The Role of Career Incentives in Environmental Regulation: Evidence from China's Environmental One-Vote Veto Evaluation Regime

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Abstract

This paper applies a difference-in-differences approach to examine the effectiveness of China's *One-Vote Veto* environmental regulation regime, which links pollution reduction targets with local officials' promotion. Using a rich set of data for 286 Chinese cities, we show that the new political incentive induced significant tradeoff between economic growth and environmental protection. The regime shifts significantly reduced industrial SO_2 emissions; however, the environmental improvement was limited only to the reduction of the targeted pollutants that are linked to performance evaluation. Firm-level evidence shows that emission reduction was mainly achieved by reducing new polluting production activities, increasing pollution abatement capacity and improving abatement performance. It is also found that compliance with emissions reduction targets indeed increases the promotion chances of local officials.

Key words

Environmental regulation; Performance evaluation system; Local officials; Pollution reduction; Economic growth

JEL classifications

Q53, P56, Q58

1. Introduction

Economic growth and environmental protection are often seen as competing goals especially in developing countries (Greenstone and Jack, 2015). Developing countries typically focus more on economic growth than environmental protection, though the benefits of pollution reduction can be much greater than its costs (Currie and Walker, 2019; Blackman et al., 2010; Zheng and Kahn, 2013)[1]. With rising income and environmental awareness, many developing countries have started to implement or enhance regulations for environmental protection in the past decades. However, low political incentives, corruption and uncertainty often lead to weak enforcement of environmental regulations (Lopez and Mitra, 2000; Wu et al., 2013; Zheng and Kahn, 2013; Ghanem and Zhang, 2014; Greenstone and Jack, 2015; Gao and Liang, 2016; Shapiro and Walker, 2018; Deng et al., 2019). One of the key challenges for effective environmental protection in developing countries is how to properly incentivize local officials to enforce environment policies.

This paper examines the impacts of China's new evaluation system for officials implemented in 2006 on local governments' economic and environmental performance. China has achieved phenomenal economic growth since 1978 at the cost of environmental deterioration. The central government has made many attempts to improve environmental protection through enacting new laws, setting new or higher targets and improving supervision, etc.; however, many of these measures failed to achieve the intended environmental objectives (Zheng et al., 2014). For example, the central government targeted to reduce SO_2 emissions by 10% in the 10^{th} Five Year Plan (FYP, 2001-2005). However, industrial and total SO_2 emissions only declined briefly during the period 2001-2002, followed by a rapid growth in 2002-2005 (Fig. 1). The 10^{th} FYP failed badly on the 10% reduction target in SO_2 emissions.

China has a decentralized environment protection system. Although cross-nation analyses of the relationship between decentralized system and environmental quality have provided evidences for different views (Sigma, 2014; Farzanegan and Mennel, 2012), recent studies on

[1] Comprehensive cost-benefit analyses are difficult and few in existing studies. On the one hand, the estimates of compliance costs are dropping due to ongoing innovations and technological breakthroughs in pollution abatement (Currie and Walker, 2019), on the other hand, our understanding of the full benefits of improving air quality are changing rapidly with continued scientific discovery. See Currie and Walker (2019) for a review of the related literature.

China have mostly argued for a race-to-the-bottom view (i.e. decentralization has a destructive effect on environmental quality). For example, Van der Kamp et al., (2017) argue that the central government's reliance on local economic growth to evaluate the performance of local officials can lead many officials to focus on economic development at the expense of the environment. Local officials recognize that economic growth in their jurisdiction is the dominant factor affecting their odds of career promotion (Zhou, 2008). Under the strong incentive of economic growth in exchange for career promotion, local officials may ignore corporate environmental violations in order to increase fiscal revenue, create employment opportunities, and promote economic growth, leading to the invalidation of environmental regulatory policies (Jiang et al., 2014; Jia et al., 2015).

In order to strengthen local governments' incentive to implement environmental protection, the central government incorporated the achievement of pollution reduction targets of the 11^{th} FYP into officials' performance evaluation system from 2006. Local officials who fail to achieve the SO_2 reduction targets in their jurisdictions would be rated as unqualified and face administrative penalties, which will also affect their promotion odds (Zheng et al., 2014; Tang et al., 2021).. The new rule is officially referred to as *environmental one-vote veto* (*EOVV*) (Fig. 1). [2] This was the first time that the Chinese government linked environmental protection performance with the promotion of local officials. The purpose was to encourage local officials to protect the environment while promoting economic growth. The regime shift of local officials' performance evaluation and promotion represents a significant deviation from the norm of Chinese political system. The *EOVV* system is expected to significantly improve regulatory compliance. It thus brings a strong and exogenous shock to the stringency of environmental regulation in local jurisdictions and provides a rare empirical opportunity to study the relationship between economic growth and environmental protection.

This paper investigates whether and how the implementation of the *EOVV* system affects environmental pollution emissions and economic growth. Under the *EOVV* system, the promotion of local officials was linked to emission reduction targets specified in the 11^{th} FYP.

[2] For a full description of the environmental protection measures under the 11^{th} FYP and the new *EOVV* rule, please see: http://www.gov.cn/jrzg/2007-06/03/content_634545.htm (in Chinese)

We further test whether the achievement of such targets indeed improved officials' promotion opportunities. We collected a rich dataset of firm-level information, environmental and socioeconomic characteristics of 286 China's prefectural-and-above (PAA) level cities from 2002 to 2010.

The empirical analysis proceeds in four stages. First, we employ a difference-in-differences (DID) approach to study the impacts of the *EOVV* system at the city level. We find that the cities with higher emission reduction targets experience greater emissions reductions but also lower economic growth after the regime shift. The exogenous shock to regulatory stringency induced significant changes in tradeoffs between environmental protection and economic growth. This suggests that at least for the period under study, tighter regulatory compliance was achieved at the cost of economic growth. It is also found that the beneficial environmental effects of the *EOVV* are only significant for the air pollutant that are specifically targeted in the 11^{th} FYP (i.e. SO_2) and therefore linked to officials' promotion odds, but not for non-targeted air pollutants such as $PM_{2.5}$ and CO_2 emissions. These results survive a number of robustness and sensitivity checks including a parallel trends test, a placebo test for random assignment of reduction targets, an instrumental variable strategy, and tests for the impacts of possible spatial spillover, financial crisis, and the exclusion of large cities and the venue cities for the 2008 Summer Olympic Games.

The second part of the analysis examines the micro-mechanisms of the effects of the regime shift. Applying a difference-in-differences-in-differences (DDD) identification strategy, we find that the reduction in SO_2 emissions was achieved by reducing pollution-intensive production activities, increasing the number and capacity of desulfurization facilities, and improving desulfurization compliance.

The third part provides a back-of-the-envelope welfare analysis. We use an approach similar to Ho and Jorgenson (2003) but recalibrate to China's city level data. SO_2 emissions and acid rain can have significant impacts on public health and agricultural yields. We thus focus on benefits related to improved public health and crop yields. The results show that the cost of the regime shift outweighs the benefit, suggesting that the government is willing to sacrifice short-term economic growth for substantial pollution reduction and long-term development.

Finally, we test whether there is an association between SO_2 emission reduction performance and mayors' promotion odds. A lack of association indicates that the central government is only paying lip service to the *EOVV*. Any short-term effects of the *EOVV* on environmental improvement may vanish in the long run. It can also decrease the credibility and effectiveness of future regulatory efforts. On the other hand, a strong association is an indication of a credible regulatory incentive which is likely to bring enduring impacts (Wu and Cao, 2021). The results show that the achievement of the SO_2 emissions reduction target in a local jurisdiction increased the probability of the local official being promoted. However, this effect is only significant in the eastern and central regions. In the least economically developed western region, where economic growth remains the dominant goal of development, environment performance has yet to be accounted for in local officials' promotions.

There has been an emerging literature on China's increasingly tightened environmental regulations. In particular, a few papers focused on the impacts of China's 11^{th} FYP and associated regulatory changes (e.g. Kahn et al., 2015; Chen et al., 2018a; Chen et al., 2018b; Shi and Xu, 2018; Fan et al., 2019; He et al., 2020)[3]. Our paper adds new evidence to the literature but differs in several important ways.

First, the existing studies either examine the impact of the regulation on an environmental outcome such as the relocation of polluting activities (Chen et al., 2018b), pollution across borders (Kahn et al., 2015), pollution at the heavily regulated Two Control Zones (TCZ) (Chen et al., 2018a) and environmental practices and innovation (Fan et al., 2019), or an economic outcome including export (Shi and Xu, 2018) and firm productivity (He et al., 2020). However, because the EOVV system introduced a regime shift from a growth-dominated evaluation

[3] We thank one anonymous referee for pointing us to a few other related studies (Jiang et al., 2020; Tang et al., 2021; Li et al., 2022). However, our paper has a distinct focus and uses a different identification strategy. Jiang et al. (2020) investigated the impact of economy, energy efficiency and pollutant emissions on the promotion odd of municipal party secretaries for the period 2005-2015. Li et al. (2022) examines the impacts of economic growth target on environmental regulation stringencies for the period 2009-2016. Tang et al. (2021) examines the threshold effect of environmental pollution on the municipal party secretaries' economic promotion tournament using the data of 281 prefecture-level cities during 2005–2015. In short, these studies largely focus on the mechanisms and changes after the introduction of the EOVV. Our research question is how the regime has brought changes to the trade-off and officials' promotion odds by comparing before and after the regime shift.

system to one that balances both growth and environmental protection, we argue that the regime shift would trigger a tradeoff between economic and environmental outcomes. Chen et al. (2018a) is the only paper that studied the economy-environment tradeoff by comparing TCZ and non-TCZ regions. However, the EOVV system is directly linked to the compliance with reduction targets set in the five-year plans (FYPs), not to those of TCZs. We therefore study this tradeoff by examining how the introduction of EOVV has affected the way that local officials responded to reduction targets allocated in the FYPs.

Second, although Chen et al (2018a) studied the regulation induced economy-environment tradeoff, we are the only paper that further investigates whether the EOVV regime shift genuinely induced a change in the association between environmental compliance performance and officials' promotion odds. The analysis of the issue and the answer to this question are critical to evaluate whether the regime shift will generate enduring effects. A significant association would send a strong signal to local officials and is likely to generate enduring effects whereas a lack of association will reduce the credibility and effectiveness of future regulatory efforts.

Third, our new dataset provides richer variations in regulatory stringency and compliance that allow sharper understanding of the regulatory effects on the economy-environment tradeoff as well as the compliance-promotion linkage induced by the EOVV system. Some of the aforementioned papers (Kahn et al., 2015; Chen et al., 2018a) use dummy proxies to indicate change in regulatory stringency such as a time dummy to indicate pre- or post-2005 periods (Kahn et al., 2015), or a regional dummy to indicate areas under different regulations (TCZ/non-TCZ in Chen et al., 2018a; upstream/downstream in He et al., 2020). This practice is largely constrained by data availability but is unable to capture potentially rich temporal and cross-sectional variations in regulatory stringency. Using provincial-level reduction targets can provide richer variation (eg. Shi and Xu, 2018). However, it is difficult, if not impossible, to examine whether the EOVV system really works in terms of affecting officials' promotion odds at the provincial level, because all provinces met the reduction targets allocated in the 11th FYP. At the prefectural-city level, 12% of cities failed to comply with allocated reduction targets. A couple of papers indeed used city-level variations (Chen et al., 2018b; Fan et al., 2019) but regulatory stringency is represented by an indirect proxy or reduction targets constructed from provincial targets. We also use city-level data; however, our data on reduction targets in 286 PAA cities during the 10th and 11th FYPs were collected manually from various government reports and official statistical publications. The new dataset provides a direct measure of regulation stringency with rich variation. We also collected city-level data on actual reduction (i.e. compliance) which allows us to directly evaluate the effects of the EOVV system on officials' promotion odds.

The remainder of this paper is structured as follows. Section 2 provides relevant policy background. Section 3 and Section 4 describe the empirical strategy and data. Section 5 shows the main results, the results from several robustness checks and the analyses of the micro-mechanisms. Section 6 concludes the paper.

2. Policy background

2.1 SO_2 emissions regulations

Under China's decentralized environment protection system, the central government enacts environmental laws and sets national environmental goals while local governments are responsible for formulating and implementing detailed environmental regulations and action plans (Van Rooij and Lo, 2010; Zheng and Kahn, 2013). However, this environmental regulation system has proved to be often ineffective before 2006. For example, recognizing the harmful impacts of SO_2 emissions and acid rain on human health and the economy, the Chinese central government started to regulate SO_2 emissions from the 1990s. In the 9th FYP (1996-2000), the government set a zero-growth target on total SO_2 emissions– that is, total SO_2 emissions should be kept below the 1995 level by 2000. One of the most important policy tools used to achieve the target was designating 175 prefecture jurisdictions as the Acid Rain Control Zone and SO_2 Pollution Control Zone in 1998 (Two Control Zones (TCZ) for short). Specific policy measures taken in the TCZ include constraining the production (and therefore consumption) of high-sulfur coal and eliminating outdated production capacity. Following the moderate success in the 9th FYP, the central government set even tougher targets of a 10% reduction in total national SO_2 emissions in the 10th FYP (2001-2005) and a 20% reduction target for the TCZ. In 2000, the State Council announced a national list of 47 Key Cities for Environmental Protection (later expanded to 113 cities) where more stringent regulations and emission targets for pollutants including SO_2 were implemented (Huang et al., 2018). However, these reduction efforts failed with a 31% increase in total actual SO_2 emissions from 19.47 million tons in 2001 to 25.49 million tons in 2005 (Fig.1).

2.2 Chinese officials' performance evaluation

One of the key reasons why environmental protection policies failed lies in the lack of adequate mechanisms to ensure accountability of local regulators in the decentralized regulation system. Under the old officials' performance evaluation system, local officials have no or very low motivation to implement and enforce centrally-established environmental protection policies. Since China's reform and opening-up in 1978, the government has made economic growth its main goal of development. This pro-growth ideology was also reflected and incorporated in the way that local officials were evaluated and promoted (Li and Zhou, 2005; Yao and Zhang, 2015). Local leaders who perform well in the economic growth of their jurisdictions are likely to get more promotion opportunities. The pro-growth performance evaluation system has contributed significantly to China's rapid economic growth in the past 30 years, and is even taken as a model for the central government to provide effective professional incentives to local officials (Blanchard and Shleifer, 2000). However, a performance evaluation system that overemphasizes economic growth will have many negative effects. Driven by career concerns, local officials tend to give major GDP-contributing industries and enterprises as much preference and care as possible in taxation, financing and land supply which could result in serious resource distortion. Preferential treatment and care also include flexibility in compliance with environmental regulations or even protection from punishment for producing excessive pollution (Wu et al., 2013; Ghanem and Zhang, 2014; Jiang et al., 2014). Such institutional arrangements inevitably resulted in the overcapacity of polluting industries, the unwillingness to eliminate backward production technologies, and the lack of a compelling mechanism to implement and enforce targets for energy conservation and emissions reduction.

2.3 Environmental One-Vote Veto

To motivate local officials to enforce centrally-implemented environmental policies, the central government started to incorporate the compliance of environmental targets into the performance evaluation system and promotion criteria for local officials since 2006 (Landry, 2008; Zheng, et al., 2014). Under the new regime, a top-down target responsibility system was established. National emission reduction targets were first disaggregated to the provincial level and then further to lower administrative levels. Target responsibility contracts were signed between the leaders of upper- and lower-level governments. The assessment and evaluation were conducted by the upper-level government in various ways, including daily inspections, half-year and annual supervisions, and a final evaluation by the end of target assessment period.[4] Local government leaders are therefore bound by clear environmental performance indicators. Local officials who successfully comply with emission reduction targets will receive favorable evaluations and more promotion opportunities, while those who fail to meet the targets will not be promoted, face administrative penalties or be dismissed from the positions.[5] Although economic growth still occupies an important position in the evaluation of officials, the *one vote* of bad performance in environmental protection can now *veto* good performance of all other evaluation indicators including economic growth.

2.4 Allocation of SO_2 emission reduction targets

The *EOVV* system was officially stipulated in December 2005[6], and first took effect through the implementation of the environmental protection goals set in the 11th FYP (2006-2010). Specifically, the assessment of officials' performance in environmental protection is directly linked to the compliance with the allocated emission reduction targets.

The central government set an overall target of 10% reduction in total national SO_2 discharge below the 2005 level by 2010. The allocation of the national target among provinces is based

[4] Notice of the State Environmental Protection Agency on Issuing the Measures for the Evaluation of Total Emission Reduction of Major Pollutants in the Eleventh Five-Year Plan (Trial). (No.124 (2007): http://www.gov.cn/gongbao/content/2008/content_961664.htm (in Chinese)

[5] Notice of the State Council on Issuing the Comprehensive Working Schemes on Energy Conservation and Emission Reduction (No. 15 [2007] of the State Council): http://www.gov.cn/jrzg/2007-06/03/content_634545.htm (in Chinese)

[6] Decision on Implementing the Scientific Outlook on Development and Strengthening Environmental Protection (No.39, 2005, State Council, in Chinese): http://www.gov.cn/zwgk/2005-12/13/content_125680.htm

on a number of factors including historical emission levels, environmental quality and capacity, economic development stage and special needs for environmental protection.[7] However, the allocation of reduction targets to the prefecture levels and then to the emission sources are primarily based on their recent emission levels. All emission sources that have already complied with national emission standard will receive emission targets grandfathered from their 2005 levels. Non-compliant emission sources that have average annual air concentrations of SO_2 below the threshold of 0.06 mg/m^3 will be required to achieve full compliance with national emission standard as their emission target. Non-compliance emission sources in the prefectures whose average SO_2 concentrations are above the threshold will receive an even tougher target – that is, full compliance further scaled down by the ratio of the threshold to the prefecture's annual air concentrations of SO_2 in 2005.[8] One implication of these allocation rules is that those prefectures with higher historical emission levels received more stringent targets of greater reduction. The differentiated allocation of emission reduction targets to each individual emission source results in substantial variation in emission targets at the prefecture level (Fig.A1). These reduction targets became institutionally binding with the concurrent implementation of the *EOVV* regime. In contrast, the 10th FYP (2001-2005) also stipulated a target of 10% reduction in SO_2 emissions which was largely non-binding due to lack of an adequate accountability mechanism. Fig.1 shows that compliance to reduction target improved significantly with 14.29% reduction in the 11th FYP compared to a 31% increase in the 10th FYP. However, some cities still failed to comply with their allocated reduction targets (Fig. A2). This variation allows us to investigate whether environmental compliance indeed affected local official's promotion odds.

3. Estimation framework

3.1 City level analysis

The first objective of the study is to analyze the impacts of the regime shift on environment

[7] Reply of the State Council on the Plan for Controlling the Nationwide Total Discharge Volume of Major Pollutants in the 11th Five-year Plan Period (No. 70, 2006, State Council, in Chinese): http:/ www.gov.cn/gongbao/content/2006/content_394866.htm

[8] Guiding Opinions on the Allocation of Total Sulfur Dioxide (No.182, 2006, MEE, in Chinese): http://www.mee.gov.cn/gkml/zj/wj/200910/t20091022_172430.htm

and trade-offs made between environmental protection and economic growth. The *EOVV* regime is a major deviation from the old pro-growth appraisal system and brings a significant shock to environmental regulation stringency. We estimate the environmental and economic impacts using the following DID specification:

$$Y_{ct} = \alpha_1 + \beta_1 Target_{cp} * Post_t + \gamma_1 Target_{cp} + \rho_1 X_{ct} + \delta_c + \gamma_t + \varepsilon_{ct} \quad (1)$$

The outcome variables Y_{ct} include GDP growth rate, SO_2 emissions (log) which is targeted in the 11th FYP, and $PM_{2.5}$ concentration (log) and CO_2 emissions (log) which are not targeted in the 11th FYP, in city c and year t. $Target_{cp}$ is the SO_2 emissions reduction target in 10,000 tons for city c and period p (p is 2001-2005, or 2006-2010). Ideally, one would compare results using both relative and absolute values to check robustness[9]. To our best knowledge, the relative values of reduction target for the 10th FYP at the city level are not available to date. In fact, no study has ever used city-level reduction targets (relative or absolute) at all. The majority of the city-level reduction targets we manually collected are in absolute values. Of course, one can always covert these absolute targets to relative targets only if emission data for base period (2000) is available. However, we are not aware of any data source that reports city-level emission data for 2000. We thus follow Chen et al. (2018b) and use absolute values instead of relative values to measure SO_2 reduction targets. $Post_t$ is a dummy variable that indicates the post-treatment period, which equals to 0 for 2002 to 2005 and 1 for 2006 to 2010. Variations in the reduction targets provide an indication of the difference in regulatory stringency in local jurisdictions; however, the local governments may not comply if these targets are not binding. The *EOVV* regime shift effectively make these targets binding on local governments and the responsible officials. The DID term $Target_c * Post_t$ therefore captures the impacts of the regime shift on local environment and economy through a shock to regulatory stringency. X_{ct} is a vector of control variables including R&D investment, population density, the number of

[9] Reduction targets in absolute values do not reflect the difference in marginal abatement costs (MAC) in cities with different levels of emissions. However, relative reduction targets are not an ideal fix either. There has been a large literature on the estimation of MACs of pollutants but no consensus that MAC is empirically related to the size of emissions in any systematic manner. This is because MAC is essentially a reflection of production technology associated with a specific industry structure. Production technology can be heterogeneous across regions and so is industry structure. It is not uncommon that an underdeveloped region with relatively low level of emissions also has lower MAC. This complexity perhaps partly explains the fact that scholars have argued for and used both absolute (Chen et al., 2018b; Fan et al., 2019) and relative targets (Shi and Xu, 2018).

college students per 10,000 population, total imports and exports in city c and year t. δ_c is the city fixed effect, which controls all time-invariant factors in each city, such as geographical features, climate, etc. γ_t is the year-fixed effect capturing temporal shocks to all cities every year. ε_{ct} is the error term. The standard errors are clustered at city level. We conduct several robustness tests including a check for parallel trends, a placebo test with random assignment of pollution reduction targets, an instrumental variable regression, and sensitivity analyses on the impacts of spatial spillover, the financial crisis, large cities, and the venue cities of the 2008 Summer Olympic Games.

3. 2 Micro-mechanisms

Some may be concerned that possibly omitted time-varying city characteristics may bias the DID estimate. Given the wide scope of city-level characteristics, it is difficult to control for all such characteristics. Here we exploit the fact that the impact of the regime shift through changing regulatory stringency may be different across emission sources, industries and regions with different pollution performance. This is because the stringency of the targets is differentiated for regions above or below the threshold of 0.06 mg/m^3, and for emission sources that comply or do not comply with national emission standards. As our data do not contain information about actual compliance of individual emission sources, we use SO_2 emission intensity at the industry level as an indicator of average performance and estimate the following DDD specification:

$$Y_{ict}=\alpha_2+\beta_2 * Target_{cp} * Post_t * Pollution_i + \mu_{ct} + \delta_{ci} + \gamma_{it} + \varepsilon_{ict} \quad (2)$$

The outcome variables Y_{ict} include the number of firms (log) and total output value (log) in city c, industry i, and year t. $Pollution_i$ is the logarithm of SO_2 emissions intensity of industry i defined as total SO_2 emissions divided by total added value. A key advantage of the DDD specification (2) is that it allows to control for unobserved time-invariant and time-varying city as well industry characteristics using city-year fixed effects (μ_{ct}), city-industry fixed effects (δ_{ci}) and industry-year fixed effects (γ_{it}). The city-year fixed effects control for all time-varying and time-invariant city characteristics, e.g., productivity spillovers, input prices, local public policies, workforce quality. The industry-city fixed effects allow industry production conditions to differ across cities. The industry-year effects capture all time-varying and time-invariant industry characteristics, e.g., industry-specific technology progress and government's industry policies. ε_{ict} is an error term. The standard errors are two-way clustered at city-industry level to control for potential spatial and serial correlations.

3. 3 Political incentives

The *environmental veto* incorporated in the new performance evaluation system provides a strong incentive for local officials to adjust their governance. Instead of focusing on economic growth alone, local officials now must improve regulatory enforcement and compliance with allocated environmental targets. Economic growth is well known to be the prime determinant for the promotion of local Chinese officials (Maskin et al., 2000; Whiting, 2004; Li and Zhou, 2005; Chen et al., 2005; Wu et al., 2013). A few recent studies also studied the role of environmental performance in Chinese officials' promotion; however, no clear consensus has been reached. Zheng et al (2014) find that improved environmental performance is associated with higher chance of city mayors' promotion during 2004-2009. However, Feng et al. (2018) find no significant association between environmental performance and political turnover of cities' party secretaries during 2002-2013. More recently, Wu and Cao (2021) ascribed such inconsistency to officials' relatively weaker motivation to achieve environmental compliance at the city or provincial level. Indeed, they find stronger association at the county level. Building on these existing studies, we also explore how environmental performance affects officials' promotion odds. However, our analysis differs from the existing studies in several important ways. First, we argue that it is the regime shift since 2006 that systematically changes how local officials are evaluated for promotion. We exploit the variation induced by this quasi-natural experiment. If the *EOVV* was effectively enforced, we would expect significant difference in the association between environmental performance and promotion odds before and after the regime shift. Second, we examine how target compliance, not actual emission levels, affect officials' promotion odds. After all, it is target compliance that is directly assessed in officials' appraisal. Third, we focus on mayors rather than city secretaries as the former is typically responsible for economic and environmental governance.[10] Last, as the new regime may induce tradeoffs between different development goals, we explore this issue for regions at different development stages. Specifically, we estimate the following specification:

$$Promotion_{ct} = \alpha_4 + \beta_4 Compliance_{cp} * Post_t + \beta_5 Compliance_{cp} * D.GDP * Post_t + \beta_6\, Compliance_{cp} + \gamma_4 D.GDP_{ct} + \gamma_5 D.GDP_{ct} * Post_t + \rho_4 Z_{ct} + \delta_c + \gamma_t + \varepsilon_{ct} \quad (3)$$

Following Li and Zhou (2005) and Zheng et al. (2014), $Promotion_{ct}$ is a categorical variable taking the value of 0 if the mayor in city *c* retires or resigns at the end of the term, 1 if the mayor remains on the current position, or moves to another position at the same or lower level, and 2 if the mayor is promoted to be a CCP secretary in the same or another city[11] or moves to a higher level. "Abnormal" changes (e.g. death, arrest due to corruption) are excluded from the sample. Our focus is on the environmental performance indicators $Compliance_{cp}$ and $Compliance_{cp} * Post_t$, where $Compliance_{cp}$ equals 1 if city *c* achieved the allocated SO_2 emissions reduction targets by each FYP period, and 0 otherwise. The DDD term $Compliance_{cp} * D.GDP * Post_t$ is also included to reflect the possible influence of the EOVV on the impact of economic performance on the promotion chance. We control for relative GDP growth ($D.GDP_{ct}$) measured as the difference between the average annual GDP growth during the current mayor's term and that during the predecessor's tenure (Wu et al., 2013; Zheng et al.,2014). Z_{ct} is a set of control variables including FDI and the personal characteristics (age, educational attainment and the term length) of the mayor. The equation is firstly estimated using an ordered probit model with standard errors clustered by city. The estimate may be biased if omitted heterogeneity contributes to both better compliance and higher odds of promotion (Wu and Cao, 2021). We estimate an extended ordered probit model with $Compliance_{ct}$ instrumented with ventilation coefficient to address potential endogeneity.

[10] In China, mayor is the executive officer of a city government by law. The division of labor is that secretary is in charge of the personnel and other political duties, while the mayor is in charge of the daily operation of government including economic growth and environmental protection (Zheng et al., 2014; Yao and Zhang, 2015). Therefore, we follow Zheng et al. (2014) and use city mayors. However, we also provide results on party secretaries as supplementary materials.

[11] The party secretary is considered a higher level than the mayor because key decisions are often made in the party committee.

4. Data and variables

Our data consist of a prefecture-level data set on the environmental and socioeconomic characteristics of 286 PAA level cities spanning from 2002 to 2010, two comprehensive firm-level data sets from 2001 to 2010 on operational and environmental performance, and a data set on the characteristics of local official from 2001 to 2012. Our empirical analyses focus on the 10th and 11th FYPs (i.e. 2001-2010). As city-level information about SO_2 emissions are not available for 2001, the city-level regressions are limited to the period of 2002-2010. The analysis of the impact of environmental compliance on local officials' promotion odds is extended to 2012, the first year of routine changes in local officials following the 11th FYP (2006-2010).

City level outcome variables and control variables. The main outcome variables (GDP growth rate and industrial SO_2 emissions[12]) and the control variables (R&D investment, population density, number of college students per 10,000 population, total imports and exports) were collected from the *China City Statistical Yearbooks 2003-2011,* supplemented by the provincial-level *Statistical Yearbooks 2003-2011*. The city-level $PM_{2.5}$ concentration data comes from the grid data of the annual average global $PM_{2.5}$ concentration published by the Social Economic Data and Application Center of Columbia University. The data is based on the world satellite monitoring data provided by the National Aeronautics and Space Administration (NASA). The calculation of carbon dioxide (CO_2) emissions in each city follows Wu et al. (2016) and Wu and Ma (2019).

City level reduction target and achieved reduction. The data on pollution reduction targets and actual reduction of 286 PAA cities during the 10th and 11th FYPs were collected manually by authors from various government reports and official statistical publications. We provide detailed information about the collection and processing of city-level targets and reduction achievements in the Supplementary Materials.

City level instrument variable. Following Combes et al. (2013), we use historical famous cities

[12] As GDP growth is most directly related to industrial rather than residential SO_2 emissions, this paper uses industrial SO_2 emissions which account for most of the SO_2 emissions in China.

and treaty ports as instrument variables, which are sourced from governmental publications. We also use ventilation coefficient, a variable based on the product of wind speed and the mixing height, as another instrument variable. The wind speed information and the boundary lay height are sourced from the European Center for Medium-Term Weather Forecasting ERA-interim dataset.

Local officials' promotion records. The data on local officials contain the mayor's name, the month and year in which they took and left office and the nature of the turnover—promotion, lateral moves, staying at the same position or retirement. We manually collected the information from three main sources: the official newspaper of the Chinese Communist Party - People's Daily (people.cn), the state-run news agency – Xinhua News Agency (xinhuanet.com) and the largest Chinese online encyclopedia - Baidu Baike.

Industry level variables. To calculate industrial SO_2 emissions intensity, we collected data on SO_2 emissions and added values in 2007 at the 2-digit-industry level from the *Report on the First National Census of Polluting Source* published by the Ministry of Environment Protection. The report provides the nation's first and only comprehensive estimation of industrial pollution emissions up to date.

City-industry level and firm level variables. The information at these finer levels are derived from two firm-level data sources - Annual Surveys of Industrial Firms (ASIF) and China's Environmental Statistics Database (CESD).

The ASIF are conducted by the National Bureau of Statistics of China (NBS), which cover all state-owned firms plus all non-state-owned firms with annual sales of more than 5 million RMB (roughly $769,000). The ASIF data contains basic firm identification information (ID number, name, address, industrial classification code, etc.) and accounting and financial information (output, employee, capital, wage, tax, and subsidy, etc.). The firms sampled in the ASIF account for 70% of national industrial employment and generate 90% of total industrial output and 98% of total exports (Brandt et al., 2012). Because the variations used for identification in Specification (2) are at the city-industry level, we collapsed the firm-level outcome variables (the number of firms and output) to construct a panel of city-industry-year observations. Following most recent studies (Hering and Poncet, 2014; Cai et al., 2016; Chen et al., 2018a), we conducted the aggregation at the two-digit industrial level (*GB/T 4754-2002*). China's industrial classification system changed from *GB/T4754-1994* to *GB/T4754-2002* in 2002. For consistence, we convert all industry codes to *GB/T4754-2002*[13]. We also constructed the same city-industry aggregated outcome variables for new and old firms separately using the ASIF data. The sub-sample of old firms consist only of those established before 2001 and the sub-sample of new firms include only those established each year after 2001.

The CESD is the most extensive nationwide environmental micro-dataset in China, collected by the Ministry of Environmental Protection. Firms in each county are first ranked in descending order of their annual discharges of COD, NH_3, SO_2, NO_X, industrial smoke and dust, and solid waste. The largest firms accumulatively accounting for 85% of the county's annual discharges of at least one pollutant are then included in the CESD. The CESD is updated annually, and contains information about each firm's identification, production, pollution emissions, pollution abatement equipment, and other environmental-relevant information. The CESD data can be merged with the ASIF data using the name, the identifier code and the address of the firms. For our empirical analysis, we extract information on SO_2 emissions and removals, the number and capacity of desulfurization facilities from the CESD dataset.

Table 1 shows the summary statistics for key socioeconomic and environmental variables. Panel A reports the summary statistics of the variables at city level. Panel B provides information at the 2-digital-indsutry level. Panel C and Panel D present the summary statistics at city-industry-year level and firm level. The summary statistics of the other variables are presented in Table A1 in the Supplementary Materials.

5. Empirical findings

5.1. Main results

Table 2 reports the main results corresponding to Equation (1). Columns 1 and 2 present the

[13] China's national industrial classification standard *GB/T 4754-2002* classifies all industrial production into 39 two-digit industries, ranging from 6 to 46 with 12 and 38 left vacant in the classification.

estimates for SO_2 emissions and Columns 3 and 4 for GDP growth. All regressions in Table 2 control for city and year fixed effects and the regressions in Columns 2 and 4 have additional controls (R&D investment, population density, the number of college students per 10,000 population, total imports and exports). The coefficients of the DID term are negative and statistically significant across all specifications. The estimate in Column 2 suggests that an increase of 10,000 tons in SO_2 reduction target will result in actual reduction of 5,341 tons in the 11th FYP relative to the 10th FYP (estimated at the sample mean emission level of 60,770 tons: 60770*(1-EXP(-0.092)). This shows that the *EOVV* regime has indeed provided a strong incentive for local governments to implement and enforce SO_2 reduction targets. In fact, 88.8% of all cities have complied with their allocated reduction targets in the 11th FYP whereas the city-level compliance rate is only 34.6% for the 10th FYP period.

The estimates for GDP growth in Columns 3 and 4 also suggest that improved environmental compliance with SO_2 reduction targets in the 11th FYP was achieved at the cost of GDP growth. The estimate in Column 4 implies a reduction of 0.335 percentage point in GDP growth rate relative to the 10th FYP for an increase of the SO_2 reduction target by 10,000 tons, or a reduction of 0.4 percentage point evaluated at the sample mean reduction target of 11,950 tons. This reduction in GDP growth is non-trivial given the mean of GDP growth of 13.6%, suggesting that the *EOVV* induced a significant trade-off between economic growth and environmental protection.[14]

5.2 Robustness tests

5.2.1. Parallel pre-treatment trends

A potential concern regarding the DID estimation is that the estimated impact of the regime shift may be biased in part by the efforts that local governments made prior to 2005 such that the change in the SO_2 emissions and GDP growth after 2005 was caused by a pre-existing trend.

[14] We do not include longer data periods (e.g. 12th FYP) in the main analysis. This is to avoid possible influences from confounding policies introduced later, the Air Pollution Prevention and Control Action Plan implemented in 2013 in particular. Although this plan mainly addresses emissions of $PM_{2.5}$, its impacts on SO_2 emissions are also obvious. Focusing on the 10th FYP and 11th FYP thus reduces possible confounding effects and provides us a cleaner identification. We provide additional results based on longer datasets in Table A2 in the Supplementary Materials. The results are largely similar to those reported here.

A necessary condition for satisfying our identifying assumption is that the cities allocated different SO_2 reduction targets in the 11th FYP had similar time trends in the outcomes (SO_2 emissions and GDP growth) in absence of the treatment. We test this condition for the pre-treatment period by estimating the following equation:

$$Y_{ct} = \sum_{t=2003}^{2010} \beta_t Target_{cp} * year_t + Target_{cp} + \rho X_{ct} + \delta_c + \gamma_t + \varepsilon_{ct} \quad (4)$$

In which β_t is a series of estimates of yearly differences from 2003 to 2010, $year_t$ represents the calendar year dummies, and the year of 2002 is the omitted category.

Fig. 2 a and b plot the estimates of β_t for the outcomes of SO_2 emissions and GDP growth along with 95% confidence intervals. The parallel trend assumption generally holds except for the significant estimate for SO_2 emissions in 2005 Overall, we do not observe any consistent and significant pre-trends in SO_2 emissions and GDP growth between cities with different SO_2 reduction targets. However, there are significant differences in both outcomes in the post-treatment period (2006-2010), suggesting strong impacts of the regime shift on the outcomes. The significant estimate for SO_2 emissions in 2005 (Fig.2a)_could be a result of symbolic compliance effort towards the end of the 10th FYP period. It is not uncommon that local government delays compliance or makes a symbolic compliance effort towards an allocated target approaching the end of a compliance period (every five years in this case). If such end-of-period compliance behavior exists, it is more likely to occur in areas under compulsory or almost compulsory compliance regulation compared to those without formal compliance regulation. SO_2 mitigation was not compulsory nationwide during the 10th FYP period. However, TCZ cities were under more stringent regulation with compliance requirement than non-TCZ cities. Key desulfurization projects in TCZ cities are also under more stringent supervision. Therefore, we also tested parallel pre-treatment trends using split TCZ and non-TCZ samples. As expected, the estimate for SO_2 emissions in 2005 is only significant for the TCZ sample. We rerun our baseline regression on the non-TCZ sample and the results remain robust. We report these additional trend tests and regressions in Fig. A3 in the Supplementary Materials.

5.2.2 Placebo test

The SO_2 reduction targets are not randomly assigned to cities (see Section 2.4 for details of target allocation). The validity of the DID identification also depends on the assumption that the outcomes Y_{ct} are independent of target allocation, conditional on other controlled heterogeneity. We conducted a placebo test by randomly assigning SO_2 reduction target to cities (for similar practices, see, e.g., Chetty et al., 2009; La Ferrara et al.,2012; Cai et al., 2016; Chen et al., 2018a). Specifically, we randomly assigned an SO_2 reduction target within the range of actual targets to each of the 286 cities, and then constructed a false regressor of $Target^{false} \times Post$. The necessary condition for satisfying our identification assumption is that we should observe no treatment effect of the false regressor on SO_2 emissions and GDP growth. We conducted this random data generating process 500 times to avoid possible impacts of incidental events. Fig.3 a and b plot the distributions of the 500 estimated coefficients of the false regressor and corresponding p-values for SO_2 emissions (a) and GDP growth (b). Both distributions center around zero and most estimates are not statistically significant. The estimates from Columns 2 and 4 in Table 2 (-0.092 and -0.335) are also indicated by the vertical lines in Fig. 3. In general, these results provide additional support for our identification strategy.

5.2.3 IV regressions

As the emission targets were determined prior to the 11th five-year period (2006-2010), we are less concerned about reverse causality. However, our estimate may still be biased due to omitted variables. Our first strategy here is to use ventilation coefficient as an instrumental variable (IV) for SO_2 emission reduction target. Ventilation coefficient is closely related air concentration level of SO_2 in a region (Hering and Poncet, 2014; Wu and Cao, 2021), which is one of the key determinants of allocated SO_2 reduction target (see Section 2.4 for details). Specifically, Shi and Xu (2018) used ventilation coefficient as IV for SO_2 emission reduction target at the provincial level. Table A4 in the Supplementary Materials provides first-stage analyses at both the provincial level and the PAA city level. Although ventilation coefficient is significant at the provincial level, the F tests fail to reject the null of weak IVs at both the provincial and the PAA city level. Shi and Xu (2018) used different first-stage specifications and considered proportional reduction targets whereas we use absolute reduction targets.

As discussed in Section 2.4, the allocation of emission reduction targets could also consider special requirements for environmental protection. Our second strategy is to employ an IV of whether the city is a nationally listed Famous Historical and Cultural City (FHCC) or historical treaty ports. The FHCCs are designated by China's State Council and the treaty ports are those forced to open to trade by the Western powers in the nineteenth century under a series of unequal treaties (Au and Henderson, 2006; Combes et al., 2013; Bracken, 2019). Both have an unusual wealth of cultural relics of high historical value and major revolutionary significance. The State Council has also formulated specific measures to protect these cities[15]. Our hypothesis here is that the status of being nationally listed as an FHCC or a historical treaty port creates a special requirement for environmental protection. These cities could have been allocated greater emission reduction targets. The first-stage results of the IV estimation confirm the validity of the IV (Table A4 in the Supplementary Materials). The F test rejects the null of a weak instrument. However, being an FHCC or a historical treaty port should have no direct influence on current SO_2 emissions level or current GDP growth rate. Table 3 reports the second-stage results. The IV estimates for both SO_2 emissions and GDP growth remain negative and statistically significant. In addition, these estimates are larger than those reported in Table 2, suggesting that the OLS estimates have underestimated the negative impacts of the regime shift on SO_2 emissions reduction and GDP growth.[16]

5.2.4 Other robustness tests

(1) *The financial crisis*. The 2008-2009 international financial crisis has had a significant impact on the Chinese economy. If the impact of the international financial crisis is systematically different for cities and industries with higher or lower SO_2 reduction targets, the estimate of the treatment effect may be biased. We dropped observations in 2008 and 2009 and re-estimated Equation (1). The results are reported in Column (1) in Table 4. The DID estimates for SO_2 emissions (Panel A) and GDP growth (Panel B) are slightly smaller than those reported

[15] Cultural Relics Protection Law of the People's Republic of China (2013 Amendment) (No. 5 [2013], Standing Committee of the National People's Congress): http://www.gov.cn/flfg/2013-06/30/content_2437158.htm (in Chinese)

[16] A city being nationally listed FHCC or historical treaty ports is likely to have a stronger economic base or a characterized industrial structure. or have a significant impact on attracting labor and investment. Jia (2014) indicated that commerce and service sector are the major support of treaty ports. As a robustness check, we included FDI, total labor and the share of tertiary industry in GDP as additional controls. The results are similar to those reported in Table 3. We provide these results in Table A5 as supplementary materials.

in Table 2, but remain negative and statistically significantly, suggesting the robustness of the baseline estimates.

(2*) The Olympic Games*. The 2008 Summer Olympic Games in China also had significant impacts on the economic growth and pollution emissions especially in venue cities. To ensure high environmental quality in the venue cities of the Olympic Games, these cities and their surrounding cities have temporarily or permanently shut down many pollution-intensive enterprises (He et al., 2016). In Column (2) of Table 4, we exclude the main venue city of Beijing and its surrounding cities, as well as vice venue cities[17]. The results are similar to those reported in Table 2, which shows that our baseline results are not driven by the 2008 Summer Olympic Games.

(3) *The four municipalities*. The sample of PAA level cities Beijing, Shanghai, Tianjin and Chongqing. These four municipalities are huge in economy and are directly under the jurisdiction of the central government. The regulatory compliance may be more stringent to ensure good environmental quality (or less stringent to achieve strong economic growth). To rule out the possibility that the different regulatory institutions in these huge municipality economies may bias our estimates, we excluded these four large cities in Column (3) of Table 4. The results show that our baseline estimates are robust.

(4) *Spillover effects*. Valid causal inference rests on the stable unit treatment value assumption (SUTVA). The response of a particular unit should depend only on the treatment to itself, not the treatments to others around it. However, polluting firms may be motivated to relocate to bordering cities with lower emission reduction targets if differences in emission reduction targets also bring genuine differences in the stringency of environmental regulations. Relocation of pollution-intensive firms to bordering cities will result in overestimates of *EOVV*'s treatment effects on SO_2 emissions and GDP growth. Such spillover is most likely to occur where the two bordering cities have large difference in SO_2 reduction targets. To rule out this possibility, we calculated the difference of the SO_2 emissions reduction targets between each pair of bordering cities and excluded those pairs of cities with top 5% largest differences

[17] Beijing, Tianjin, Shanghai, Qingdao, Shenyang, Qinhuangdao, Tangshan, Zhangjiakou, Baoding, Cangzhou, and Chengde.

in SO_2 reduction targets.[18] As shown in Column (4) of Table 4, the new estimates remain negative and significant. In fact, the magnitudes of the new estimates are even larger than those reported in Table 2.

5.3 Effects on non-targeted pollutants

The results in Tables 2-4 all indicate that the new regime successfully prompted cities to make trade-offs between SO_2 emissions reduction and economic growth. We argue that this is because the regime shift effectively makes the reduction of SO_2 (a FYP-targeted air pollutant) a binding target. Because the implementation of the *EOVV* was specifically linked to the FYP-targeted pollutants, it is also of interest to know whether the regime shift induced reductions in other non-targeted pollutants. We examined two other air pollutants - $PM_{2.5}$ and CO_2 - that are most often under the spotlight but not directly targeted in the 11th FYP. As shown in Table 5, neither of the estimates are statistically significant, suggesting that the emissions of non-targeted pollutants have not been affected by the *EOVV*. The benefit of improved environmental performance seems limited to the FYP--targeted pollutant rather than the overall environment.

5.4 Micro-mechanisms of the policy effects

Our city-level analysis shows that the regime shift in 2006 induced a significant trade-off between SO_2 emissions reduction and GDP growth. We now turn to the micro-mechanisms by examining the production activities of firms and industries with different characteristics.

5.4.1 Industries with different pollution intensity

Table 6 reports the results based on Equation (2). Columns (1) and (2) present the estimates for the number of firms and total industrial output. The negative and statistically significant coefficients in both regressions imply that the regime shift had greater impacts on industries that are more intensive in SO_2 emission. Columns (3) and (4) report results estimated from a

[18] A total of 44 cities are removed from the sample. The calculated mean and standard deviation of the differences in SO_2.reduction targets of bordering cities are -0.007 and 3.093 respectively.

sub-sample and a slightly different specification in which the continuous variable *Pollution* in Equation (2) is redefined as a dummy variable *D.Pollution* taking the value of 1 for the five most SO_2-polluting industries and 0 for the five least SO_2-polluting industries.[19] The new estimates also suggests that the regime shift had much greater impact on the most SO_2-polluting industries than the least polluting ones. Columns (1) – (4) are all based on the ASIF data. In Columns (5) and (6), we re-estimate Equation (2) with a continuous *Pollution* variable, but use the CESD-ASIF matched data. The CESD data is the most extensive nationwide environmental micro-data set in China. The new estimates in Columns (5) and (6) are larger than those reported in Columns (1) and (2). This may be explained by the fact that the new sample contains only the largest polluting firms that accumulatively account for 85% of total national emissions of major pollutants. Given the target allocation rules outlined in Section 2.4, pollution intensive production is more likely to be allocated greater reduction targets. In addition, these top-85% polluting firms are closely monitored by China's Ministry of Environmental Protection, and therefore the impact of the *EOVV* regime shift is understandably greater. Results from all specifications in Table 6 indicate that the regulatory pressure induced by the *EOVV* resulted in a greater decline in output and a larger number of firms being closed in more pollution-intensive industries.

5.4.2 New vs old firms

The negative impact of the *EOVV* on the production activities of industrial firms may be a result of reduced production or exit of older production capacity. It is also possible that the new system has lifted the entry standard for new polluting firms. To investigate the relative importance of these two mechanisms, following previous literature (e.g., Chen et al., 2018b), we identify two groups of firms: those established before our sample period (i.e., before 2001) as old firms and those entering the market each year after 2001 as new firms. The outcome variables for old and new firms are aggregated separately for each city-industry-year unit. Table

[19] The five most SO_2-polluting industries include "production and supply of electric power and heat power", "manufacture of non-metallic mineral products", "melting and pressing of ferrous metals", "manufacture of raw chemical materials and chemical products" and "melting and pressing of non-ferrous metals". These five most polluting industries comprise 85% of total industrial SO_2 emissions. The five least SO_2-polluting industries include "production and distribution of water", "printing, reproduction of recording media", "recycling and disposal of waste", "manufacture of measuring instruments and machinery for cultural activity and office work" and "manufacture of tobacco". These five least SO_2- polluting industries account for less than 1% of total industrial SO_2 emissions.

7 shows that the effect of the regime change is negative and statistically significant for new firms but not for old firms, suggesting that the policy effects are mainly driven by restricting the growth of new pollution-intensive production.

5.4.3 Desulfurization facilities, capacity and performance

The results so far have indicated that the regime shift induced significant cut on the level of production activities of pollution-intensive industries and firms. This will have direct impact on the level of SO_2 generated. However, industrial SO_2 emissions also depends on desulfurization capacity and performance. Larger desulfurization capacity and better performance would also help to contain SO_2 emissions. We focus on three desulfurization indicators, namely the total number of desulfurization facilities, total nameplate SO_2 treatment capacity and actual SO_2 removal rate. Using the ASIF-CESD matched dataset, we estimate Specification (2) with these new outcome variables. We present the city-industry level and firm-level results in Panel A and B in Table 8. Both indicate that the new performance evaluation system has significantly increased desulfurization capacity and improved desulfurization performance in more polluting industries and firms, relative to less polluting ones. Table A6 in the Supplementary Materials also provide city-level and firm-level results based on the discrete indicator of pollution intensity (*D.Pollution*). The results are consistent with those reported here in Table 8.

5.5 Welfare analyses

Using estimates reported in Column 4 in Table 2 and allocated city-level emission reduction targets for the 11th FYP (2006-2010), we are able to calculate corresponding loss in GDP growth rate (0.335*target) in each city due to the introduction of the EOVV regime. The loss in GDP growth rate is then converted to actual loss of GDP for each city. The total annual cost for all cities in our sample is aggregated to be 178.7 billion CNY. We adjust all GDP values to 2002 prices using provincial GDP deflators.

Similarly, we can also calculate policy-induced reduction in SO_2 emissions in each city (EXP(-

0.092*target)) using estimates reported in Column 2 in Table 2. To quantify the full range of benefits of emission reductions is challenging for at least two reasons. First, our understanding of the benefits of improving air quality are evolving rapidly with continued scientific discovery and second, many identified benefits involve non-market values (Currie and Walker, 2019). In this analysis, we focus on mortality and health related consequences, and losses in crop yields as scientific support is relatively abundant and robust. As these benefits are typically linked to changes in pollutant concentrations (μg/m^3). We need to convert the policy-induced changes in emission reductions to reductions in SO_2 concentrations. This involves a model of calibration from emission reductions to reductions in airborne concentrations. The detailed model we used to calibrate the conversion is described in the supplementary materials. Using this method, we find that the regime shift has resulted in an average reduction in SO_2 air concentration of 6.41 μg/m^3 at the city level.

The impacts of SO_2 and related acid rain include human healthy losses, crop and wood losses (World Bank, 1997, 2007). According to World Bank (1997), there is no direct mortality risk associated with SO_2 exposure. The report also suggests that the disease incidences associated with per million per μg/m^3 increase in SO_2 concentration for chest discomfort and respiratory symptoms (child) are 10,000 cases and 5 cases per million people, respectively. Ho and Jorgenson (2003) suggest that the cost per case is 9.61 in 2002 CNY. With a population of 1.3 billion and a reduction of SO_2 air concentration by 6.41 μg/m^3, the estimated health benefit of the policy has a total monetary value of 0.8 billion (2002 CNY) (6.41× 1300 × (10,000 × 9.61 + 5 ×9.61) =0.8 billion). World Bank (2007) also estimated that total crop losses in China in 2003 is approximately 29.64 billion (2002 CNY). The average SO_2 air concentration is 14.88 and 20.04 μg/m^3 in 2003 and 2006. Assuming a linear dose-response relationship between SO_2 concentration and loss in crop yields (World Bank, 2007), we estimated the total crop losses in 2006 is approximately 39.92 billion (2002 CNY) (29.64× 20.04/14.88=39.92 billion). The policy-induced benefit related to crop yields is 12.77 billion (2002 CNY) (39.92× 6.41/20.04=12.77 billion). Thus, the total benefit due to the introduction of the EOVV regime is 13.57 billion (2002 CNY) (0.8+12.77=13.57 billion). This is much lower than the total cost estimate of 178.7 billion CNY. As we are unable to capture the full range of benefits, the calculation has its limitations. However, our result is consistent with Chen et al. (2018a), and suggests that the government is willing to sacrifice short-term economic growth for substantial pollution reduction and long-term development.

5.6 Political incentives

The regime shift provides a strong political incentive for local officials to achieve better compliance with reduction targets. In this section, we examine whether officials' compliance effort was rewarded with better chance of promotion.

Table 9 reports the results based on Specification (3).[20] The full-sample analysis shows that compliance with SO_2 emissions reduction targets indeed improves the odds of promotion; however, this is only the case after the regime shift. Environmental compliance does not help the mayor in performance evaluation before the regime shift. The existing studies have provided mixed evidence on the association between Chinese officials' promotion and environmental performance. Wu and Cao (2021) recently ascribed such inconsistency to the level of data and empirically demonstrated stronger association at county level than more aggregated prefectural and provincial levels. Our analysis provides an alternative explanation. Studies using data including earlier years often find insignificant association (e.g. Feng et al., 2018) whereas those using data from more recent periods find significant results (e.g. Zheng et al., 2014). We argue that the regime shift in 2006 induced a stronger association between promotion and environmental performance. Column (1) in Table 9 also indicates that economic growth (relative to the previous mayor) has always been an important determinant of a mayor's promotion. It has become less significant since the regime shift, but the change is statistically insignificant.

Chinese regions differ greatly in economic development. The central government may have

[20] We also provide the analysis and results on party secretaries in Table A7 in the Supplementary Materials. The literature on the effects on secretaries are rather mixed (Zheng et al., 2014; Yao and Zhang, 2015; Wang and Lei, 2021). Zheng et al. (2014) and Wang and Lei (2021) both found that the effects are different for mayors and secretaries. Zheng et al. (2014) found the effect on party secretaries is insignificant. The results provide in Table A7 also show that the effect on party secretaries is statistically insignificant..

different priorities for regional development. The socio-economic development in central and eastern regions is more advanced than that of western regions, and the government imposes more stringent environmental regulation in the former (Chen et al., 2018b). However, socio-economic development remains the main goal for the less-developed western regions. The differences in development priorities may also be considered in local officials' performance evaluation. We conduct two split-sample analyses and report the results in Columns (2)-(3) in Table 9. These results suggest that environmental compliance is an important factor in city mayors' promotion evaluation only in the central and eastern regions. For the under-developed western regions, the association is statistically insignificant even after the regime shift.

To check whether our estimate may be biased due to omitted heterogeneity we employ an IV approach using ventilation coefficient as the instrument. Because the potentially endogenous variable $Compliance_{ct}$ is discrete, we estimate an extended ordered probit model in which the first stage is estimated by a probit rather than a linear probability model. The first-stage results are provided in Table A4 in the Supplementary Materials. Column (4) in Table 9 reports the second-stage results which are very similar to those reported in Column (1). Wu and Cao (2021) mentioned a possibility that party secretaries with higher probability for promotion are appointed to counties with better potentials in environmental protection and economic growth. However, one can make a similar argument that the government may try to toughen up officials with higher odds of promotion by appointing them to poor-performing areas. The empirical association may be ambiguous. After addressing possible endogeneity by an IV approach, they also identify a significant impact of environmental performance on cadres' promotion odds.

6. Conclusion

Weak enforcement of environmental regulation is very common in most developing countries (Zheng et al., 2014). By focusing on a prominent regime shift of performance evaluation system in China, this study examines whether the Chinese local officials were effectively incentivized to strengthen environmental protection and how it works. Given the serious environmental challenges faced in most developing countries, the findings have important implications for the design of more effective environmental policies.

Our results show that simply setting emission reduction targets was ineffective with pro-growth institutions. However, linking target compliance performance with officials' promotion odds successfully induced significant tradeoff between environmental protection and economic growth. Improved environmental protection was largely achieved by constraining new production activities of SOEs in pollution-intensive industries, and enhancing pollution treatment capacity and performance. Officials with better environmental compliance performance were indeed rewarded with higher chance of promotion, which is important for the new regime to provide credible and long-term incentive.

Our analyses also reveal several limits of the new environmental regulation system. First, we find that the achievement of pollution reduction target only increases the promotion opportunity in the central and eastern regions, but not in the western regions. This may weaken the efforts of local officials in the western China on pollution reduction in the long-run. The lax enforcement of environmental protection in the western region may induce relocation of polluting production activities to the inner regions that will expose a greater population to pollution (Chen et al., 2018b). Second, the benefit of improved environmental protection was limited to the FYP targeted pollutants. It proves the effectiveness of the new regime in addressing the most pressing pollution issues identified in the FYPs. However, it also raises the broader question how policy institutions should be designed to encourage more comprehensive improvement of the environment conditions.

Reference

[1] Au Chun-Chung, and J. Vernon Henderson. 2006. How migration restrictions limit agglomeration and productivity in China. *Journal of Development Economics,* 80(2), 350-388.

[2] Blackman Allen, Bidisha Lahiri, William Pizer, Marisol Blackman, and C. Munoz-Pina. 2010. Voluntary environmental regulation in developing countries: Mexico's clean industry program. *Journal of Environmental Economics and Management*, 60(3): 182-192.

[3] Blanchard Olivier, and Andrei Shleifer. 2000. Federalism with and without political centralization. China versus Russia. *IMF Staff Papers*, 48(1): 171-179.

[4] Bracken Gregory. 2019. Treaty ports in China: their genesis, development, and influence. *Journal of Urban History*, 45(1): 468-176.

[5] Brandt Loren, Johannes Van Biesebroeck, and Yifan Zhang. 2012. Creative accounting or creative destruction: firm level productivity growth in Chinese manufacturing. *Journal of Development Economics,* 97 (2): 339-351.

[6] Cai Xiqian, Yi Lu, Mingqin Wu, and Linhui Yu. 2016. Does environmental regulation drive away inbound foreign direct investment? evidence from a quasi-natural experiment in China. *Journal of Development Economics*, 123: 73-85.

[7] Chen Yvonne Jie, Pei Li, and Yi Lu. 2018a. Career concerns and multitasking local bureaucrats: evidence of a target-based performance evaluation system in China. *Journal of Development Economics*, 133: 84-101.

[8] Chen Zhao, Matthew E. Kahn, Yu Liu, and Zhi Wang. 2018b. The consequences of spatially differentiated water pollution regulation in China. *Journal of Environmental Economics and Management*, 88: 468-485.

[9] Chen Ye, Hongbin Li, and Li-An Zhou. 2005. Relative Performance Evaluation and the Turnover of Provincial Leaders in China. *Economics Letters*, 88(3): 421-425.

[10] Chetty Raj, Adam Looney, and Kory Kroft. 2009. Salience and taxation: theory and evidence. *American Economic Review*, 99 (4): 1145–1177.

[11] Combes Pierre-Philippe, Sylvie Démurger, and Shi Li. 2013. Urbanization and migration externalities in China. Aix-Marseille School of Economics Working Papers No.1307.

[12] Currie Janet, and Reed Walker. 2019. What do economists have to say about the clean air act 50 Years after the establishment of the environmental protection agency? *Journal of Economic Perspectives*, 33(4): 3-26.

[13] Deng Yuping, Yanrui Wu, and Helian Xu. 2019. Political turnover and firm pollution discharges: An empirical study. *China Economic Review*, 58:101363.

[14] Fan Haichao, Zivin Joshua S. Graff, Kou Zonglai, Liu Xueyue, and Wang Huanhuan. (2019). Going green in China: Firms' responses to stricter environmental regulations (No. w26540). National Bureau of Economic Research.

[15] Feng Gen-Fu, Minyi Dong, Jun Wen, and Chun-Ping Chang. 2018. The impacts of environmental governance on political turnover of municipal party secretary in China. *Environmental Science & Pollution Research*, 25:24668–24681

[16] Farzanegan, Mohammad Reza, and Tim Mennel. 2012. Fiscal decentralization and pollution: institutions matter. *MAGKS Joint Discussion Paper Series in Economics*, No. 22-2012. https://www.unimarburg.de/fb02/makro/forschung/magkspapers/22-2012_farzanegan.pdf.

[17] Gao Nan, and Pinghan Liang. 2016. Fresh cadres bring fresh air? Personnel turnover, institutions, and China's water pollutions. *Review of Development Economics*, 20(1): 48-61.

[18] Garbaccio Richard, Ho Mun. and Dale Jorgenson. (Eds.), March 2000. The Health Benefits of ContControl Carbon Emissions in China, Ancillary Benefits and Costs of Greenhouse Gas Mitigation, Proceedings of an IPCC Co-sponsored Workshop, Washington, D.C. Organization for Economic Co-operation and Development.

[19] Ghanem Dalia, and Junjie Zhang. 2014. "Effortless perfection:" Do Chinese cities manipulate air pollution data? *Journal of Environmental Economics and Management*, 68(2):203–225.

[20] Greenstone Michael, and B. Kelsey Jack. 2015. Envirodevonomics: A research agenda for an emerging field. *Journal of Economic Literature*, 53(1):5-42.

[21] He Guojun, Maoyong Fan, and Maigeng Zhou. 2016. The effect of air pollution on mortality in China: Evidence from the 2008 Beijing Olympic Games. *Journal of*

Environmental Economics and Management, 79:18-39.

[22] He Guojun, Shaoda Wang, and Bing Zhang. 2020. Watering down environmental regulation in China. *The Quarterly Journal of Economics*, 135(4): 2135-2185.

[23] Hering Laura, and Sandra Poncet. 2014. Environmental policy and exports: Evidence from Chinese cities. *Journal of Environmental Economics and Management*, 68(2): 296-318.

[24] Ho Mun. and Dale Jorgenson, 2002. Pollution taxes and public health. In: Economics of the Environment in China. Boyds: Aileen International, Maryland. China Council for International Cooperation on Environment and Development Environmental Economics Working Group, 165–200.

[25] Ho Mun, and Dale Jorgenson, 2003. Air pollution in China: Sector allocation emissions and health damage." China Council for International Cooperation on Environment and Development.

[26] Huang Jianhuan, Yantuan Yu, and Chunbo Ma. 2018. Energy efficiency convergence in China: Catch-up, lock-in and regulatory uniformity. *Environmental and Resource Economics*, 70, 107-130.

[27] Jia Ruixue. 2014. The legacies of forced freedom: China's treaty ports. *Review of Economics and Statistics*, 96(4), 596-608.

[28] Jia Ruixue, Masayuki Kudamatsu, and David Seim. 2015. Political selection in China: the complementary roles of Connections and performance. *Journal of the European Economic Association*, 13(4): 631-668.

[29] Jia Ruixue. 2017. Pollution for Promotion (March 21, 2017). *21st Century China Center Research Paper*, No. 2017-05, Available at SSRN: https://ssrn.com/abstract=3029046 or http://dx.doi.org/10.2139/ssrn.3029046

[30] Jiang Qisheng., Yang Shuwang, Tang Pengcheng, and Bao, Lei. 2020. Promoting the polluters? The competing objectives of energy efficiency, pollutant emissions, and economic performance in Chinese municipalities. *Energy Research & Social Science*, 61, 101365.

[31] Jiang Liangliang, Chen Lin, and Ping Lin. 2014. The determinants of pollution levels: firm-level evidence from Chinese manufacturing. *Journal of Comparative Economics*,

42(1): 118-142.

[32] Kahn Matthew E., Pei Li and Daxuan Zhao. 2015. Water pollution progress at borders: the role of changes in China's political promotion incentives. *American Economic Journal Economic Policy*, 7(4):223-242.

[33] La Ferrara Eliana, Alberto Chong, and Suzanne Duryea. 2012. Soap operas and fertility: Evidence from Brazil. *American Economic Journal Applied Economics*, 4 (4):1–31.

[34] Landry Pierre Francois. 2008. Decentralized Authoritarianism in China: The Communist Party's Control of Local Elites in the Post-Mao Era. Cambridge Press, Cambridge.

[35] Li Feiyang, Zhen Wang, and Liangxiong Huang, 2022. Economic growth target and environmental regulation intensity: Evidence from 284 cities in China. *Environmental Science and Pollution Research*, 29(7), 10235-10249.

[36] Li Hongbin, and Li-An Zhou. 2005. Political turnover and economic performance: the incentive role of personnel control in China. *Journal of public economics*, 89(9-10): 1743-1762.

[37] Lopez Ramon, and Siddhartha Mitra. 2000. Corruption, pollution, and the Kuznets environment curve. *Journal of Environmental Economics and Management*, 40(2):137-150.

[38] Lvovsky Kseniya, and Gordon Hughes, 1997. An Approach to Projecting Ambient Concentrations of SO_2 and PM10. Unpublished Annex 3.2 to World Bank, Clear water, blue skies: China's environment in the new century. World Bank, Washington, D.C.

[39] Maskin Eric, Yingyi Qian, and Chenggang Xu. 2000. Incentives, information, and organizational form. *Review of Economic Studies*, 67(2): 359-378.

[40] Shapiro Joseph S., and Reed Walker. 2018. Why is pollution from US manufacturing declining? The roles of environmental regulation, productivity, and trade. *American Economic Review*, 108(12): 3814-54.

[41] Shi Xinzheng, and Zhufeng Xu. 2018. Environmental regulation and firm exports: Evidence from the eleventh FYP in China. *Journal of Environmental Economics and Management*, 89:187-200.

[42] Sigma, Hilary, 2014. Decentralization and environmental quality: an international analysis

of water pollution levels and variation. Land Economics, 90(1), 114-130.

[43] Tang Pengcheng, Qisheng Jiang, and Lili Mi. 2021. One-vote veto: the threshold effect of environmental pollution in China's economic promotion tournament. *Ecological Economics*, 185, 107069.

[44] Van der Kamp, Denise Peter Lorentzen, and Daniel Mattingly. 2017. Racing to the bottom or to the top? Decentralization, revenue pressures, and governance reform in China. *World Development*, 95:164–176.

[45] Van Rooij, Benjamin, and Carlos Wing-Hung Lo. 2010. Fragile convergence: understanding variation in the enforcement of China's industrial pollution law. *Law Policy*, 32(1): 14-37.

[46] Wang Jiayi, and Lei Ping. 2021. The tournament of Chinese environmental protection: Strong or weak competition? *Ecological Economics,* 181, 106888.

[47] Whiting Susan H. 2004. "The cadre evaluation system at the grass roots: the paradox of party rule." in D. Yang, and B. Naughton (eds.), Holding China Together: Diversity and National Integration in the post-Deng Era, (New York: Cambridge University Press), 101-119.

[48] World Bank, 1997. Clear water, Blue Skies: China's Environment in the New Century. Technical report, Washington D.C.

[49] World Bank, 2007. Cost of Pollution in China: Economic Estimates of Physical Damages. Technical report. World Bank, East Asia and Pacific Region, Washington, DC.

[50] Wu Jianxin, and Ma Chunbo. 2019. The convergence of China's marginal abatement cost of CO2: an emission-weighted continuous state space approach. *Environmental and resource economics*, 72(4), 1099-1119.

[51] Wu Mingqin, and Xun Cao. 2021. Greening the career incentive structure for local officials in China: Does less pollution increase the chances of promotion for Chinese local leaders? *Journal of Environmental Economics and Management*, 107:102440.

[52] Wu Jianxin, Yanrui Wu, Xiumei Guo, and Tsun Se Cheong. 2016. Convergence of carbon dioxide emissions in Chinese cities: a continuous dynamic distribution approach. *Energy Policy*, 91: 207-219.

[53] Wu Jing, Yongheng Deng, Jun Huang, Randall Morck, and Bernard Yin Yeung. 2013. Incentives and outcomes, China’s environmental policy. *Capitalism and Society*, 9(1): 1–41.

[54] Yao Yang, and Muyang Zhang. 2015. Subnational leaders and economic growth: evidence from Chinese cities. *Journal of Economic Growth*, 20(4), 405-436.

[55] Zheng Siqi, Matthew E. Kahn, Weizeng Su, and Danglun Luo. 2014. Incentives for China's urban mayors to mitigate pollution externalities: The role of the central government and public environmentalism. *Regional Science and Urban Economics*, 47:61-71.

[56] Zheng Siqi, and Matthew E. Kahn. 2013. Understanding China's urban pollution dynamics. *Journal of Economic Literature*, 51(3): 731-772.

[57] Zhou Li-An. 2008. *Local Governments in Transition: Incentive and Governance of Officials in China*. Shanghai People’s Press, Shanghai.

Table 1 Summary statistics

Variables	Definition	N. Obs.	Mean	S.D.
Panel A: city level				
Target	SO_2 emissions reduction target (10^4 tons)	572	1.195	2.278
Compliance	Dummy=1 if the city fully complied with the reduction target; 0 otherwise	572	0.617	0.487
FHCC	Dummy=1 if the city is a historical famous city or treaty port	286	0.139	0.347
Ventilation	Ventilation coefficient	2,574	1657.915	502.278
GDP.G	Real annual GDP growth (%)	2,574	13.601	3.401
SO_2	Total annual industrial SO_2 emissions (10^4 tons)	2,574	6.077	6.166
CO_2	Total annual CO_2 emissions (tons)	2,574	845.599	1383.924
$PM_{2.5}$	Concentrations of $PM_{2.5}$ (μg /m^3)	2,574	53.488	22.933
Promotion	0 for termination, 1 for no change or lateral moves and 2 for promotion.	3,334	1.540	0.517
D.GDP	Difference in average term GDP growth relative to the previous mayor.	3,334	0.013	0.060
Panel B: industry level				
Pollution	SO_2 emissions intensity of 2-digit industries (tons/hundred million CNY)	39	117.303	245.102
Panel C: city-industry level				
ASIF				
N.Firm	Number of industrial firms	111,540	25.298	82.961
Output	Output value of industrial firms (million CNY)	111,540	2835.116	13687.45
CESD matched with ASIF				
N.Firm	Number of industrial firms	111,540	3.535	10.949
Output	Output value of industrial firms (million CNY)	111,540	982.079	5914. 236
N.Facility	Number of desulfurization facilities	111,540	1.105	6.199
Capacity	Desulfurization capacity (kg/h)	111,540	695.735	20216.41
Removal	SO_2 removal rates (%)	111,540	0.066	0. 172
Panel D: firm level (CESD matched with ASIF)				
N.Facility	Number of desulfurization facilities	394,517	0.312	1.499
Capacity	Desulfurization capacity (kg/h)	394,517	197.728	10516.51
Removal	SO_2 removal rates (%)	394,517	0.088	0.209

Table 2 Main results†

	(1)	(2)	(3)	(4)
	Ln(SO_2)	Ln(SO_2)	*GDP.G*	*GDP.G*
Target×*Post*	-0.091***	-0.092***	-0.334***	-0.335***
	(0.014)	(0.015)	(0.102)	(0.103)
Controls		YES		YES
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
N. Obs.	2,574	2,574	2,574	2,574
Adj-R^2	0.916	0.916	0.454	0.456

† *Target* is the SO_2 reduction target in the two FYP periods (10^{th} and 11^{th} FYP). *Post* is a dummy variable that takes the value of 1 if the year is 2006 or later and 0 otherwise. Control variables include target, logarithm form of population density, R&D investment, number of college students per 10,000 population, total imports and exports (full results for control variables see Table A3). Robust standard errors are clustered at the city level and are reported in the parentheses. *, ** and *** denote significance at 10%, 5% and 1%. The sample covers the period 2002-2010.

Table 3 IV estimate†

	(1) Ln(SO_2)	*(2) GDP.G*
Target×Post	-0.123***	-0.786**
	(0.041)	(0.339)
Controls	YES	YES
City FE	YES	YES
Year FE	YES	YES
N. Obs	2,574	2,574

† *Target* is the SO_2 reduction target in the two FYP periods (10^{th} and 11^{th} FYP). *Post* is a dummy variable that takes the value of 1 if the year is 2006 or later and 0 otherwise. Control variables include target, logarithm form of population density, R&D investment, number of college students per 10,000 population, total imports and exports. Robust standard errors are clustered at the city level and are reported in the parentheses. *, ** and *** denote significance at 10%, 5% and 1%. The sample covers the period 2002-2010.

Table 4 Other robustness tests†

	(1)	(2)	(3)	(4)
Panel A: Ln*(SO_2)*				
Target×Post	-0.083***	-0.095***	-0.105***	-0.108***
	(0.013)	(0.016)	(0.017)	(0.027)
Adj-R2	0.917	0.914	0.913	0.914
Panel B: *GDP.G*				
Target×Post	-0.280***	-0.358***	-0.431***	-0.477***
	(0.085)	(0.118)	(0.137)	(0.176)
Adj-R^2	0.525	0.453	0.457	0.462
Controls	YES	YES	YES	YES
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
N. Obs.	2,002	2,475	2,538	2,178

† *Target* is the SO_2 reduction target in the two FYP periods (10th and 11th FYP). *Post* is a dummy variable that takes the value of 1 if the year is 2006 or later and 0 otherwise. Control variables include target, logarithm form of population density, R&D investment, number of college students per 10,000 population, total imports and exports. Robust standard errors are clustered at the city level and are reported in the parentheses. *, ** and *** denote significance at 10%, 5% and 1%. The sample covers the period 2002-2010.

Table 5 Non-targeted pollutants†

	(1) Ln($PM_{2.5}$)	(2) Ln(CO_2)
Target×Post	0.003	-0.005
	(0.002)	(0.006)
Controls	YES	YES
City FE	YES	YES
Year FE	YES	YES
N. Obs.	2,574	2,574
Adj-R^2	0.966	0.971

† *Target* is the SO_2 reduction target in the two FYP periods (10^{th} and 11^{th} FYP). *Post* is a dummy variable that takes the value of 1 if the year is 2006 or later and 0 otherwise. Control variables include target, logarithm form of population density, R&D investment, number of college students per 10,000 population, total imports and exports. Robust standard errors are clustered at the city level and are reported in the parentheses. *, ** and *** denote significance at 10%, 5% and 1%. The sample covers the period 2002-2010.

Table 6 Industries with different pollution intensity †

	(1) Ln(*N.firm*)	(2) Ln(*output*)	(3) Ln(*N.firm*)	(4) Ln(*output*)	(5) Ln(*N.firm*)	(6) Ln(*output*)
Target×Post×Pollution	-0.002**	-0.007**			-0.003***	-0.014***
	(0.001)	(0.003)			(0.001)	(0.005)
Target×Post×D.Pollution			-0.011**	-0.043*		
			(0.005)	(0.025)		
City-Year FE	YES	YES	YES	YES	YES	YES
City-Industry FE	YES	YES	YES	YES	YES	YES
Industry-Year FE	YES	YES	YES	YES	YES	YES
N. Obs.	111,540	111,540	28,600	28,600	111,540	111,540
Adj-R^2	0.962	0.892	0.964	0.892	0.905	0.816

† *Target* is the SO_2 reduction target in the two FYP periods (10^{th} and 11^{th} FYP). *Post* is a dummy variable that takes the value of 1 if the year is 2006 or later and 0 otherwise. *Pollution* is the logarithm of SO_2 emissions intensity at the industry level defined as total SO_2 emissions divided by total added value. *D.Pollution* is a dummy variable that takes the value of 1 for the five most SO_2-polluting industries and 0 for the five least SO_2-polluting industries. Control variables include target, logarithm form of population density, R&D investment, number of college students per 10,000 population, total imports and exports. The outcome variables, number of firms and output, are aggregated separately to city-industry level. Robust standard errors are clustered at the city-industry level and are reported in the parentheses. *, ** and *** denote significance at 10%, 5% and 1%. The sample covers the period 2001-2010.

Table 7 New vs old firms. †

	(1)	(2)	(3)	(4)
	NEW		OLD	
Dependent Variable:	Ln(*firm*)	Ln(*output*)	Ln(*firm*)	Ln(*output*)
Target×Post×Pollution	-0.002**	-0.012***	-0.001	0.001
	(0.001)	(0.004)	(0.001)	(0.003)
City-Year FE	YES	YES	YES	YES
City-Industry FE	YES	YES	YES	YES
Industry-Year FE	YES	YES	YES	YES
N. Obs.	111,540	111,540	111,540	111,540
Adj-R^2	0.642	0.516	0.963	0.894

† *Target* is the SO_2 reduction target in the two FYP periods (10th and 11th FYP). *Post* is a dummy variable that takes the value of 1 if the year is 2006 or later and 0 otherwise. *Pollution* is the logarithm of SO_2 emissions intensity at the industry level defined as total SO_2 emissions divided by total added value. The outcome variables, number of firms and output for old and new firms, are aggregated separately to city-industry level. Robust standard errors are clustered at the city-industry level and are reported in the parentheses. *, ** and *** denote significance at 10%, 5% and 1%. The sample covers the period 2001-2010.

Table 8 The effects of *EOVV* on desulfurization

	(1)	(2)	(3)
Dependent Variables:	Ln(*N.facility*)	Ln(*capacity*)	*Removal_rate*
Panel A: city-industry level			
Target×Post×Pollution	0.003***	0.007*	0.002***
	(0.001)	(0.003)	(0.000)
City-Year FE	YES	YES	YES
City-Industry FE	YES	YES	YES
Industry-Year FE	YES	YES	YES
N. Obs.	111,540	111,540	111,540
Adj-R2	0.730	0.642	0.518
Panel B: firm level			
Target×Post×Pollution	0.002***	0.005***	0.001***
	(0.001)	(0.001)	(0.000)
Firm FE	YES	YES	YES
Industry-Year FE	YES	YES	YES
N. Obs.	356,336	356,336	356,336
Adj-R^2	0.625	0.568	0.541

† *Target* is the SO_2 reduction target in the two FYP periods (10^{th} and 11^{th} FYP). *Post* is a dummy variable that takes the value of 1 if the year is 2006 or later and 0 otherwise. *Pollution* is the logarithm of SO_2 emissions intensity at the industry level defined as total SO_2 emissions divided by total added value. In Panel A, the three dependent variables, total number of desulfurization facilities, total nameplate SO_2 treatment capacity and actual SO_2 removal rate, are aggregated to city-industry level. In Panel B, firm level data are directly used in the estimation. Robust standard errors are clustered at the city-industry level and are reported in the parentheses. *, ** and *** denote significance at 10%, 5% and 1%. The sample covers the period 2001-2010.

Table 9 Promotion and environmental compliance

	(1) Full sample	(2) Central & Eastern	(3) Western	(4) IV Full sample
Compliance×Post	0.363***	0.569***	-0.033	0.446***
	(0.129)	(0.177)	(0.206)	(0.186)
Compliance×D.GDP×Post	-2.293	0.369	-4.118	-1.963
	(2.501)	(2.837)	(4.035)	(2.111)
Compliance	-0.138	-0.178	-0.078	-1.684
	(0.120)	(0.156)	(0.209)	0.647)
D.GDP×Post	0.871	-2.393	2.786	2.274
	(2.249)	(2.422)	(3.714)	(2.053)
D.GDP	1.815***	2.512**	1.512*	1.647***
	(0.695)	(1.242)	(0.912)	(0.784)
Controls	YES	YES	YES	YES
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Cutoff point 1	-2.320***	-2.242***	-2.246***	-2.318***
Cutoff point 2	0.031	-0.042	0.634	0.030
N. Obs.	3,334	2,333	1,001	3,334
Adj-R^2	0.047	0.050	0.052	

† *Compliance* is a dummy variable which equals 1 if city c achieved the allocated SO_2 emissions reduction targets by each FYP period, and 0 otherwise. *Post* is a dummy variable that takes the value of 1 if the year is 2006 or later and 0 otherwise. *D.GDP* is the relative GDP growth measured as the difference between the average annual GDP growth during the current mayor's term and that during the predecessor's tenure. Control variables include logarithm form of FDI and the personal characteristics (age, local, educational attainment and the term length) of the mayor. Column (4) use ventilation coefficient as instrument variables. Robust standard errors are clustered at the city level and are reported in the parentheses. *, ** and *** denote significance at 10%, 5% and 1%. The sample covers the period 2001-2012.

Fig. 1 SO_2 emissions in China (1996-2010)

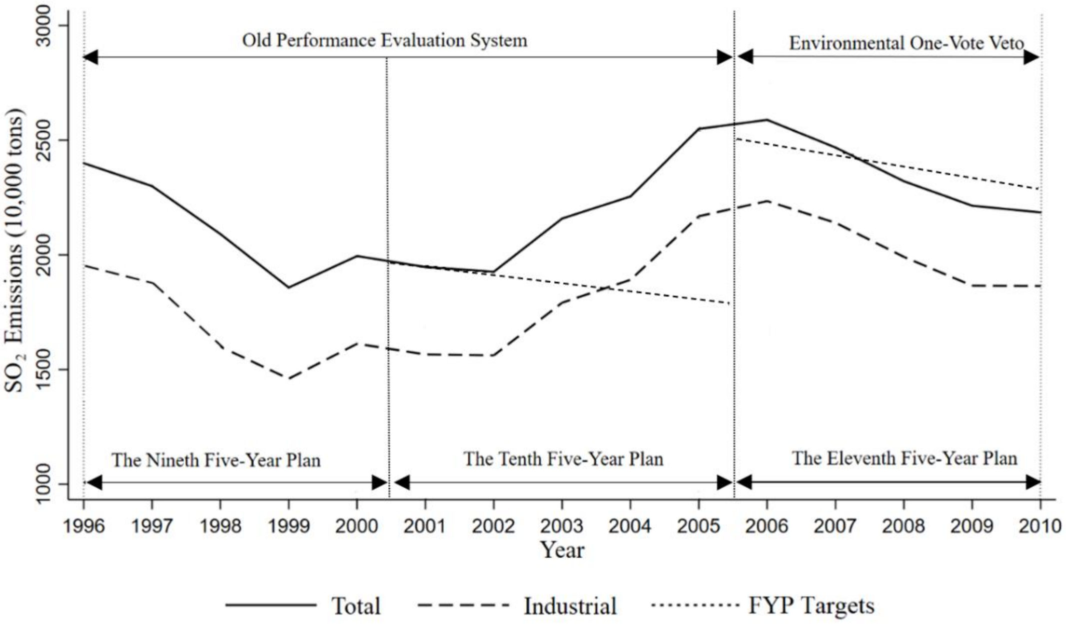


Fig. 2 Parallel trend tests

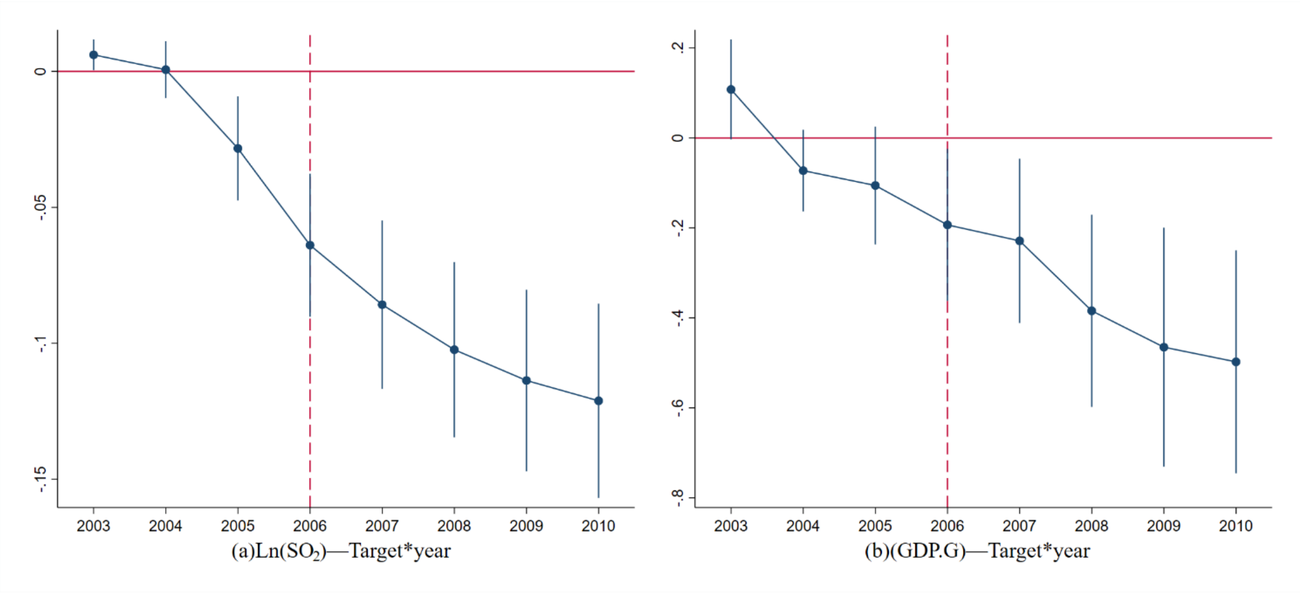
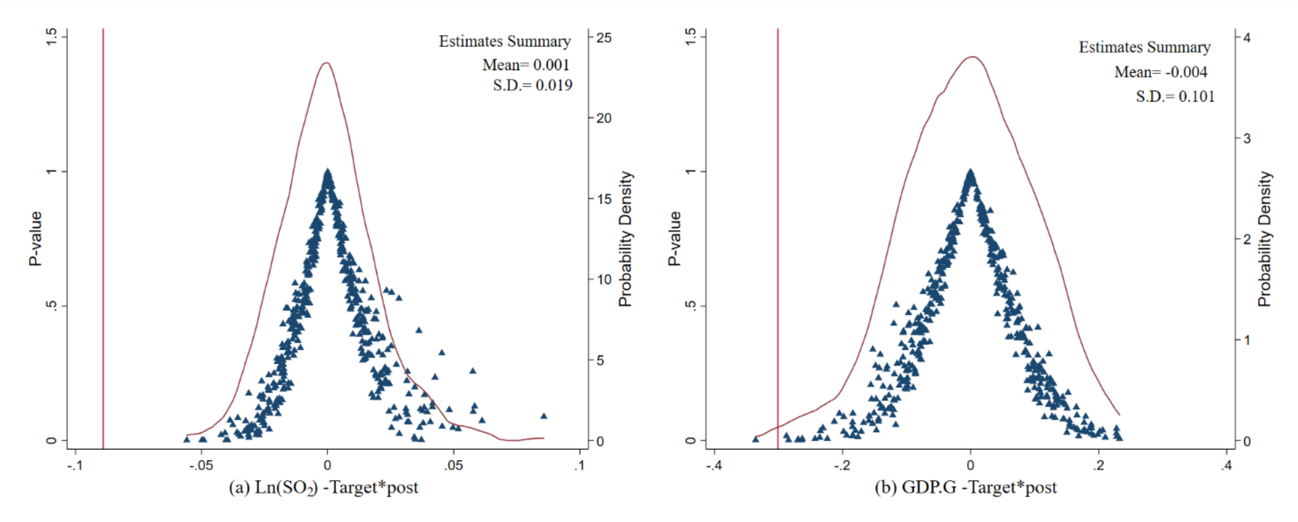


Fig. 3 Placebo test with random treatment assignment



Supplementary Materials

S1. Data on SO_2 mitigation targets

2006-2010 (11th FYP)

Mitigation targets for all PAA cities are manually sourced from the official websites of prefectural and provincial governments.

2001-2005 (10th FYP)

Information about prefectural level mitigation targets for the 10th FYP is limited. We managed to directly collect target information for 58 PAA cities from the official websites of prefectural and provincial governments. For all other PAA cities, we estimated emission reduction targets for the 10th FYP. China Environmental Statistical Yearbook 2002 reports the allocation plan for total emissions of major pollutants for the 10th FYP. The plan has SO_2 emission reduction targets for TCZ and non-TCZ zones for each province. Detailed information about how these targets were allocated among the prefectures within the TCZ or non-TCZ zones are unavailable. However, it is reasonable to assume that the allocation to lower administrative levels were proportional to their emission levels in base year (i.e. 2000). We therefore estimated the SO_2 emission reduction target of a PAA city in TCZ zone (or non-TCZ zone) as the proportion of the city's SO_2 emission in total provincial TCZ (or non-TCZ) SO_2 emission, multiplied by provincial SO_2 emission reduction targets.

S2. Data on SO_2 targets compliance

2006-2010 (11th FYP)

Targets compliance for all PAA cities are manually sourced from the official websites of prefectural and provincial governments.

2001-2005 (10th FYP)

Information about prefectural level targets compliance for the 10th FYP is also limited. We directly collect target compliance information for the same 58 cities from the official websites of prefectural and provincial governments. Targets compliance for all other cities are assessed based on actual emissions in 2010 and estimated emission targets for the 10th FYP.

S3. SO_2 Emission-airborne concentration calibration

Calculations of health-related benefits of SO_2 emission reduction is typically based on changes in pollutant concentrations ($\mu g/m^3$). This involves a model of calibration converting emission changes to changes in airborne concentrations. We use a similar approach to those developed in Ho and Jorgenson (2002), Ho and Jorgenson (2003) and Chen et al. (2018a), but recalibrate to China's city-level emission-concentration data.

First, all industries are categories into three classes by the height of emissions (low, medium and high). Total SO_2 emissions can be aggregated across all industries within the same height class (c = low, medium, high):

$$EM_c = \sum_{j \in c} EM_i \quad (5)$$

where low-emissions industries include agriculture and tertiary sectors, medium-emissions industries include most manufacturing industries, and high-emissions industries include electricity, steam & hot water sectors. The classification of industries into the emission height groups follows Ho and Jorgenson (2002). Table S1 provide the full list of industries by emission height class.

The emission data are easy to obtain. The next step is to convert the total emissions by class EM_c into air concentration. Following Ho and Jorgenson (2002) and Garbaccio et al. (2000), we use the following linear reduced form:

$$C = \gamma_{low} EM_{low} + \gamma_{medium} EM_{medium} + \gamma_{high} EM_{high} \quad (6)$$

The key parameters needed for the emission-concentration conversion are the three conversion coefficients γ_{low}, γ_{medium} and γ_{high}. Our starting point is Lvovsky and Hughes (1997) who estimated a set of coefficients (γ_{low}= 0.03364, γ_{medium} = 0.00607 and γ_{high}= 0.00096) using an emission-concentration dispersion model for urban SO_2 emissions in 11 Chinese cities. Following Ho and Jorgenson (2003) and Chen et al. (2018a), we recalibrated these coefficients proportionately for each city in our sample so that it matches each city's average SO_2 concentration level. Specifically, for each city, we conduct the following calibration:

$$C^c = 0.03364 \rho^c EM^c_{low} + 0.000607 \rho^c EM^c_{medium} + 0.00096 \rho^c EM^c_{high}$$

$$\text{s.t.} \quad EM^c_{low} + EM^c_{medium} + EM^c_{high} = E^c \quad (7)$$

where ρ^c, C^c, EM^c_{low}, EM^c_{medium}, EM^c_{high}, and E^c are the scaling factor, air concentration, emissions in low, medium and high industries, and total emissions in city c, respectively. We matched the firm level ASIF data with CESD data to obtain emission data by industry by city. The emissions are then collapsed into three emission height classes. According to the China Pollution Source Census 2007, industrial emissions usually consist of 91.4% of the total emissions, while the remaining 8.6% is non-industrial emissions. We proportionally scale up emissions by class to get total emissions. The average city-level SO_2 air concentration data for our sample period comes from the world satellite monitoring data provided by the National Aeronautics and Space Administration (NASA). The city-level calibration yields heterogeneous conversion coefficients. Fig. S1 reports the distribution of three conversion coefficients across cities.

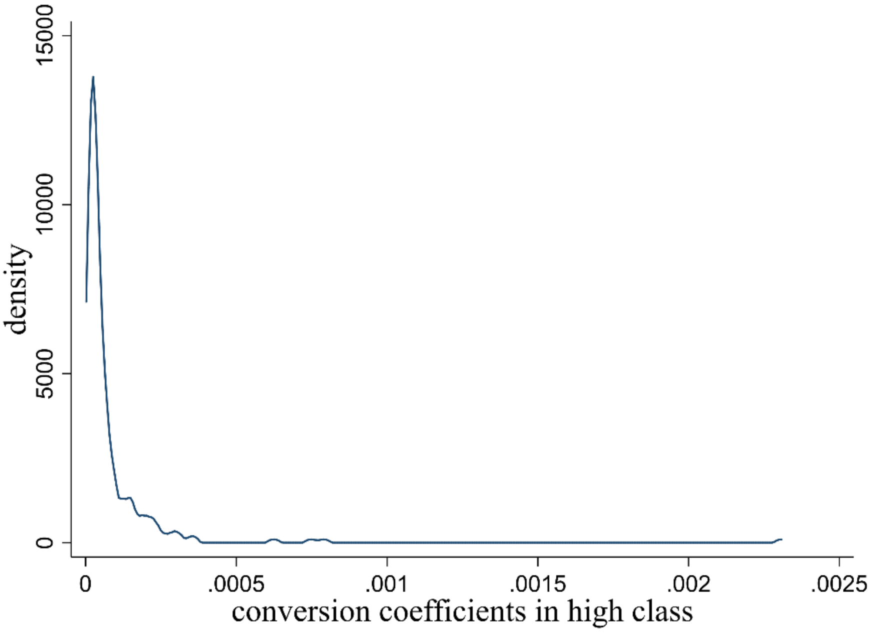
With these city-level conversion coefficients determined, we can now compute the reduction in the SO_2 concentration induced by the EOVV policy. We have calculated each city's policy-induced reductions in SO_2 emissions in Section 5.5. We assume the distributions of the reductions across the three classes are proportionate to the emission shares of the three classes in each city. Our final results suggest that the EOVV has resulted in an average reduction of concentration of 6.41 μg/m^3 for an increase of 10,000 tonnes in city's SO_2 reduction target. The changes in the SO_2 concentration can then be used to calculate health-related benefits of SO_2 emission reduction.

Table S1 The emission height of industries

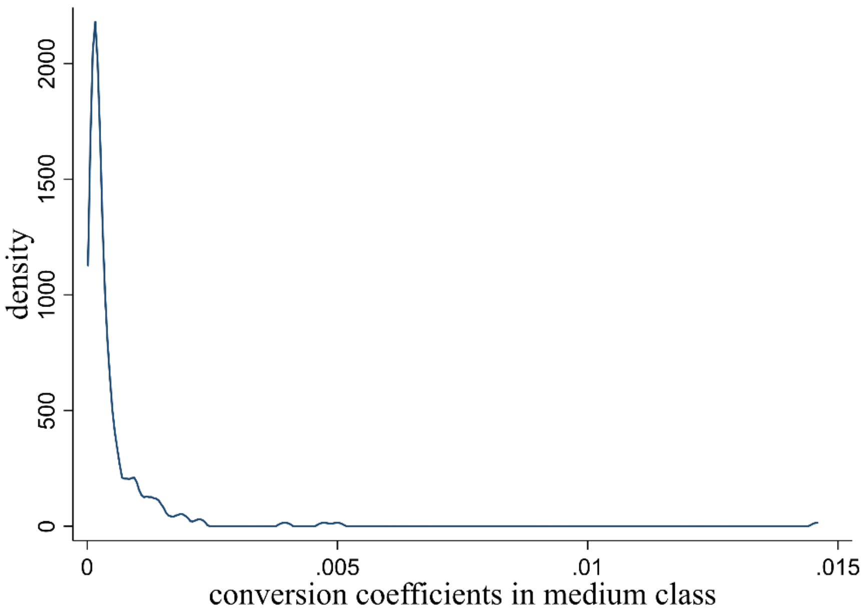
Sector	Emission height class
1 Agriculture	low
2 Coal mining and processing	medium
3 Crude petroleum mining	medium
4 Natural Gas Mining	medium
5 Metal ore mining	medium
6 Non-ferrous mineral mining	medium
7 Food products and tobacco	medium
8 Textile goods	medium
9 Apparel, leather	medium
10 Sawmills and furniture	medium
11 Paper products, printing	medium
12 Petroleum processing & coking	medium
13 Chemical	medium
14 Nonmetal mineral products	medium
15 Metals smelting and pressing	medium
16 Metal products	medium
17 Machinery and equipment	medium
18 Transport equipment	medium
19 Electrical machinery	medium
20 Electronic & telecom. equipment	medium
21 Instruments	medium
22 Other manufacturing	medium
23 Electricity, steam & hot water	high
24 Gas production and supply	medium
25 Construction	low
26 Transport and warehousing	low
27 Post & telecommunication	low
28 Commerce & Restaurants	low
29 Finance and insurance	low
30 Real estate	low
31 Social services	low
32 Health, Education, other services	low
33 Public administration Households	low

Data source: the table are directly sourced from the report *Air pollution in China: sector allocation of emissions and health damage* by Ho and Jorgenson (2002).

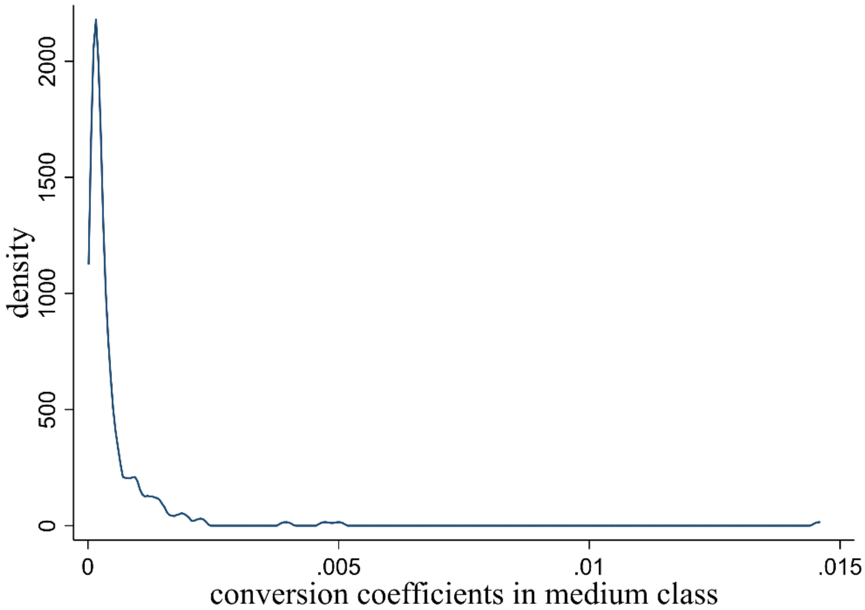
Fig. S1 Distribution of city-level conversion coefficients by emission height class



(a)The distribution of conversion coefficients in high class



(b)The distribution of conversion coefficients in medium class



(c)The distribution of conversion coefficients in low class

Table A1 Additional summary statistics

Variables	Definition	N. Obs.	Mean	S.D.
Panel A: city level				
RD	Annual R&D investment (million CNY)	2,574	165.977	931.641
Density	Population density (person/km^2)	2,574	412.995	316.415
Student	Number of college students per 10,000 population	2,574	123.006	178.252
Trade	Total imports and exports (million USD)	2,574	6177.727	27752.19
FDI	Foreign Direct Investment (million CNY)	2,574	23476.58	88010.58
Labor	Employees in urban areas (10,000)	2,574	68.818	88.431
Tertiary	Share of tertiary sector (%)	2,574	35.879	8.003
Ventilation	Ventilation coefficient	2,574	1657.915	502.278
Panel B: city-industry level (ASIF)				
N.New	Number of new firms	111,540	0.867	3.073
Output.New	Output value of new firms (million CNY)	111,540	33.217	275.014
N.Old	Number of old firms	111,540	12.738	41.682
Output.Old	Output value of old firms (million CNY)	111,540	1768.232	8779.268
Panel C: province level				
Target	SO_2 emissions reduction target (10^4 tons)	270	8.455	8.869
GDP.G	Real annual GDP growth (%)	270	9.346	7.230
SO_2	Total annual industrial SO_2 emissions (10^4 tons)	270	57.934	38.991
RD	Annual R&D investment (million CNY)	270	1582.315	3332.536
Density	Population density (person/km^2)	270	402.7494	384.664
Student	Number of college students per 10,000 population	270	414.743	159.144
Trade	Total imports and exports (million USD)	270	58894.33	118040.9
Ventilation	Ventilation coefficient	270	1678.789	439.594

Table A2 Baseline specification with different time periods†

	(1)	(2)	(3)	(4)
	Ln(*SO_2*)	Ln(*SO_2*)	*GDP.G*	*GDP.G*
Target×Post	-0.092***	-0.088***	-0.335***	-0.238*
	(0.015)	(0.016)	(0.099)	(0.123)
Controls	YES	YES	YES	YES
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
N. Obs.	2,574	4,004	2,574	4,004
Adj-R^2	0.916	0.846	0.454	0.385
Time period	2002-2010	2002-2015	2002-2010	2002-2015

† *Target* is the SO_2 reduction target in the two FYP periods (10^{th} and 11^{th} FYP). *Post* is a dummy variable that takes the value of 1 if the year is 2006 or later and 0 otherwise. Control variables include target, logarithm form of population density, R&D investment, number of college students per 10,000 population, total imports and exports. In Column (1) and (3), the sample covers the period 2002-2010, while in Column (2) and (4), the sample covers the period 2002-2015. Robust standard errors are clustered at the city level and are reported in the parentheses. *, ** and *** denote significance at 10%, 5% and 1%.

Table A3 Specifications with different controls†

	(1)	(2)	(3)	(4)	(5)	(6)
	Ln(SO_2)	Ln(SO_2)	Ln(SO_2)	*GDP.G*	*GDP.G*	*GDP.G*
Target×Post	-0.091***	-0.092***	-0.090***	-0.334***	-0.335***	-0.288***
	(0.014)	(0.015)	(0.015)	(0.102)	(0.103)	(0.099)
Target	0.043***	0.043***	0.042***		0.013	-0.011
	(0.015)	(0.015)	(0.015)		(0.113)	(0.108)
Ln(density)		0.097*	0.093*		0.784***	0.745***
		(0.055)	(0.055)		(0.290)	(0.275)
Ln(RD)		-0.251	-0.191		-3.076*	-2.541*
		(0.242)	(0.252)		(1.599)	(1.343)
Ln(student)		-0.075	-0.074		-0.052	0.003
		(0.060)	(0.059)		(0.226)	(0.259)
Ln(trade)		0.007	0.007		0.035	0.017
		(0.019)	(0.018)		(0.123)	(0.120)
Ln(tertiary)			-0.207			-5.729***
			(0.191)			(1.051)
Ln(labor)			-0.113			-1.620***
			(0.099)			(0.566)
Ln(FDI)			0.023			-0.053
			(0.017)			(0.106)
Constant	1.336***	2.513*	3.182*		27.303***	51.329***
	(0.015)	(1.411)	(1.766)		(9.716)	(9.377)
City FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
N. Obs.	2,574	2,574	2,574	2,574	2,574	2,574
Adj-R^2	0.916	0.916	0.916	0.454	0.456	0.480

† *Target* is the SO_2 reduction target in the two FYP periods (10th and 11th FYP). *Post* is a dummy variable that takes the value of 1 if the year is 2006 or later and 0 otherwise. Column (1) and (4) report the results without control variables except city and year fixed effects. Column (2) and (5) report the results which controls target, logarithm form of population density, R&D investment, number of college students per 10,000 population, total imports and exports. In Column (3) and (6) we add more control variables, include share of tertiary sector, FDI, and labor. All the sample covers the period 2002-2010. Robust standard errors are clustered at the city level and are reported in the parentheses. *, ** and *** denote significance at 10%, 5% and 1%.

Table A4 IV estimations, first stage

Dependent Variable:	*Target×Post*[††]			*Compliance*[†††]	*Compliance×Post*[†††]
	(1)	(2)	(3)	(4)	(5)
	PAA City Level	Province Level			
Ventilation×Post	0.316	-7.671**			0.087***
	(0.533)	(3.292)			(0.005)
FHCC×Post			1.938***		
			(0.615)		
Ventilation				0.117***	
				(0.043)	
Controls	YES		YES	YES	YES
Province FE		YES			
City FE	YES			YES	YES
Year FE	YES	YES	YES	YES	YES
N. Obs.	2,574	270	2,574	3,334	3,334
Adj-R^2	0.568	0.654	0.222		
F-test	1.588	0.845	18.50***	114.99***	755.24***

[†] *Target* is the SO_2 reduction target in the two FYP periods (10th and 11th FYP). *Post* is a dummy variable that takes the value of 1 if the year is 2006 or later and 0 otherwise. *Compliance* is a dummy variable which equals 1 if city c achieved the allocated SO_2 emissions reduction targets by each FYP period, and 0 otherwise. *Ventilation* is ventilation coefficient. *FHCC* is a dummy variable indicates that whether a city is a nationally listed Famous Historical and Cultural City (FHCC) or historical treaty ports. In Column (1)-(3), Control variables include target, logarithm form of population density, R&D investment, number of college students per 10,000 population, total imports and exports. In Column (4)-(5), Control variables include logarithm form of FDI and the personal characteristics (age, local, educational attainment and the term length) of the mayor. Robust standard errors (reported in parentheses) are clustered at the city level except Column (2) in which errors are clustered at the province level. *, ** and *** denote significance at 10%, 5% and 1%; [††] First-stage analyses for IV estimates reported in Table 3. Sample period: 2002-2010; [†††] First-stage analyses for IV estimates reported in Table 9. Sample period: 2001-2012.

Table A5 IV estimate with more control variables†

	(1) Ln(SO_2)	(2) *GDP.G*
Target×Post	-0.120***	-0.720**
	(0.042)	(0.323)
Controls	YES	YES
City FE	YES	YES
Year FE	YES	YES
N. Obs	2,574	2,574

† Column (1) and column (2) use FHCC or historical treaty port as instrument variables. *Target* is the SO_2 reduction target in the two FYP periods (10^{th} and 11^{th} FYP). *Post* is a dummy variable that takes the value of 1 if the year is 2006 or later and 0 otherwise. Control variables include target, logarithm form of population density, R&D investment, number of college students per 10,000 population, total imports and exports, share of tertiary sector, FDI, and labor. Robust standard errors are clustered at the city level and are reported in the parentheses. *, ** and *** denote significance at 10%, 5% and 1%. The sample covers the period 2002-2010.

Table A6 Additional results on the effects of *EOVV* on desulfurization based on discrete pollution indicator[†]

We consider the heterogeneous effects of *EOVV* on desulfurization using an alternative operationalization of pollution intensity indicator. Instead of using a continuous measure (Table 8), the pollution intensity indicator (*D.Pollution*) here takes a discrete definition: *D. pollution* =1 for the top 10 most pollution intensive industries and 0 for the top 10 least pollution intensive industries. The DDD estimates are larger in magnitude but overall consistent with those reported in Table 8.

	(1)	(2)	(3)
Dependent Variables:	Ln(*N.facility*)	Ln(*capacity*)	*Removal_rate*
Panel A: city-industry level[††]			
Target×Post×D.Pollution	0.030***	0.058**	0.011***
	(0.008)	(0.028)	(0.003)
City-Year FE	YES	YES	YES
City-Industry FE	YES	YES	YES
Industry-Year FE	YES	YES	YES
N. Obs.	28,600	28,600	28,600
Adj-R2	0.754	0.676	0.555
Panel B: firm level[†††]			
Target×Post×D.Pollution	0.006**	0.021**	0.004
	(0.003)	(0.008)	(0.002)
Firm FE	YES	YES	YES
Industry-Year FE	YES	YES	YES
N. Obs.	126,166	126,166	126,166
Adj-R^2	0.647	0.599	0.540

[†] *Target* is the SO_2 reduction target in the two FYP periods (10^{th} and 11^{th} FYP). *Post* is a dummy variable that takes the value of 1 if the year is 2006 or later and 0 otherwise. *D.Pollution* is a dummy variable equals 1 for the top 10 most pollution intensive industries and 0 for the top 10 least pollution intensive industries. In Panel A, the three dependent variables, total number of desulfurization facilities, total nameplate SO_2 treatment capacity and actual SO_2 removal rate, are aggregated to city-industry level. In Panel B, firm level data are directly used in the estimation. Robust standard errors reported in the parentheses. *, ** and *** denote significance at 10%, 5% and 1%. The sample covers the period 2001-2010; [††] S.E.s clustered at the city-industry level; [†††] S.E.s clustered at the city level.

Table A7 Promotion and environmental compliance for Party secretaries†

	(1) Full sample	(2) Central & Eastern	(3) Western
Compliance×Post	0.193	0.194	-0.063
	(0.176)	(0.233)	(0.280)
Compliance×D.GDP×Post	-3.040	-1.320	0.550
	(3.134)	(4.816)	(4.845)
Compliance	0.037	-0.005	-0.035
	(0.170)	(0.225)	(0.268)
D.GDP×Post	1.222	-0.363	0.618
	(2.917)	(4.794)	(3.255)
D.GDP	-0.267	-0.374	3.761*
	(0.265)	(0.290)	(1.968)
Controls	YES	YES	YES
City FE	YES	YES	YES
Year FE	YES	YES	YES
Cutoff point 1	-5.671***	-5.849***	-3.939**
Cutoff point 2	-2.568***	-2.990***	0.326
N. Obs.	2,755	1,943	812
Adj-R^2	0.0813	0.0890	0.121

† *Compliance* is a dummy variable which equals 1 if city c achieved the allocated SO_2 emissions reduction targets by each FYP period, and 0 otherwise. *Post* is a dummy variable that takes the value of 1 if the year is 2006 or later and 0 otherwise. *D.GDP* is the relative GDP growth measured as the difference between the average annual GDP growth during the current mayor's term and that during the predecessor's tenure. Control variables include logarithm form of FDI and the personal characteristics (age, local, educational attainment and the term length) of the mayor. Column (4) use ventilation coefficient as instrument variables. Robust standard errors are clustered at the city level and are reported in the parentheses. *, ** and *** denote significance at 10%, 5% and 1%. The sample covers the period 2001-2012.

Fig. A1 City-level SO_2 emissions reduction targets for the 11th FYP (2006-2010)

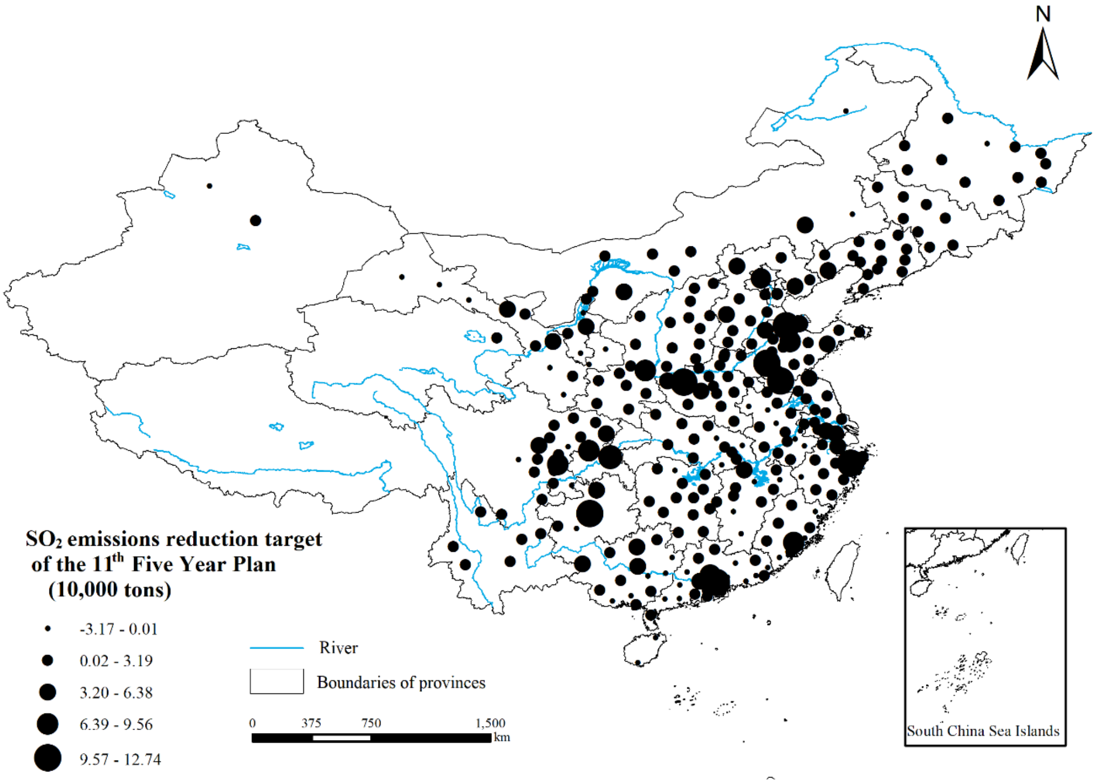


Fig. A2 City-level SO_2 reduction compliance for the 11th FYP (2006-2010)

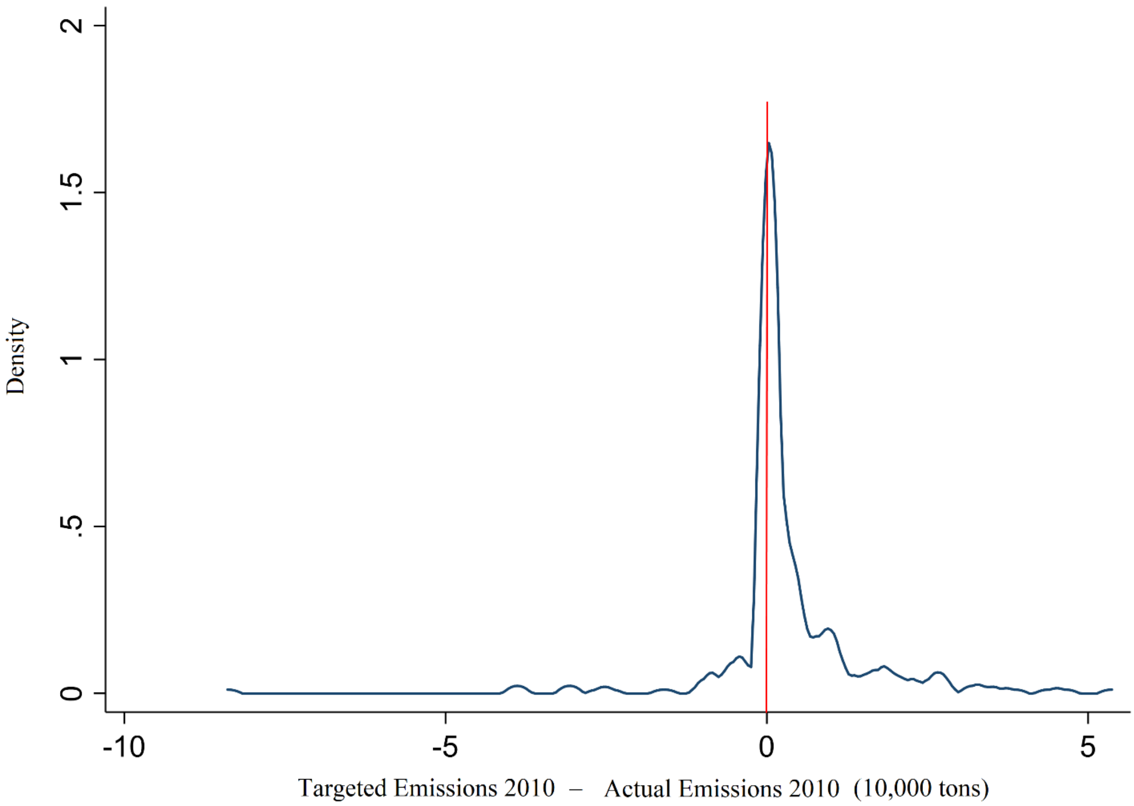
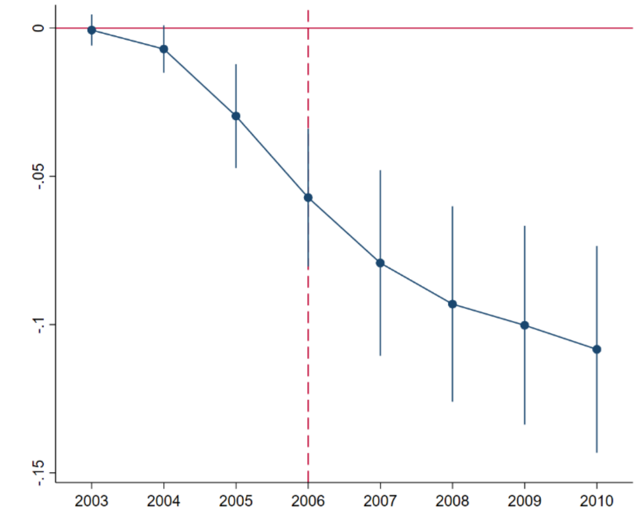
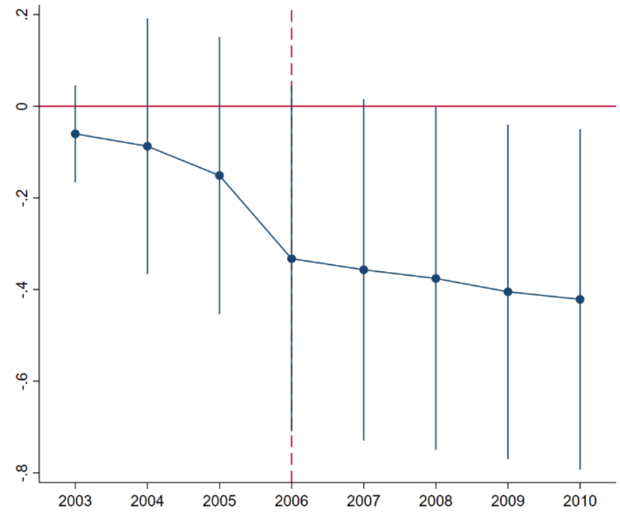


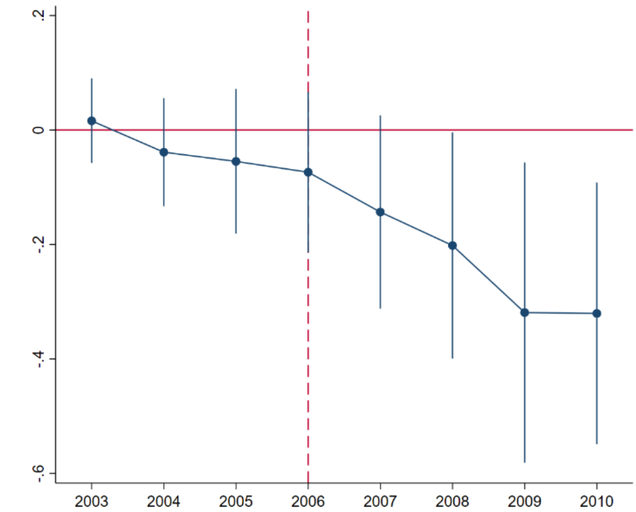
Fig. A3 Parallel trend tests for TCZ and non-TCZ cities



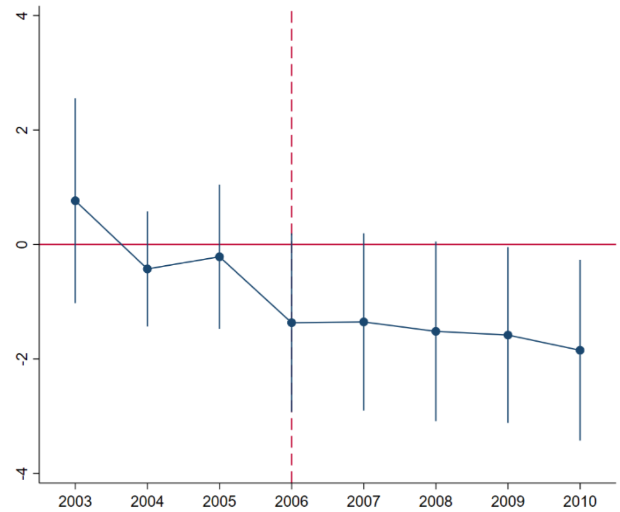
(a) Ln(SO_2)—Target*year—TCZ



(b) Ln(SO_2)—Target*year—non-TCZ



(c) (GDP.G)—Target*year—TCZ



(d) (GDP.G)—Target*year—non-TCZ