the extent to which county EPBs are confronted with influential polluters that may exert influence over environmental enforcement through their political connections.

In addition to ownership, we gather data on affiliations for the polluting enterprises identified in the 592 counties mentioned earlier. Based on this, we identify whether the polluting enterprise is affiliated with provincial or national administrative divisions. So we construct another variable by calculating the ratio of polluting enterprises affiliated with provincial or national administrative divisions to the total number of polluting enterprises in each county. With this variable, we aim to explore whether the EVM reform at the county level can affect the potential local capture occurring at higher administrative levels.

D. Environmental Administrative Penalties

To understand how the EVM reform affects the behavior of local EPBs, we analyze data on environmental administrative penalties. According to the Environmental Protection Law, local EPBs have the power to execute administrative penalties on organizations or individuals in breach of the environmental statute. Meanwhile, these penalties must be publicly disclosed in accordance with the law. Correspondingly, we use the intensity of environmental administrative penalties as a measure of the governance efforts made by county EPBs to combat pollution.

Owing to the disclosure requirement, we collect the cases of environmental administrative penalties from the PKU Law database and local official websites.[25] Specifically, we extract data on nearly 40,000 environmental administrative penalties imposed by 592 county EPBs during our sample period.

Based on the announcement dates and agencies responsible for the punishment, we create a binary variable to indicate whether the county EPB imposes any environmental administrative penalty.[26] These allow us to further gauge the magnitude of efforts by county EPBs in containing pollution.

E. Government Procurement on Environmental Products and Services

To examine whether the EVM reform affects local governments' attitudes towards environmental protection, we analyze data on government procurement. Government procurement is an important part of fiscal policy and government expenditure in China.

[22] Note that data on questionable monies is missing for 14 counties in the China Audit Yearbook (2.3%). We show that this missing data is unrelated to the introduction of the EVM reform. Specifically, we use the indicator of missing data on questionable monies as the outcome variable and conduct the regression based on Eq. (1). The results provide compelling evidence that the missing status is balanced between the treatment group and the control group (available upon request).

[23] Ideally, we would have preferred to use the data sets from the year 2017, as it is the most recent year close to the EVM reform. However, due to data limitations, we can only utilize 2014 data sets for calculation. We believe that the 2014 list of polluters is similar to the 2017 list because the Chinese Industrial Enterprises Data collects information on large industrial enterprises with annual revenue of 20 million yuan or more, which tend to have stable locations over time.

[24] Note that there are 17 counties (2.8% of the sample) where no major polluting enterprise is located. For these counties, we designate the variable value as missing. Furthermore, we investigate whether the missing status differs between the treatment and control groups and find no significant difference(available upon request).

[25] We obtain access to the PKU LAW database via the following website: https://www.pkulaw.com/penalty. The PKU Law database is an online platform that provides nearly comprehensive coverage of administrative penalties from China imposed by the Chinese central and local governments, spanning from 2000 to the present. It contains nearly 1,540,000 cases of administrative penalties in various fields such as environmental protection and food safety.

[26] Note that for 215 counties (36% of the sample), only the most recent environmental administrative penalties are disclosed online, and we have no access to their penalties for the years 2018 and 2019. We show that this sample attrition is unrelated to the vertical management reform, resulting in negligible estimation bias. Specifically, we conduct the estimation based on Eq. (2), with the dependent variable being the indicator of missing data on environmental administrative penalties. Our analysis reveals no significant impact of the EVM reform on the data missing status, indicating that the missing conditions are largely balanced between the treatment group and the control group (available upon request).

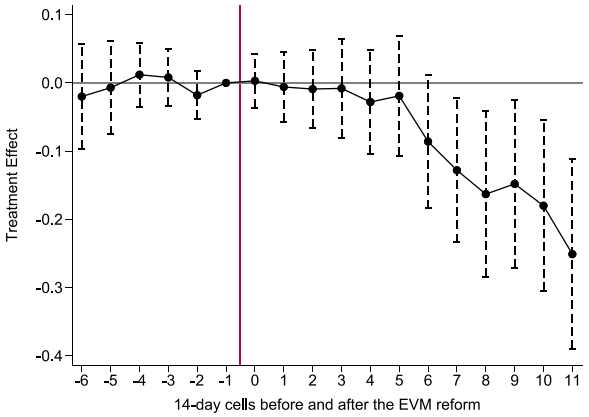


Fig. 4. Effects of the EVM reform on air pollution.
Notes: This figure plots the estimated coefficients of the series of β_τ and their 95% confidence intervals for each 14-day time cell within the event window, as specified in Eq. (1). The dependent variable is the logarithm of the AQI. The vertical line denotes the commencement of the EVM reform. The omitted variable is one 14-day cell prior to the introduction of the EVM reform. Standard errors are clustered at the event level.

From 2002 to 2017, government procurement in China increased from 0.1 trillion yuan to 3.2 trillion yuan, accounting for 15.8% of national fiscal expenditure from 10.3%.

Specifically, the Ministry of Finance requires that information on government procurement should be disclosed on an online platform, the Chinese Government Procurement Platform.[27] Based on this data set, we trace the procurement contracts of environmental products and services by local governments in 592 counties from January 1, 2018, to December 31, 2019.

According to the signing dates and purchasers of the contracts, we calculate the number of environment-related procurement contracts and the sum of procurement expenditures for each county-day observation. We construct three variables to capture government expenditure on the environment; that is, whether the county government makes any environment-related procurement, the number of environment-related procurement contracts, and the total expenditures of environment-related contracts.[28]

4. Baseline estimates

4.1. Baseline results

We use the DD strategy specified in Eq. (1) to estimate the causal effect of the EVM reform on local air pollution. To illustrate the dynamic treatment effects, we present a graphical presentation of the estimated coefficients β_τ and their 95% confidence intervals for each two-week time unit within the event window in Fig. 4. The vertical line denotes the initiation of the EVM reform. Detailed estimation results from this regression are provided in Online Appendix Table A2.

Our data renders six pre-treatment time units and twelve post-treatment time units. As depicted in Fig. 4, prior to the implementation of the EVM reform, there were no clear differential trends in AQI between the treatment and control groups. These results confirm the parallel trend assumption commonly used to validate the DD estimation, lending support to our estimation strategy.

After the EVM reform was implemented, the AQI in treated counties significantly decreased, compared with the control counties. Specifically, the difference in AQI between treated and control counties hovered in the first eight weeks after the introduction of the EVM reform ($\tau \in [0, 3]$), and then started to gradually decline. Fourteen weeks after the EVM reform ($\tau = 6$), the AQI in treated counties decreased by 8.6% at the significant level of 10%. This decline accelerated to 18.0% after twenty-two weeks ($\tau = 10$) and further to 25.1% after twenty-four weeks ($\tau = 11$) following the introduction of the EVM reform. Combined, these results indicate that the EVM reform significantly improves local air quality.

4.2. Gradual take-up

Note that the impact of the EVM reform takes several weeks to show up. The lagging effect can be attributed to the institutional nature of the reform. Specifically, the EVM is a comprehensive institutional reform, involving the reconstruction of several

[27] The Chinese Government Procurement Platform could be accessed via http://www.ccgp.gov.cn. It is maintained by the Ministry of Finance, which discloses more than 3.5 million procurement contracts issued by Chinese governments at all levels between 2013 and 2021.

[28] Note that the Chinese Government Procurement Platform does not provide the procurement information for 186 counties during the period of 2018 and 2019 (31% of the sample). We estimate the relationship between the missing data status and the EVM reform based on Eq. (2) using the indicator of missing status as the dependent variable. The results reveal no significant economic or statistical impact of the EVM reform, confirming that the missing data is balanced between the treatment and control groups (results available upon request).

governance functions, such as personnel control, financial support, budgeted posts, assets transfer, and others. For the local implementation, renaming the county EPBs as sub-bureaus of prefectural EPBs constitutes the initial step of the reform, with other institutional rearrangements being introduced sequentially. For example, in Hunan Province, the EVM was launched in July 2018, while the relevant departments were expected to complete the transfer of budgeted posts in August 2018 and finish other work by the end of October 2018. Therefore, the effect of the EVM reform hinges on the gradual progress of the whole institutional rearrangement.

Take financing as an example. The EVM reform requires prefectural EPBs to provide financial support to their sub-bureaus, which takes time for the former to adjust their financial resources to support the latter. When prefectural EPBs have sufficient budgetary resources, the transition of financial dependency can be completed swiftly. However, for prefectural EPBs with constrained financial resources, arranging financial support for county EPBs may take a prolonged time.

To corroborate this argument, we conduct a formal examination of the role of available financial resources in shaping the timing of the EVM reform effect. Specifically, we use fiscal revenue per capita to measure the extent of financial resources, and explore how variations in this variable across prefectural EPBs in 2017 affect the dynamic pattern of the EVM reform.[29] This analysis examines whether the effect of the EVM reform on air pollution is more immediate when the controlling prefectural EPBs have greater financial resources. As shown in Online Appendix Figure A2, we indeed find that with ample financial resources from the upper authorities, treated counties experience an immediate decrease in the AQI after the introduction of the EVM reform. Conversely, when prefectural EPBs have limited financial resources, it takes a longer time for the EVM reform to impose a negative effect on the AQI. Alternatively, we use the ratio of financial revenue to the financial budget of prefectural EPBs in 2017 to measure feasible financial resources for regime shift, and find a consistent pattern in Online Appendix Figure A3. The corresponding regression results are reported in Online Appendix Table A3.

These results suggest that the lagging effect of the EVM reform can be attributed to the complicated process of restructuring organizational structures. A well-prepared prefectural EPB can expedite the impact of the EVM reform in reducing pollution.

4.3. Comparison with the literature

To further illustrate the economic significance of our focal environmental reform, we benchmark the magnitude of our estimated effects to the literature. First, using the similar environmental vertical management reform but at the city level, Chen et al. (2024) estimate an coefficient of 4.1% in a staggered DD specification with about two years post-reform period, which is much smaller than our documented effect of 25.1% at the twenty-four weeks after the reform. There are a few differences in the estimation specification between ours and Chen et al. (2024)'s work explaining such discrepancy. One primary reason is that we estimate a series of marginal effects in Fig. 4, corresponding to the reduction at each specific post-reform time. In contrast, Chen et al. (2024) estimate an average of these marginal effects over a time span of about two years. Using the staggered DD specification similar to Chen et al. (2024), we find an average effect over a two-year span of 7% (results available upon request), which is slightly larger than Chen et al. (2024)'s. The remaining difference can be explained by the nature of the estimators. Specifically, we use the implementation day of the EVM reform as the time of treatment and hence, estimate an average treatment effect on treated, whereas Chen et al. (2024) use the reform schedule issued by the provinces as the time of treatment for cities. Given that cities implemented the reforms later than the schedule, they essentially estimate the intent to treat effect, which is muted by the non-compliance degree.

Second, compared with other environmental policies implemented in China, the EVM reform achieved a comparable reduction in air pollution within a relatively shorter timeframe of approximately twenty-four weeks (about six months). Specifically, Li et al. (2020) indicate that five months after the implementation of the upgraded fuel standard (gasoline IV), the AQI in the treated cities marginally decreased by 9.5%. Greenstone et al. (2021) find that following unprecedented regulatory changes in 2014, which marked a declaration of a "War on Pollution" by Premier Li Keqiang, PM_{10} concentration reduced by 33.5% by the end of 2018.

Third, to gain further insights into the effect of the EVM, we compare our estimates with the estimated effects of environmental regulations in other countries as documented in the literature. In the United States, the Clean Air Act (CAA) serves as a cornerstone of environmental protection. Currie et al. (2023) find that, one year after the implementation of the CAA's $PM_{2.5}$ National Ambient Air Quality Standards, $PM_{2.5}$ concentration marginally decreased by 0.7 $\mu g/m^3$ (i.e., 6.2%) in the newly regulated areas. Barreca et al. (2021) find that in the year when the Acid Rain Program was introduced, a provision of the CAA Amendment, SO_2 levels marginally declined by 0.2 parts per billion (i.e., 2.7%) for one standard deviation in weighted sulfur controls. In Germany, Margaryan (2021) demonstrates that five years after the enactment of the Low Emission Zones Policy, a reduction of 1.5 $\mu g/m^3$ (i.e., 5.4%) in $PM_{2.5}$ concentration was observed. In India, Greenstone and Hanna (2014) investigate the effect of the fitment of catalytic converters in vehicles and show that five years after the policy went into place, PM concentration decreased by 48.6 $\mu g/m^3$ (i.e., 19.3%). For more details about the literature comparison, see the Online Appendix Table A4. Compared to the effects of the aforementioned policies, the EVM reform demonstrates a considerable improvement in air quality within a shorter time.

One reason for the sizable EVM effect on air quality lies in the Chinese political institutions. Specifically, in China, local officials have played a central role in driving local economic growth and providing public goods (Li and Zhou, 2005; Jia and Nie, 2017). The incentives of local EPB officials are pivotal to environmental governance, as they wield considerable discretionary powers to regulate polluters (He et al., 2020c). Following the EVM reform, county EPB officials, who seek for promotion within the top-down hierarchy system, are held accountable to the prefectural EPBs rather than county governments. Consequently, these county EPB officials exert greater efforts to achieve improved environmental performance.

[29] We manually collect financial statements of prefectural EPBs for the year 2017, which provide data on financial revenue and budget. Furthermore, we divide the yearly financial revenue by the prefecture population.

4.4. Robustness checks

To support our baseline results, we provide several robustness checks.

First, we consider potential confounding factors by controlling for other concurrent events that may overlap with the pattern of the EVM reform and thus bias our estimation. Note that we find that there is no any other county-level event that coincides with multiple timing slots of the EVM reform, which could then differentially affect air quality in the treatment and control groups. Nonetheless, to further validate our results, we examine the sensitivity of our estimated effects by controlling for two centralized events related to environmental regulations; specifically, the central environmental inspection (*ducha*) and the environmental talk (*yuetan*). We construct a dummy variable, $D_{sc} \times T_{st}$, which takes the value of 1 if county c experienced either the central environmental inspection or the environmental talks in relative day t of event s, and 0 otherwise. We include this dummy in Eq. (1) and the corresponding results are reported in Online Appendix Figure A4 and column (1) of Table A5. Another potential confounding policy comes from the EVM reform occurred at the prefecture level. Specifically, the city-level EVM reform centralized the authority to nominate the director and deputy director of prefectural EPBs to provincial EPBs, although final personnel decisions still required consultation with the prefectural CCP committee. To mitigate potential confounding effects from the EVM reform at the prefecture level, we include prefecture × year-month fixed effects. Estimation results are reported in Online Appendix Figure A5 and column (2) of Table A5. The trends are similar to our baseline findings, suggesting that our baseline results are not driven by this confounding policy.

Second, we incorporate additional constructed samples. In our baseline specification, we exclude events occurring near the end of 2019 to ensure a sufficient post-treatment observation period of 24 weeks.[30] To examine the sensitivity of our results to the sample construction, we expand the sample to include all events from 2018 and 2019, stacking these together. Online Appendix Figure A6 and column (3) of Table A5 present the results for the newly stacked sample, which demonstrate that our baseline conclusions remain unchanged. This suggests that our baseline results are robust to the alternative approach of sample construction.

Third, to ensure that the EVM reform leads to meaningful improvements rather than merely simulating data manipulation (Zou, 2021; Yang et al., 2024), we conduct a robustness check by using the AOD-based $PM_{2.5}$ data, which acquire the information on air pollution through remote sensing AOD retrievals and cannot be manipulated by humans. Specifically, the AOD measures the extent to which sunlight duration is absorbed, reflected, and scattered by suspended particulates in the atmosphere. The popularity of AOD-based $PM_{2.5}$ data is growing in economic studies as it fills gaps in-ground monitoring networks and validates data quality at ground level (Chen et al., 2022; Yang et al., 2024). We obtain the AOD data from the National Aeronautics and Space Administration (NASA)'s Modern-Era Retrospective Analysis for Research and Applications version 2 (MERRA-2).[31] This dataset is reported at a $0.5° \times 0.625°$ grid resolution (which roughly corresponds to 50 km×60 km) on a monthly basis, spanning from 1980 onwards. To calculate the AOD-based $PM_{2.5}$ concentration, we follow the methodology detailed by Buchard et al. (2017) and aggregate the monthly pollution data from the grid to the county. Our analysis sample uses monthly AOD-based $PM_{2.5}$ data for 592 counties from 2018 to 2019, and applies the stack-by-event approach based on the implementation date of the EVM reform at the monthly level. Online Appendix Figure A7 and Table A6 report the results using monthly AOD-based $PM_{2.5}$ remote sensing data.[32] We continue to find that the EVM reform significantly reduces $PM_{2.5}$ concentrations, with this effect manifesting after approximately three months, mirroring the patterns observed in the baseline results.

Fourth, our baseline model employs never-treated counties as the control group. We further conduct a robustness check by including the not-yet treated counties into the control group.[33] Estimation results are reported in Online Appendix Figure A8 and column (4) of Table A5. There is a significant reduction in local air pollution attributable to the EVM reform using the new set of control counties, corroborating our baseline findings.

Fifth, our baseline model adopts the stack-by-event approach to address the issue of heterogeneous effects in the staggered DD (Cengiz et al., 2019; Deshpande and Li, 2019; Fadlon and Nielsen, 2019; Gu et al., 2021; Liao and Kousky, 2022). To examine the sensitivity of our findings to the specific methodology we choose, we also experiment with alternative estimators developed in the literature to deal with heterogeneous effects in the staggered DD (Callaway and Sant'Anna, 2021; Sun and Abraham, 2021; Borusyak et al., 2024; De Chaisemartin and d'Haultfoeuille, 2020). As shown in Online Appendix Figure A9, prior to the EVM reform, no discernible differences were observed between the treatment and control groups. Implementation of the EVM reform significantly reduces local air pollution, consistent with our baseline findings using the stack-by-event approach. This reinforces the conclusion that the EVM reform reduces local air pollution.

Sixth, to address concerns about spatial contamination in our estimation, we perform a series of robustness checks. Firstly, spillovers are more likely to happen among border monitoring stations than inland county stations. In Online Appendix Figure A10 and column (5) of Table A5, we conduct a robustness check by excluding monitoring stations located within 3 kilometers of the county borders. The estimated policy effects remain consistent with our baseline findings. Secondly, spatial contamination largely exists among neighboring counties. Hence, we conduct a robustness check by excluding neighboring control counties adjacent to treated counties and report the results in Online Appendix Figure A11 and column (6) of Table A5. These results exhibit trends

[30] For example, 5 counties experienced the EVM reform on December 30, 2019, resulting in only 2 days of post-treatment observations within the sample period, which is insufficient compared to the 24-week duration utilized in the baseline specification.

[31] See https://disc.gsfc.nasa.gov/datasets/M2TMNXAER_5.12.4/summary.

[32] The baseline result covers six 14-day time intervals before the EVM reform and twelve 14-day time intervals after. To maintain a consistent time frame with the baseline, Figure A7 spans the four months preceding the EVM reform to six months afterward.

[33] By doing this, the ratio of the control group increases from 10.9% to 35.2%.

similar to those in the baseline model. Thirdly, we consider the possibility of economic spillovers, such as firms relocating to avoid stricter environmental regulations, which could result in pollution being transferred between counties. To investigate this, we analyze firm registration data to determine whether the EVM reform led to significant changes in firm location patterns. The results, shown in Online Appendix Figure A12 and Table A7, suggest no substantial relocation of firms, whether from polluting or non-polluting industries, in response to the EVM reform. Combined, these findings indicate that our estimates are not significantly biased from the spatial contamination.

5. Explanations and mechanisms

We document that introducing the EVM reform significantly reduces local air pollution. The substantial improvement in air quality embodies the strengthened motivation of local EPBs to combat pollution and their concrete actions to protect the environment. We conduct formal investigations to understand how local EPBs become motivated after the EPM reform and what efforts they take to reduce air pollution.

Specifically, we first examine whether the EVM reform reduces the local capture of local EPBs by local governments, which could then change their attitudes towards pollution controls. Second, we investigate whether the EVM reform enhances local EPBs' efforts in enforcing environmental law enforcement. In particular, as the EVM reform aligns the interests of local EPBs with the central government's objectives, local EPBs may prioritize the achievement of central environmental targets over local interests. Third, we explore the impact of the EVM reform on the pollution control actions of local governments. The EVM reform substantially removes the intervention power of local governments in local EPBs, including the practice of providing special protection or favoritism. Consequently, local governments may need to allocate more resources and take active measures to fulfill their commitments and meet environmental targets set by the central government.

5.1. Local capture of county EPBs

Before the EVM reform, environmental governance in China was managed by a fragmented bureaucratic structure with limited vertical control, in which local governments controlled the staffing and financing of local EPBs. Grasping the political and economic interests of local EPBs, local governments could easily capture local EPBs to pursue their own local interests. When the central government's interest clashes with those of local interest groups in environmental protection, local EPBs tend to collude with these interest groups and intentionally weaken environmental regulation. The EVM reform aims to break up this institutional foundation of local capture by transferring the decision-making authority over personnel and budget of county EPBs to prefectural EPBs. After the reform, local EPBs become less likely to be captured by local interest groups, strengthening their fulfillment in environmental supervision.

To empirically investigate this potential mechanism, we explore how variations in the likelihood of pre-existing local capture across counties affect the effectiveness of the EVM reform. Specifically, we construct six alternative variables to reflect the potential of county EPBs being locally captured, including collusion among county EPBs, county governments, and firms. Counties with a higher likelihood of local capture are expected to have larger negative effects of the EVM reform on air pollution than their counterparts with a lower likelihood of local capture. To present the results, we utilize the graphical presentations, with all the estimation results reported in the Online Appendix Table A8.

The first variable is whether the county mayor is a native resident. Native mayors, with their deep personal networks in the community, have lower transaction costs for engaging in local collusions (Jia and Nie, 2017). Meanwhile, rooted in the local environment, native mayors have entrenched local interests, making them more inclined to pursue local over national interests when the two are in conflicts. Hence, counties governed by natives, which have a higher potential for local capture, are expected to benefit more from the EVM reform. Fig. 5 shows the heterogeneity analysis based on whether the county mayor was born in the city where they worked. As illustrated in panel B, in counties whose county mayors are natives, there is a large reduction in air pollution after the EVM reform is introduced. However, the EVM reform exerts a small negative effect on air pollution in the other group of counties. These findings support the hypothesis that the EVM reform takes effect by reducing the likelihood of county EPBs being locally captured.

Our second measure explores the duration that county mayors have worked in current counties. Persson and Zhuravskaya (2016) find that local leaders who establish long-term careers in one place are more likely to develop reciprocal relationships and be subject to implicit contracts with local elites. If county mayors have been working in a county for a longer period of time, they are more likely to develop entrenched connections with county EPB bureaucrats, compared to county mayors who have recently started working in the county. With the common interests increasing with time, county EPBs are more likely to be captured by county mayors. Specifically, we divide counties into two groups based on whether the county mayor's duration of work in the current county is higher or lower than the sample median (i.e., 33 months). Fig. 6 presents the results based on the county mayor's working duration. The EVM reform casts a greater improvement in air quality in counties where the county mayor has been working there for a longer period of time. These findings are consistent with our argument that local capture increases with the duration of the county mayor's working in the locality and the EVM reform reduces air pollution by curbing local capture.

The third measure explores the frequency of county mayor replacement. Bureaucratic replacement can be used to limit informal connections and influence activities (Stovel and Savage, 2006; Olken, 2007). Rotating local officials has long been employed by the Chinese government to curb local interest networks. If the county mayor is frequently replaced, the local interest network established by a county mayor is expected to be unstable and fragile. With the expectation of unstable collusion interests, county EPBs are less

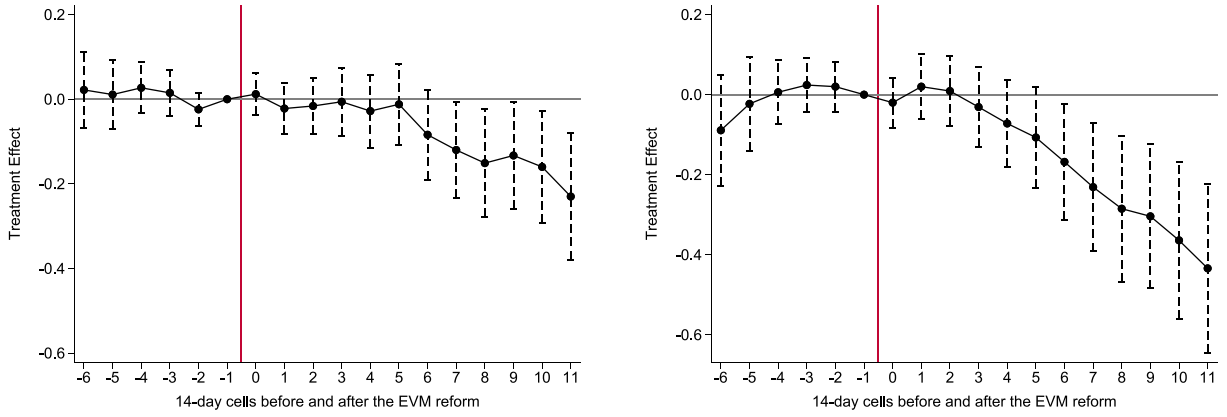


Fig. 5. The EVM reform and local capture of county EPBs: heterogeneity analyses by county mayors' birthplaces.
Notes: This figure plots the estimated coefficients of the series of β_τ and their 95% confidence intervals for each 14-day time cell within the event window, as specified in Eq. (1). We divide the sample based on whether the county mayor was born in the prefecture where the county is located. Panel A presents the results for counties whose county mayors are not native. Panel B shows the results for counties whose county mayors are native. The dependent variable is the logarithm of the AQI. The vertical line denotes the commencement of the EVM reform. The omitted variable is one 14-day cell prior to the introduction of the EVM reform. Standard errors are clustered at the event level.

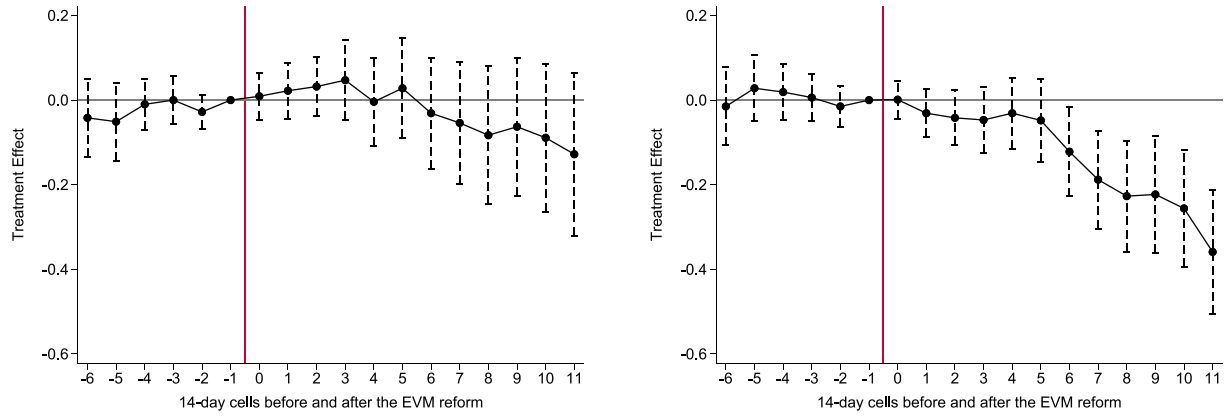
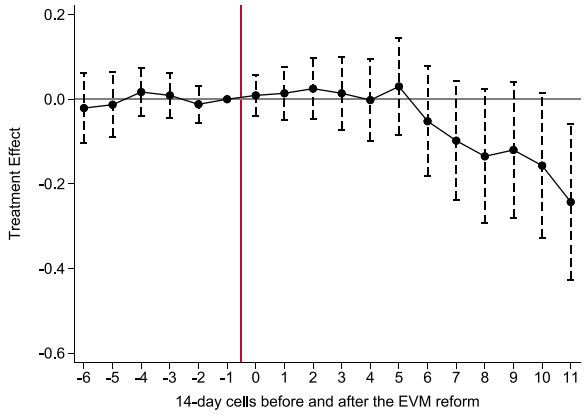


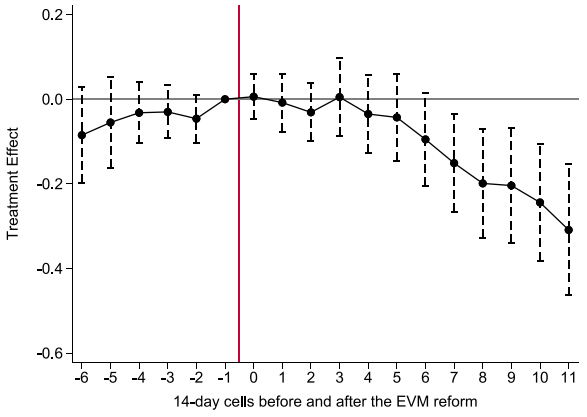
Fig. 6. The EVM reform and local capture of county EPBs: Heterogeneity analyses by county mayors' working duration.
Notes: This figure plots the estimated coefficients of the series of β_τ and their 95% confidence intervals for each 14-day time cell within the event window, as specified in Eq. (1). We divide the sample by comparing the county mayor's duration of work in the current county with the sample median. Panel A shows the results for counties where the county mayor has recently started working there. Panel B displays the results for counties where the county mayor has been working there for a longer period of time. The dependent variable is the logarithm of the AQI. The vertical line denotes the commencement of the EVM reform. The omitted variable is one 14-day cell prior to the introduction of the EVM reform. Standard errors are clustered at the event level.

likely to be influenced by county mayors. Therefore, more frequent changes in county mayors decrease the likelihood of county EPBs being captured. Empirically, we divide the sample based on whether the frequency of changing county mayors before the EVM reform (i.e., between January 2008 and December 2017) exceeds the sample median value (i.e., 3 times). Fig. 7 presents the estimation results. The EVM reform exerts a smaller impact on air pollution in counties that experienced more frequent mayor replacements compared to those with infrequent replacements. These findings confirm our local capture argument through which the reform generates policy effects.

Our fourth measure of local capture is inspired by Fredriksson and Svensson (2003), who find that corruption largely implies the easiness of local capture. To capture this aspect, we adopt the approach used by Chu et al. (2021) to construct a proxy for corruption, which is based on the ratio of suspicious expenditures uncovered by government auditing to total budget expenditures in a county. The more suspicious money in government, the more corruption is embodied in the bureaucratic systems, which facilitates the flow of interests among sectors engaged in collusion. We divide the sample into two groups with the threshold being the sample mean value of the suspicious expenditure ratio (i.e., 28.1%). Fig. 8 presents the estimation results. The EVM reform has a larger impact

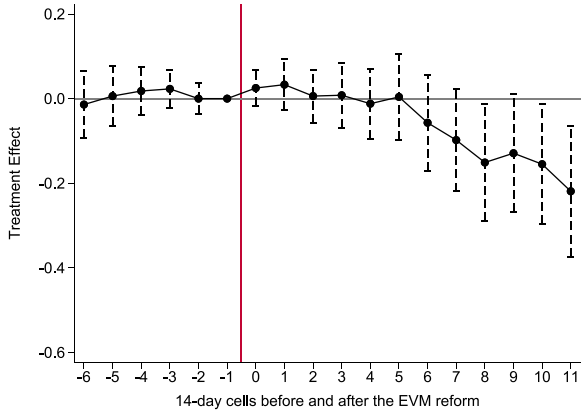


Panel A: The frequency of changing county mayors is higher

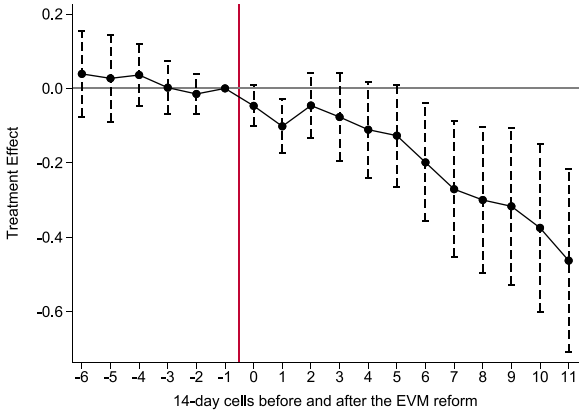


Panel B: The frequency of changing county mayors is lower

Fig. 7. The EVM reform and local capture of county EPBs: Heterogeneity analyses by county mayors' replacement frequency.
Notes: This figure plots the estimated coefficients of the series of β_τ and their 95% confidence intervals for each 14-day time cell within the event window, as specified in Eq. (1). We classify the sample by comparing the frequency of changing county mayors with the sample median. Panel A presents the results for counties that experienced more frequent mayor replacements. Panel B shows the results for counties with infrequent replacements. The dependent variable is the logarithm of the AQI. The vertical line denotes the commencement of the EVM reform. The omitted variable is one 14-day cell prior to the introduction of the EVM reform. Standard errors are clustered at the event level.



Panel A: Less suspicious money in county government auditing

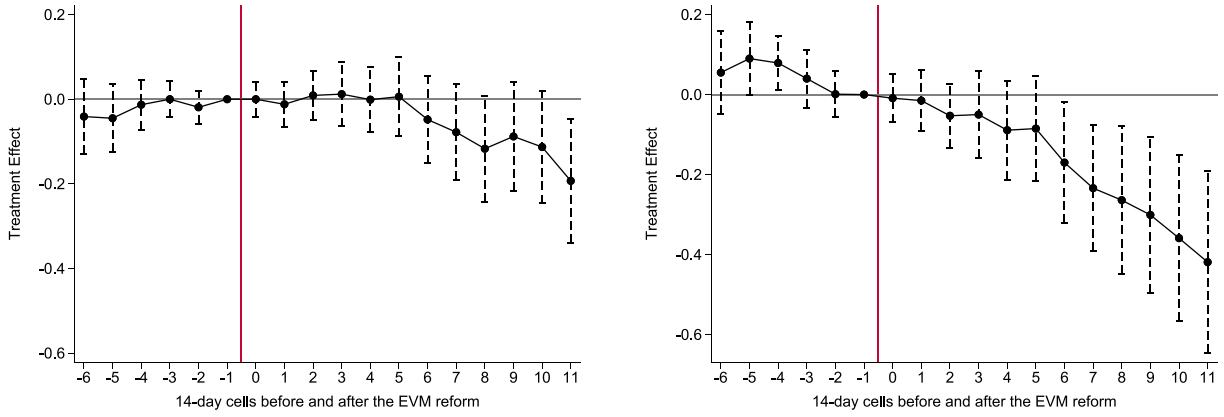


Panel B: More suspicious money in county government auditing

Fig. 8. The EVM reform and local capture of county EPBs: Heterogeneity analyses by suspicious money in county government auditing.
Notes: This figure plots the estimated coefficients of the series of β_τ and their 95% confidence intervals for each 14-day time cell within the event window, as specified in Eq. (1). We classify the sample by comparing the ratio of a county's suspicious expenditures uncovered by government auditing to total budget expenditures with the sample mean. Panel A shows the results for counties with less suspicious money. Panel B presents the results for counties with more suspicious money. The dependent variable is the logarithm of the AQI. The vertical line denotes the commencement of the EVM reform. The omitted variable is one 14-day cell prior to the introduction of the EVM reform. Standard errors are clustered at the event level.

on counties with higher ratios of suspicious government expenditures than those with lower ratios. These findings provide further support for the local capture argument.

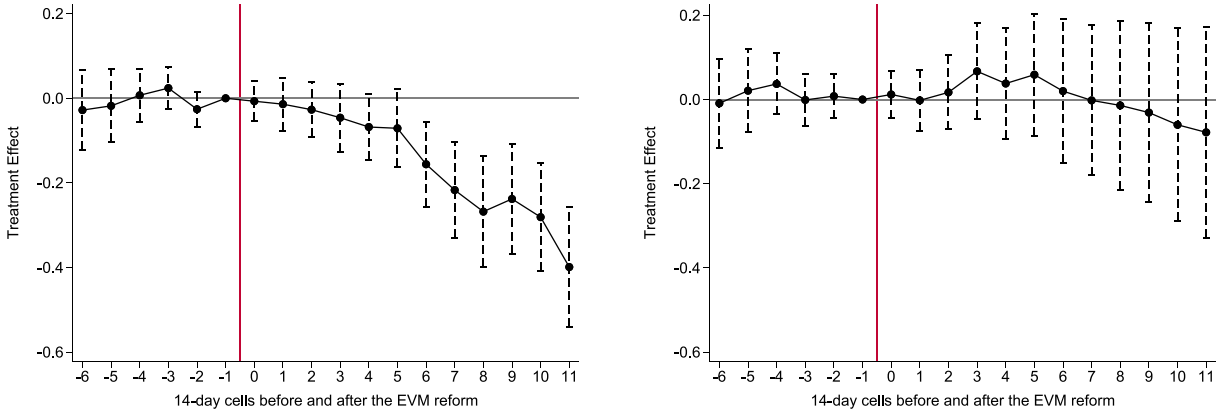
The fifth measure is the ratio of state-owned polluting enterprises to the total number of polluting enterprises in the county. The literature finds that political connections can help enterprises gain patronage and favor from governments (Fisman, 2001; Faccio, 2006; Ferguson and Voth, 2008). In China, the heads of state-owned enterprises are appointed by higher-level governments, rendering them remarkable political connections with local governments. Moreover, some heads of state-owned enterprises even hold comparable government hierarchical ranks compared to county mayors. These political connections embodied in state-owned polluting enterprises could potentially facilitate their influence over local government officials including local EPBs. Hence, when the county has a higher ratio of state-owned polluting enterprises, local EPBs could be more influenced in their environmental enforcement. Empirically, we divide the sample into two groups based on whether the ratio of state-owned polluting enterprises is



Panel A: Counties with less state-owned polluting enterprises

Panel B: Counties with more state-owned polluting enterprises

Fig. 9. The EVM reform and local capture of county EPBs: Heterogeneity analyses by ownership of polluting enterprises in the county.
Notes: This figure plots the estimated coefficients of the series of β_τ and their 95% confidence intervals for each 14-day time cell within the event window, as specified in Eq. (1). We divide the sample by comparing the ratio of state-owned polluting enterprises to the total number of polluting enterprises in the county with the sample mean. Panel A shows the results for counties with less state-owned polluting enterprises. Panel B presents the results for counties with more state-owned polluting enterprises. The dependent variable is the logarithm of the AQI. The vertical line denotes the commencement of the EVM reform. The omitted variable is one 14-day cell prior to the introduction of the EVM reform. Standard errors are clustered at the event level.



Panel A: Counties with less polluting enterprises affiliated with the provincial or national administrative divisions

Panel B: Counties with more polluting enterprises affiliated with the provincial or national administrative divisions

Fig. 10. The EVM reform and local capture of county EPBs: Heterogeneity analyses by affiliations of polluting enterprises in the county.
Notes: This figure plots the estimated coefficients of the series of β_τ and their 95% confidence intervals for each 14-day time cell within the event window, as specified in Eq. (1). We divide the sample by comparing the ratio of state-owned polluting enterprises to the total number of polluting enterprises in the county with the sample mean. Panel A shows the results for counties with less state-owned polluting enterprises. Panel B presents the results for counties with more state-owned polluting enterprises. The dependent variable is the logarithm of the AQI. The vertical line denotes the commencement of the EVM reform. The omitted variable is one 14-day cell prior to the introduction of the EVM reform. Standard errors are clustered at the event level.

higher than the sample mean (i.e., 7.3%). Fig. 9 presents the estimation results. As shown in panel B, for counties with a higher proportion of state-owned polluting enterprises, implementing the EVM reform has a larger impact on local air quality compared to counties with a lower ratio of politically connected polluting enterprises shown in panel A. These findings are consistent with the argument that the reform, by reducing local capture, motivates local EPBs to strictly enforce environmental regulations.

The sixth measure explores the affiliation of polluting enterprises in counties. When polluting enterprises are affiliated with provincial or national administrative divisions, they can establish interest connections with the respective provincial/central governments and the corresponding EPBs, which are unlikely to be affected by our focal EVM reform carried out at the county level. To this end, we calculate the ratio of polluting enterprises affiliated with provincial or national administrative divisions to the total number of polluting enterprises in the county. A higher ratio indicates lower local capture and smaller effects of the EVM

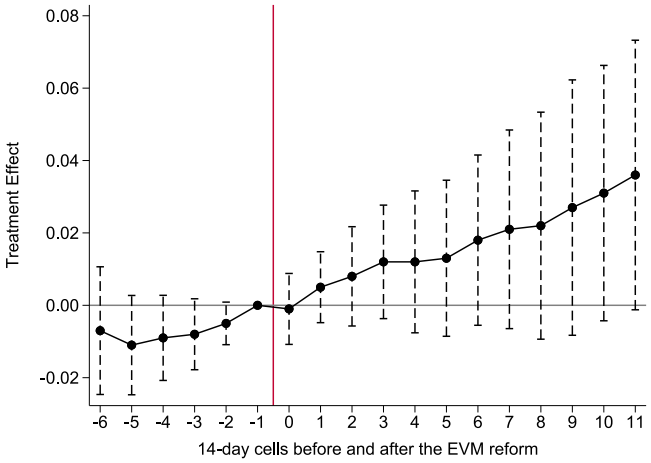


Fig. 11. The EVM reform and county EPBs' environmental administrative penalties.
Notes: This figure plots the estimated coefficients of the series of β_τ and their 95% confidence intervals for each 14-day time cell within the event window, as specified in Eq. (2). The dependent variable is the indicator of whether the county EPBs impose any environmental administrative penalty. The vertical line denotes the commencement of the EVM reform. The omitted variable is one 14-day cell prior to the introduction of the EVM reform. Standard errors are clustered at the event level.

reform. We divide the sample into two groups based on the sample mean value (i.e., 12.2%) and present the results in Fig. 10. As shown in panel B, the EVM reform exerts a limited impact on local air pollution in counties with a large percentage of polluting enterprises affiliated with provincial or national administrative divisions. However, as illustrated in panel A, it significantly improves local air quality in counties with a smaller share of high-level affiliated polluting enterprises. These results are consistent with the fact that the reform is conducted at the county level, which could only reduce the potential capture at the county level but not at the higher administrative level.

In sum, the analyses presented in this subsection establish that the EVM reform exerts a larger negative impact on air pollution for counties where county EPBs are more likely to be captured by local governments. These findings confirm the key policy goal of the reform; that is, to reduce the influence by local governments in the work of local EPBs, which significantly distort the efforts and outcomes of environmental protection.

5.2. Efforts by local EPBs

The previous analyses demonstrate that the EVM reform significantly reduces the capture of county EPBs by local government officials. Additionally, this reform aligns the interests of county EPBs with their upper-level administrators in terms of environmental regulations, given that the latter are now empowered with rewards and punishments for the former by the EVM reform. To further understand how the EVM reform improves air quality, we examine the increased efforts of county EPBs resulting from the reform.

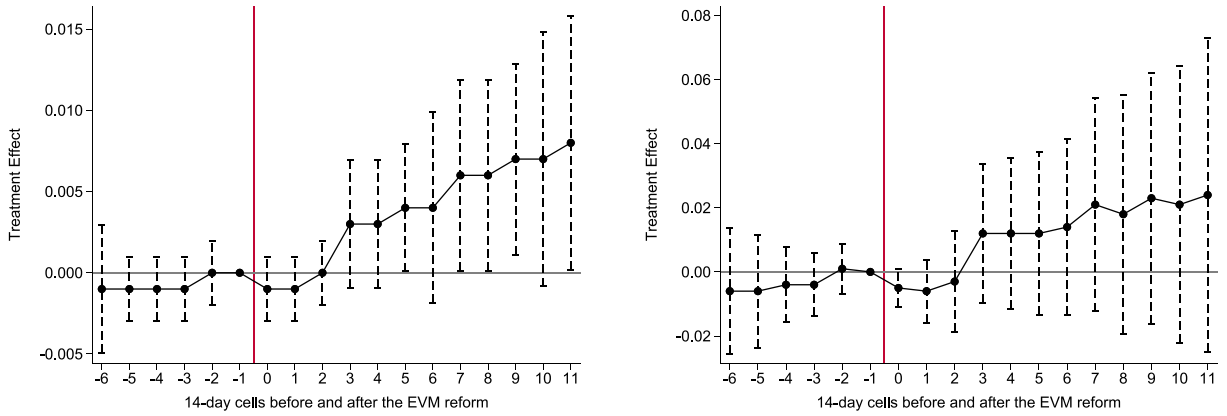
To capture the unobserved efforts, we apply the principle of revealed preferences; that is, the realized actions reflect the underlying decisions. Specifically, we investigate whether local EPBs increase the intensity of environmental penalties following the implementation of the EVM reform. Blundell (2020) shows that imposing penalties for violations of environmental law is an essential tool for environmental governance, which significantly reduces firms' emissions and improves overall environmental quality.[34] To this end, we manually compile data on environmental administrative penalties from various environmental administrative cases collected by the PKU Law database, as described in Section 3. Since the dependent variable varies across counties rather than monitoring stations, we conduct a DD estimation at the county level, using the following specification:

$$Y_{sct} = \sum_{\tau=-6,\tau\neq-1}^{12} \beta_\tau Treat_{sc} \times I_{st}^{\tau} + \delta_{sc} + \rho_{st} + \gamma W_{sct} + \epsilon_{sct} \tag{2}$$

where s, c, and t denote the EVM reform event, county, and relative day, respectively. Y_{sct} is a binary variable indicating whether the EPB of county c imposes any environmental administrative penalty on the relative day t in the EVM reform event s. δ_{sc} is a set of event×county fixed effects. All other variables are defined as in Eq. (1).

Fig. 11 plots the estimated coefficients of a series of β_τ and their 95% confidence intervals for each 14-day time unit based on Eq. (2), with the complete estimation results reported in Online Appendix Table A9. After the introduction of the EVM reform,

[34] The environmental penalty has also been a powerful tool for environmental governance in China. For example, according to the Ministry of Ecology and Environmental Environment of China, in the period from January to June 2019, a total of 63,744 penalty decisions were issued nationwide, with a cumulative fine amount of 4.633 billion RMB, resulting in an average fine of 72,700 Yuan per case. See https://www.mee.gov.cn/xxgk2018/xxgk/xxgk15/201908/t20190823_729906.html.



Panel A: The number of environment-related county government procurement contracts

Panel B: The sum of environment-related county government procurement expenditures

Fig. 12. The EVM reform and county governments' procurement on environmental goods and services.
Notes: This figure plots the estimated coefficients of the series of β_τ and their 95% confidence intervals for each 14-day time cell within the event window, as specified in Eq. (2). In Panel A, the dependent variable is the IHS transformation of the number of environment-related county government procurement contracts. In Panel B, the dependent variable is the IHS transformation of the sum of environment-related county government procurement expenditures. The vertical line denotes the commencement of the EVM reform. The omitted variable is one 14-day cell prior to the introduction of the EVM reform. Standard errors are clustered at the event level.

county EPBs increase the probability of imposing environmental administrative penalties. Specifically, twenty-four weeks after the reform, the likelihood of environmental administrative penalty increases by 3.6 percentage points.

In sum, we provide evidence of increased efforts by county EPBs after the EVM reform by using environmental administrative penalties. This finding helps explain the significant reduction in air pollution resulting from the reform.

5.3. Responses by local governments

Despite the reduced control over local EPBs resulting from the EVM reform, local governments continue to play a significant role in influencing environmental protection. For example, the allocation of financial resources directed by the government can impact the production structure and, consequently, pollution emissions. Therefore, it is interesting to examine whether the EVM reform strengthens the attitude towards environmental protection by local governments. Such an understanding can further illustrate whether the reform's effect on air quality is persistent, considering the important role of the Chinese government in the economy.

To capture the responses of local governments, we examine their fiscal inputs in environmental protection. Specifically, we analyze government procurement of environmental products and services using the data discussed in Section 3. The expenditure structure of government procurement reflects the allocation of government financial resources and the priorities set by governments. An increase in government procurement of environmental products and services indicates that local governments place greater emphasis on environmental protection.

Since all the information is available at the county level, we employ the DD specification as shown in Eq. (2), with the outcome variable being the number of environment-related procurement contracts and the sum of procurement expenditures. Due to the presence of many zero values in the number of government procurement contracts of environmental products and services, we apply the Inverse Hyperbolic Sine (IHS) transformation to these two variables.[35]

We focus on the graphical presentation of the estimation results in Fig. 12, with the full set of results reported in the Online Appendix Table A10. After the EVM reform, county governments in the treatment group increase the number and total amount of procuring environmental products and services, in comparison to the control group.[36] These findings suggest that county governments respond to the EVM reform by augmenting fiscal inputs for environmental protection. The shift in the behavior of local governments towards environmental regulation may not only explain the improvement in air quality as depicted in Fig. 4, but also suggest the sustainable changes in local environmental protection, given the substantial importance of government in China.

[35] The IHS transformation has similar attributes as the natural logarithm but accommodates zero-valued observations.

[36] In Online Appendix Figure A13 and Table A10, we use an alternative outcome variable, whether the county governments make any environment-related procurement and find similar results.

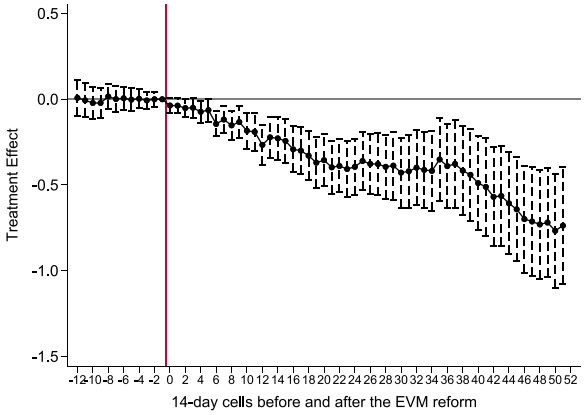


Fig. 13. Persistent effects of the EVM reform on air pollution.
Notes: This figure presents results by extending the event window and exploring the persistent effects of the EVM reform. We extend the analysis window to encompass 24 weeks pre-reform and 104 weeks (about 2 years) post-reform, supplementing with AQI data for 2020 and 2021. This figure plots the estimated coefficients of the series of β_τ and their 95% confidence intervals for each 14-day time cell within the event window. The estimation is based on the following equation:

$$Y_{skct} = \sum_{\tau=-12,\tau\neq-1}^{51} \beta_\tau Treat_{sc} \times I_{st}^{\tau} + \delta_{sk} + \rho_{st} + \gamma W_{sct} + \epsilon_{skct}$$

where k and c represent the station and county, respectively. We denote s as the identifier for each reform event. We define t as the relative day, which is the difference between the monitoring day and the day that event s occurred. We denote τ as the number of 14-day cells relative to the outset of the verticalization event. Y_{skct} is the logarithm of the AQI at station k in county c on relative day t in event s. Other variables are defined as in Eq. (1), with the addition of the number of city-level new COVID-19 deaths as a control for the pandemic's potential effects. The vertical line denotes the commencement of the EVM reform. The omitted variable is one 14-day cell prior to the introduction of the EVM reform. Standard errors are clustered at the event level.

5.4. Persistent effects

Our aforementioned analyses focus on the period from 2018 to 2019 mainly due to the outbreak of the COVID-19 shock in early 2020. The documented short-run effects of the EVM reform then raise concerns that whether the effects come from the newly appointed officials making big changes or the sustainable regulative actions aligning the interests under hierarchical governance.

To distinguish these two potential mechanisms, we extend the analysis window to encompass 24 weeks pre-reform and 104 weeks (about 2 years) post-reform, supplementing with AQI data for 2020 and 2021. To account for the potential impact of COVID-19, we include an additional control variable regarding the number of new COVID-19 deaths at the city level.[37] Specifically, the daily COVID-19 fatalities by city are sourced from the China Stock Market and Accounting Research (CSMAR) database, which compiles daily statistics on deaths, confirmed cases, and recoveries from both national and local Centers for Disease Control and Prevention (CDC) reports.[38]

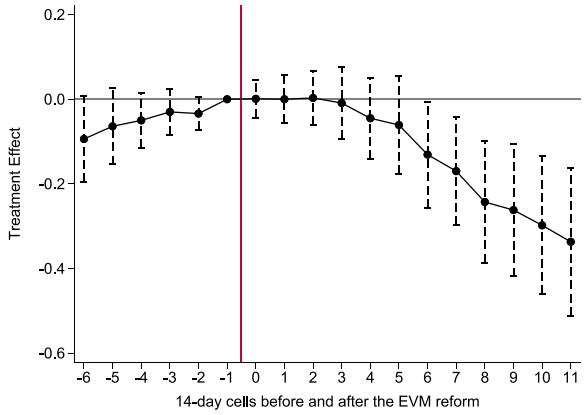
Fig. 13 shows the corresponding results. Even 2 years following the implementation of the EVM reform, the treated counties continue to exhibit a significant decrease in AQI compared to the control counties. The sustained effect suggests that the EVM reform likely establishes a long-standing mechanism that aligns the interests among different players within the hierarchical governance system.

Taken together, our mechanism analyses suggest that the EVM reform effectively eliminates a significant obstacle to local environmental enforcement, namely, the capture of EPBs by local interest groups. Consequently, county EPBs devote to enforcing environmental regulations, which is reflected by the increased likelihood of imposing environmental administrative penalties. Additionally, with the loss of direct influence over environmental regulators, local governments change their behavior towards environmental protection by allocating financial resources to environmental products and services. These results suggest that concrete actions, induced by the reshaped conflicts of interest, can contribute to sustainable air quality improvement.

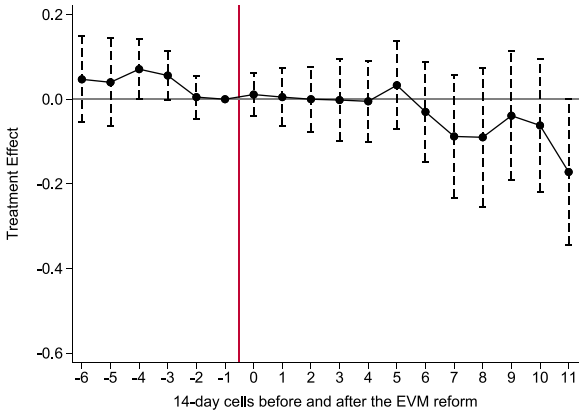
6. Cost analysis

Reform comes at costs. Exploring treatment heterogeneity across counties, we investigate two types of costs associated with the EVM reform. That is, the management burdens and information loss experienced by the prefectural EPBs.

[37] Due to the unavailability of COVID-19 data at the county level, we rely on city-level data instead.
[38] As an alternative, we experiment with the number of newly confirmed cases at the city level, which yields similar results (available upon request).

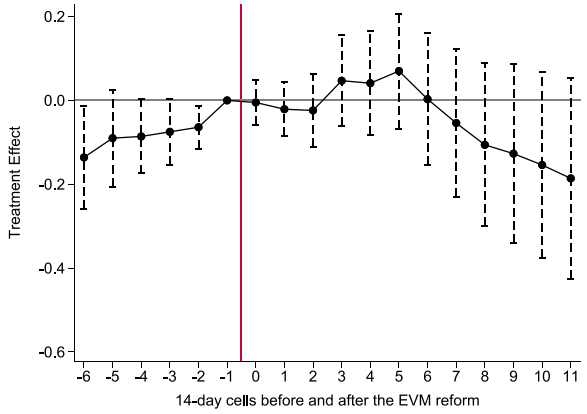


Panel A: Shorter distance between county governments and prefecture governments

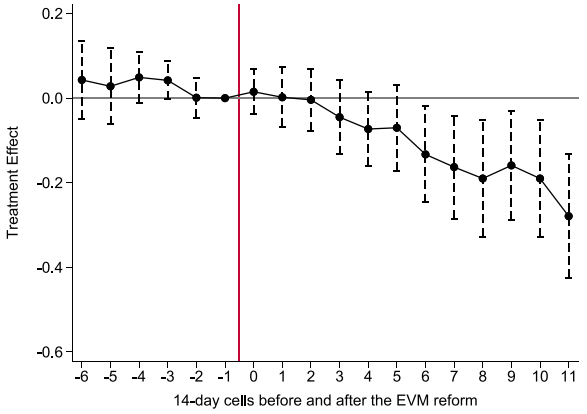


Panel B: Longer distance between county governments and prefecture governments

Fig. 14. Effectiveness of the EVM reform and *"Tiao"*'s management cost: Heterogeneity analyses by spherical distances between county and prefecture governments.
Notes: This figure plots the estimated coefficients of the series of β_τ and their 95% confidence intervals for each 14-day time cell within the event window, as specified in Eq. (1). We divide the sample by comparing the spherical distances between the county government and prefecture government with the sample median. Panel A shows the results for counties whose governments are in closer proximity to the prefecture governments. Panel B displays the results for counties whose governments are more distant from the prefecture governments. The dependent variable is the logarithm of the AQI. The vertical line denotes the commencement of the EVM reform. The omitted variable is one 14-day cell prior to the introduction of the EVM reform. Standard errors are clustered at the event level.



Panel A: Lower ratio of internet users to total population



Panel B: Higher ratio of internet users to total population

Fig. 15. Effectiveness of the EVM reform and information loss in centralization process: Heterogeneity analyses by ratio of internet broadband users to total population.
Notes: This figure plots the estimated coefficients of the series of β_τ and their 95% confidence intervals for each 14-day time cell within the event window, as specified in Eq. (1). We divide the sample by comparing the prefectures' ratio of fixed broadband internet users to the total population with the sample median. Panel A shows the results for counties with a lower ratio of fixed broadband internet users to the total population. Panel B displays the results for counties with a higher ratio. The dependent variable is the logarithm of the AQI. The vertical line denotes the commencement of the EVM reform. The omitted variable is one 14-day cell prior to the introduction of the EVM reform. Standard errors are clustered at the event level.

6.1. Management cost of the reform

The EVM reform, while improving local air quality by granting independence to county EPBs, may impose significant management burdens on prefectural EPBs. With county EPBs becoming their sub-bureaus, prefectural EPBs experience increases in the span of controls, which has been associated with loose monitoring in hierarchical organizations (Qian, 1994). The efficiency

of communication and information transmission between upper and lower government bodies tends to decrease with greater distances (Huang et al., 2017), which poses a significant governance challenge in countries with vast territories like China. If prefectural EPBs fail to effectively administer county EPBs, the overall effectiveness of the EVM reform could be compromised.

To examine this argument, we use the spherical distances between county and prefecture governments to capture the cost of managing county EPBs by prefectural EPBs. The geographic distance decides the travel cost of onsite inspections. A shorter distance between cities and counties facilitates easier information gathering and supervision for prefectural EPBs. We divide the sample into two groups based on the sample median value of the spherical distances between prefectural and county governments (i.e., 4.9 km). The graphical presentations of the estimation results are shown in Fig. 14, with the full set of results presented in the Online Appendix Table A11.

We find that when the prefecture governments are closer to the county governments, the EVM reform exerts a larger negative impact on air pollution, compared to the cases where the distance is greater. In Online Appendix Figure A14, we utilize an alternative measure of the distance between prefecture and county governments; that is, the driving distance by car.[39] Similar patterns are uncovered. These results confirm that management costs influence the effectiveness of the EVM reform. When faced with an overload of management burden, prefectural EPBs may not effectively communicate with and monitor the works of county EPBs, especially those located far away.

6.2. *Information loss of the reform*

The EVM reform is characterized by centralizing the county EPBs up to the prefectural EPBs, which can strengthen top-down control. However, this centralization comes at the cost of losing the local information advantage. Specifically, prefectural EPBs may not possess the local knowledge and information that local governments have, enabling them to select the optimal policies and achieve better performance in public affairs (Duflo et al., 2018; Balan et al., 2022). Due to the loss of local information, the pollution control effect of the EVM reform may be attenuated.

To compensate for the information loss resulting from centralization, one viable approach is to introduce information technology, as the literature has documented that information technology can strengthen the central party's capacity to gather information and reduce the asymmetry of information in central-local relationships (Zhang et al., 2018; Dal Bó et al., 2021). If the prefectural EPBs have a higher level of informatization, the EVM reform is more likely to have a substantial negative effect on local air pollution.

In order to examine this hypothesis, we utilize the ratio of fixed broadband internet users to the total population for each prefecture as a measure of the informatization level of the prefectural EPBs.[40] The internet plays a crucial role in facilitating the development and dissemination of new information technology in environmental governance. A higher rate of internet availability can facilitate faster information exchange among different levels of government departments and mitigate the information loss resulting from the centralization brought about by the EVM reform. The sample is divided into two groups based on the sample median of the ratio of fixed broadband internet users to the total population in 2017 (i.e., 24.5%). The estimation results are graphically presented in Fig. 15, with the complete set of results reported in the Online Appendix Table A12.

As illustrated in Fig. 15, when the prefecture has a higher rate of internet availability, the EVM reform exerts a larger negative impact on air pollution compared to when the prefecture has a lower rate of internet coverage. In the Online Appendix, we consider an alternative measure of informatization level, namely the ratio of mobile phone users to the total population. A higher rate of mobile phone penetration enables the public to provide local information to higher-level governments more easily. Figure A15 in the Online Appendix exhibits similar policy impacts.[41] These results suggest that the loss of local informational advantages resulting from the centralization process can diminish the effectiveness of the EVM reform, whereas the application of information technology can help alleviate this information loss, thereby enhancing the potential of this reform.

In sum, to better realize the potential of the reform, policymakers need to direct their attention not only to the responses of county EPBs but also to ensuring that prefectural EPBs are adequately equipped to handle the increased management burden. Furthermore, the implementation of informatization can compensate for the loss of local informational advantages resulting from the centralized reform, thereby making the pollution control effect of the EVM reform more prominent.

7. Conclusions

During the past few decades, developing countries have faced widespread environmental regulatory enforcement gaps resulting from conflicts of interest (Burgess et al., 2012; Duflo et al., 2013; Oliva, 2015). China has long been grappling with this issue within its "fragmented" environmental management system, where local environmental agencies are influenced by local governments, compromising their oversight responsibilities.

[39] We obtain the data for driving distance by car from Baidu Map. Furthermore, we divide the sample into two groups based on the sample median value of the driving distance by car (i.e., 6.9 km) and conduct heterogeneous analyses. The relevant estimation results are also presented in the Online Appendix Table A11.

[40] Data are obtained from the China City Statistical Yearbook 2017 and prefecture's Annual Statistical Communique on National Economic and Social Development.

[41] We divide the sample into two groups based on the sample mean value of the ratio of mobile phone users to the total population in 2017 (i.e., 107.6%) and conduct heterogeneous analyses. The regression results are presented in the Online Appendix Table A12.

This paper explores how the enforcement problem in environmental regulations can be addressed through changes in institutional arrangements. Specifically, it examines the pollution control effect of the EVM reform, which centralizes decision-making authority over personnel and budget of county EPBs to prefectural EPBs. By analyzing the phased implementation of county EPBs becoming branches of and governed by prefectural EPBs, the study demonstrates that the EVM reform significantly improves local air quality. Twenty-four weeks after the EVM reform, the AQI in the treated counties significantly decreases by 25.1% compared to the control group.

To understand the underlying mechanism, the study investigates how the EVM reform reshapes the incentives of local EPBs and the actions they take to reduce air pollution. By isolating environmental management authority from local interests, the EVM reform reduces the likelihood of county EPBs being locally captured. The findings show that the EVM reform has a more pronounced negative impact on air pollution in counties with a higher likelihood of local capture than their counterparts with a lower likelihood of local capture. Moreover, as this reform empowers prefectural EPBs with rewards and punishments for county EPBs, the latter prioritize achieving environmental targets set by their upper-level administrators over local interests when conflicts arise. Consequently, after the EVM reform, county EPBs intensify the imposition of environmental administrative penalties. Additionally, with the loss of direct influence over environmental regulators, county governments demonstrate a strengthened commitment to environmental protection by allocating more financial resources to procuring products and services on environmental protection.

However, the EVM reform also comes with costs. Heterogeneity tests reveal that the increased management burden and loss of local information advantages induced by the reform may compromise its effectiveness in pollution control. Therefore, when promoting this reform, the central government should not only focus on whether grassroots agencies face an independent and impartial regulatory environment but also consider whether upper-level administrators possess sufficient capacity and resources to address the new management challenges.

Managing conflicts of interest in the public and private sectors has become a prominent governance issue globally (OECD, 2004; Chan and Dickstein, 2019). The analysis underscores the crucial policy insight that distributing management authority to different administrative levels through a vertical management system can help separate regulatory power from local interests, thereby overcoming governance challenges caused by conflicting interests and strengthening the enforcement of central policies at the local level.

CRediT authorship contribution statement

Pei Li: Methodology, Formal analysis, Data curation, Conceptualization. **Kaihao Liu:** Validation, Investigation, Data curation. **Yi Lu:** Writing – review & editing, Writing – original draft, Project administration, Conceptualization. **Lu Peng:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.jce.2024.12.001.

References

Assunção, Juliano, Gandour, Clarissa, Rocha, Romero, 2023. DETERring deforestation in the amazon: Environmental monitoring and law enforcement. Am. Econ. J.: Appl. Econ. 15 (2), 125–156.

Baker, Andrew C., Larcker, David F., Wang, Charles C.Y., 2022. How much should we trust staggered difference-in-differences estimates? J. Financ. Econ. 144 (2), 370–395.

Balan, Pablo, Bergeron, Augustin, Tourek, Gabriel, Weigel, Jonathan L, 2022. Local elites as state capacity: How city chiefs use local information to increase tax compliance in the Democratic Republic of the Congo. Amer. Econ. Rev. 112 (3), 762–797.

Barreca, Alan I., Neidell, Matthew, Sanders, Nicholas J., 2021. Long-run pollution exposure and mortality: Evidence from the acid rain program. J. Pub. Econ. 200.

Barwick, Panle Jia, Li, Shanjun, Lin, Liguo, Zou, Eric Yongchen, 2024. From fog to smog: The value of pollution information. Am. Econ. Rev. 114 (5), 1338–1381.

Blundell, Wesley, 2020. When threats become credible: A natural experiment of environmental enforcement from Florida. J. Environ. Econ. Manag. 101.

Borusyak, Kirill, Jaravel, Xavier, Spiess, Jann, 2024. Revisiting event-study designs: robust and efficient estimation. Rev. Econ. Stud. rdae007.

Buchard, V, Randles, CA, Da Silva, AM, Darmenov, A, Colarco, PR, Govindaraju, R, Ferrare, R, Hair, J, Beyersdorf, AJ, Ziemba, LD, et al., 2017. The MERRA-2 aerosol reanalysis, 1980 onward. Part II: Evaluation and case studies. J. Clim. 30 (17), 6851–6872.

Burgess, Robin, Hansen, Matthew, Olken, Benjamin A, Potapov, Peter, Sieber, Stefanie, 2012. The political economy of deforestation in the tropics. Q. J. Econ. 127 (4), 1707–1754.

Callaway, Brantly, Sant'Anna, Pedro H.C., 2021. Difference-in-differences with multiple time periods. J. Econometrics 225 (2), 200–230.

Cameron, A. Colin, Gelbach, Jonah B., Miller, Douglas L., 2011. Robust inference with multiway clustering. J. Bus. Econom. Statist. 29 (2), 238–249.

Cao, Xun, Wu, Mingqin, 2024. Can centralization of environmental regulations reduce firm emissions? Evidence from county-prefecture centralization reforms in China. J. Policy Anal. Manag..
Cengiz, Doruk, Dube, Arindrajit, Lindner, Attila, Zipperer, Ben, 2019. The effect of minimum wages on low-wage jobs. Q. J. Econ. 134 (3), 1405–1454.
Chan, David C., Dickstein, Michael J., 2019. Industry input in policy making: Evidence from medicare. Q. J. Econ. 134 (3), 1299–1342.
Chay, Kenneth Y., Greenstone, Michael, 2003. The impact of air pollution on infant mortality: Evidence from geographic variation in pollution shocks induced by a recession. Q. J. Econ. 118 (3), 1121–1167.
Chen, Shuai, Oliva, Paulina, Zhang, Peng, 2022. The effect of air pollution on migration: Evidence from China. J. Dev. Econ. 156, 102833.
Chen, Jidong, Shi, Xinzheng, Zhang, Ming-ang, Zhang, Sihan, 2024. Centralization of environmental administration and air pollution: Evidence from China. J. Environ. Econ. Manag. 103016.
Chen, Kai, Wang, Meng, Huang, Conghong, Kinney, Patrick L, Anastas, Paul T, 2020. Air pollution reduction and mortality benefit during the COVID-19 outbreak in China. Lancet Planet. Health 4 (6), e210–e212.
Chu, Jian, Fisman, Raymond, Tan, Songtao, Wang, Yongxiang, 2021. Hometown ties and the quality of government monitoring: Evidence from rotation of Chinese auditors. Am. Econ. J.: Appl. Econ. 13 (3), 176–201.
Currie, Janet, Voorheis, John, Walker, Reed, 2023. What caused racial disparities in particulate exposure to fall? New evidence from the clean air act and satellite-based measures of air quality. Amer. Econ. Rev. 113 (1), 71–97.
Dal Bó, Ernesto, Finan, Frederico, Li, Nicholas Y., Schechter, Laura, 2021. Information technology and government decentralization: Experimental evidence from Paraguay. Econometrica 89 (2), 677–701.
De Chaisemartin, Clément, d'Haultfoeuille, Xavier, 2020. Two-way fixed effects estimators with heterogeneous treatment effects. Amer. Econ. Rev. 110 (9), 2964–2996.
Deshpande, Manasi, Li, Yue, 2019. Who is screened out? Application costs and the targeting of disability programs. Am. Econ. J.: Econ. Policy 11 (4), 213–248.
Duflo, Esther, Greenstone, Michael, Pande, Rohini, Ryan, Nicholas, 2013. Truth-telling by third-party auditors and the response of polluting firms: Experimental evidence from India. Q. J. Econ. 128 (4), 1499–1545.
Duflo, Esther, Greenstone, Michael, Pande, Rohini, Ryan, Nicholas, 2018. The value of regulatory discretion: Estimates from environmental inspections in India. Econometrica 86 (6), 2123–2160.
Ebenstein, Avraham, Fan, Maoyong, Greenstone, Michael, He, Guojun, Zhou, Maigeng, 2017. New evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai river policy. Proc. Natl. Acad. Sci. 114 (39), 10384–10389.
Emekwuru, Nwabueze, Ejohwomu, Obuks, 2023. Temperature, humidity and air pollution relationships during a period of rainy and dry seasons in Lagos, West Africa. Climate 11 (5), 113.
Faccio, Mara, 2006. Politically connected firms. Amer. Econ. Rev. 96 (1), 369–386.
Fadlon, Itzik, Nielsen, Torben Heien, 2019. Family health behaviors. Amer. Econ. Rev. 109 (9), 3162–3191.
Ferguson, Thomas, Voth, Hans-Joachim, 2008. Betting on hitler–the value of political connections in Nazi Germany. Q. J. Econ. 123 (1), 101–137.
Fisman, Raymond, 2001. Estimating the value of political connections. Amer. Econ. Rev. 91 (4), 1095–1102.
Fredriksson, Per G., Svensson, Jakob, 2003. Political instability, corruption and policy formation: the case of environmental policy. J. Pub. Econ. 87 (7–8), 1383–1405.
Ghanem, Dalia, Zhang, Junjie, 2014. 'Effortless perfection:' do Chinese cities manipulate air pollution data? J. Environ. Econ. Manag. 68 (2), 203–225.
Goodman-Bacon, Andrew, 2021. Difference-in-differences with variation in treatment timing. J. Econometrics 225 (2), 254–277.
Graff Zivin, Joshua, Neidell, Matthew, 2012. The impact of pollution on worker productivity. Amer. Econ. Rev. 102 (7), 3652–3673.
Greenstone, Michael, Hanna, Rema, 2014. Environmental regulations, air and water pollution, and infant mortality in India. Amer. Econ. Rev. 104 (10), 3038–3072.
Greenstone, Michael, He, Guojun, Jia, Ruixue, Liu, Tong, 2022. Can technology solve the principal-agent problem? Evidence from China's war on air pollution. Am. Econ. Rev.: Insights 4 (1), 54–70.
Greenstone, Michael, He, Guojun, Li, Shanjun, Zou, Eric Yongchen, 2021. China's war on pollution: Evidence from the first 5 years. Rev. Environ. Econ. Policy 15 (2), 281–299.
Greenstone, Michael, Jack, B. Kelsey, 2015. Envirodevonomics: A research agenda for an emerging field. J. Econ. Lit. 53 (1), 5–42.
Gu, Yizhen, Jiang, Chang, Zhang, Junfu, Zou, Ben, 2021. Subways and road congestion. Am. Econ. J.: Appl. Econom. 13 (2), 83–115.
He, Guojun, Liu, Tong, Zhou, Maigeng, 2020a. Straw burning, PM2. 5, and death: Evidence from China. J. Dev. Econ. 145, 102468.
He, Guojun, Pan, Yuhang, Tanaka, Takanao, 2020b. The short-term impacts of COVID-19 lockdown on urban air pollution in China. Nat. Sustain. 3 (12), 1005–1011.
He, Guojun, Wang, Shaoda, Zhang, Bing, 2020c. Watering down environmental regulation in China. Q. J. Econ. 135 (4), 2135–2185.
Huang, Zhangkai, Li, Lixing, Ma, Guangrong, Xu, Lixin Colin, 2017. Hayek, local information, and commanding heights: Decentralizing state-owned enterprises in China. Amer. Econ. Rev. 107 (8), 2455–2478.
Jia, Ruixue, Nie, Huihua, 2017. Decentralization, collusion, and coal mine deaths. Rev. Econ. Stat. 99 (1), 105–118.
Jones, Alan M., Harrison, Roy M., Baker, Jacob, 2010. The wind speed dependence of the concentrations of airborne particulate matter and NOx. Atmos. Environ. 44 (13), 1682–1690.
Kahn, Matthew E., Li, Pei, Zhao, Daxuan, 2015. Water pollution progress at borders: The role of changes in China's political promotion incentives. Am. Econ. J.: Econ. Policy 7 (4), 223–242.
Kalisa, Egide, Fadlallah, Sulaiman, Amani, Mabano, Nahayo, Lamek, Habiyaremye, Gabriel, 2018. Temperature and air pollution relationship during heatwaves in Birmingham, UK. Sustainable Cities Soc. 43, 111–120.
Kofman, Fred, Lawarrée, Jacques, 1993. Collusion in Hierarchical Agency. Econometrica 629–656.
Kong, Dongmin, Liu, Chenhao, 2024. Centralization and regulatory enforcement: Evidence from personnel authority reform in China. J. Pub. Econ. 229, 105030.
Kostka, Genia, 2014. Barriers to the Implementation of Environmental Policies at the Local Level in China. World Bank Policy Research Working Paper.
Kostka, Genia, Hobbs, William, 2012. Local energy efficiency policy implementation in China: Bridging the gap between national priorities and local interests. China Q. 211, 765–785.
Laffont, Jean-Jacques, Tirole, Jean, 1991. The politics of government decision-making: A theory of regulatory capture. Q. J. Econ. 106 (4), 1089–1127.
Li, Pei, Lu, Yi, Wang, Jin, 2020. The effects of fuel standards on air pollution: Evidence from China. J. Dev. Econ. 146.
Li, Hongbin, Zhou, Li-An, 2005. Political turnover and economic performance: the incentive role of personnel control in China. J. Pub. Econ. 89 (9–10), 1743–1762.
Liao, Yanjun, Kousky, Carolyn, 2022. The fiscal impacts of wildfires on California municipalities. J. Assoc. Environ. Resource Econ. 9 (3), 455–493.
Lipscomb, Molly, Mobarak, Ahmed Mushfiq, 2016. Decentralization and pollution spillovers: Evidence from the re-drawing of county borders in Brazil. Rev. Econ. Stud. 84 (1), 464–502.
Ma, Xiaoying, Ortolano, Leonard, 2000. Environmental Regulation in China: Institutions, Enforcement, and Compliance. Rowman & Littlefield Publishers.
Marcus, Michelle, Sant'Anna, Pedro H.C., 2021. The role of parallel trends in event study settings: An application to environmental economics. J. Assoc. Environ. Resource Econom. 8 (2), 235–275.
Margaryan, Shushanik, 2021. Low emission zones and population health. J. Health Econ. 76.
Mookherjee, Dilip, Tsumagari, Masatoshi, 2004. The organization of supplier networks: Effects of delegation and intermediation. Econometrica 72 (4), 1179–1219.
Oates, Wallace E., 1999. An essay on fiscal federalism. J. Econ. Lit. 37 (3), 1120–1149.

Oates, Wallace E., Portney, Paul R., 2003. The political economy of environmental policy. In: Handbook of Environmental Economics, vol. 1. Elsevier, pp. 325–354.
OECD, 2004. Managing Conflict of Interest in the Public Service: OECD Guidelines and Country Experiences. OECD, Paris.
Oliva, Paulina, 2015. Environmental regulations and corruption: Automobile emissions in Mexico City. J. Polit. Econ. 123 (3), 686–724.
Olken, Benjamin A., 2007. Monitoring corruption: Evidence from a field experiment in Indonesia. J. Polit. Econ. 115 (2), 200–249.
Olken, Benjamin A., Pande, Rohini, 2012. Corruption in developing countries. Annu. Rev. Econ. 4 (1), 479–509.
Persson, Petra, Zhuravskaya, Ekaterina, 2016. The limits of career concerns in federalism: Evidence from China. J. Eur. Econom. Assoc. 14 (2), 338–374.
Qian, Yingyi, 1994. Incentives and loss of control in an optimal hierarchy. Rev. Econ. Stud. 61 (3), 527–544.
Sigman, Hilary, 2005. Transboundary spillovers and decentralization of environmental policies. J. Environ. Econ. Manag. 50 (1), 82–101.
Stovel, Katherine, Savage, Mike, 2006. Mergers and mobility: Organizational growth and the origins of career migration at Lloyds Bank. Am. J. Sociol. 111 (4), 1080–1121.
Sun, Liyang, Abraham, Sarah, 2021. Estimating dynamic treatment effects in event studies with heterogeneous treatment effects. J. Econometrics 225 (2), 175–199.
Tirole, Jean, 1986. Hierarchies and bureaucracies: On the role of collusion in organizations. J. Law Econ. Organ. 2, 181.
UN, 2019. Environmental Rule of Law: First Global Report. UNEP, Nairobi.
Van Rooij, Benjamin, 2006. Regulating Land and Pollution in China: Lawmaking, Compliance, and Enforcement: Theory and Cases. Amsterdam University Press.
Venter, Zander S, Aunan, Kristin, Chowdhury, Sourangsu, Lelieveld, Jos, 2020. COVID-19 lockdowns cause global air pollution declines. Proc. Natl. Acad. Sci. 117 (32), 18984–18990.
Wang, Chunchao, Lin, Qianqian, Qiu, Yun, 2022. Productivity loss amid invisible pollution. J. Environ. Econ. Manag. 112, 102638.
Yang, Lin, Lin, Yatang, Wang, Jin, Peng, Fangyuan, 2024. Achieving air pollution control targets with technology-aided monitoring: Better enforcement or localized E orts? Am. Econ. J.: Econ. Policy.
Zeng, Shenglan, Zhang, Yu, 2017. The effect of meteorological elements on continuing heavy air pollution: A case study in the chengdu area during the 2014 spring festival. Atmosphere 8 (4), 71.
Zhang, Yongli, 2019. Dynamic effect analysis of meteorological conditions on air pollution: A case study from Beijing. Sci. Total Environ. 684, 178–185.
Zhang, Bo, Cao, Cong, 2015. Policy: Four gaps in China's new environmental law. Nature 517 (7535), 433–434.
Zhang, Bing, Chen, Xiaolan, Guo, Huanxiu, 2018. Does central supervision enhance local environmental enforcement? Quasi-experimental evidence from China. J. Public Econ. 164, 70–90.
Zou, Eric Yongchen, 2021. Unwatched pollution: The effect of intermittent monitoring on air quality. Amer. Econ. Rev. 111 (7), 2101–2126.