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Environmental regulation, political incentives, and mortality in China

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ABSTRACT

China enacted an environmental regulation policy in 1998, the "Two Control Zones" (TCZ) policy, to control air pollution in selected cities. Using a panel dataset of 208 prefectural cities for 2001–2012, this study applies a difference-in-differences approach to examine the policy's impact on mortality and identify the role of political incentives. We find the following aspects. (1) The policy significantly reduces mortality in TCZ cities relative to that in non-TCZ cities by 0.305‰ in the period when the policy is strictly enforced. On average, it translates into a 5.2% reduction in mortality. (2) The effect is particularly salient in the years when local officers are evaluated for political promotion and/or when they face stronger pressure for promotion, thus suggesting that political incentives play an important role in determining the effectiveness of environmental regulation policy. (3) The policy reduces industrial emissions of sulfur dioxide instantaneously, while the accumulation of which eventually leads to a lagged reduction in mortality in the cities. (4) The policy yields health benefits worth 1.1 trillion yuan for the treatment period in our sample (i.e., 2006–2012), which accounts for approximately 5.1% of GDP in 2006.

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1. Introduction

As one of the most common and easily perceived environmental problems, air pollution has attracted worldwide attention in both academic and policy circles. Early research on the impact of air pollution on mortality mainly focused on cases in developed countries

(e.g., Pope III et al., 2002; Chay and Greenstone, 2003a; Currie and Neidell, 2005; Currie et al., 2009); however, in recent years, more effort has been devoted to studies in developing countries. Particularly in the Chinese context, many scholars point to the fact that serious air pollution has become a vital factor for mortality and the slow growth of life expectancy (Ebenstein et al., 2015, 2017; Wang et al., 2018; Zhang et al., 2019; Bombardini and Li, 2020).[1] These studies considerably raise public awareness of the necessity for environmental protection, and hence, promote governments' implementation of various environmental regulation policies.[2]

In this regard, the Chinese central government has made a series of attempts to implement environmental regulation policies over the past few decades. A significant initiative was the "Two Control Zones" (TCZ) policy in 1998, under which certain cities were selected and defined as either acid rain control zones or sulfur dioxide (SO_2) pollution control zones. According to the policy design, stricter regulations on SO_2 emissions were imposed on these selected TCZ cities to ensure a reduction of such emissions. In this context, the TCZ policy acts similarly to the Clean Air Act Amendment (CAAA) implemented in the United States in 1970.[3] While other studies have indicated the effectiveness of environmental regulations in improving public health in developed countries (Chay and Greenstone, 2003b; Luechinger, 2014; Deschenes et al., 2017), regulatory effectiveness in developing countries remains unclear. For example, there is positive evidence for the Mexican Clean Industry Program (Foster et al., 2009), air quality regulations in Delhi (Foster and Kumar, 2011), water pollution regulations in China (Wang and Yang, 2016), and temporary air pollution control measures for the APEC summit and military parade in Beijing (Lin et al., 2017). Nevertheless, Greenstone and Hanna's (2014) study on regulations on air and water pollution in India, based on city-level panel data, found that while regulations were effective in reducing concentrations of particulate matter, SO_2 and NO_2 in the air, pollution reduction did not significantly reduce infant mortality.

Additionally, political factors have been shown to be important in the effectiveness of environmental regulations (Polk and Schmutzler, 2005; Anderson and Mizak, 2006; Miao and Li, 2016; Kauder et al., 2018; Catola and D'Alessandro, 2020; Karakas and Mitra, 2020; Matsueda, 2020; Xie and Cheng, 2021). In particular, Nentjes et al. (2007) pointed out that different levels of bureaucratic effort mattered for the form and effectiveness of environmental policies and, subsequently, firms' behavioral responses. Another cluster of studies took a step further to identify the key political determinants of enforcement for environmental regulations, including election incentives (List and Sturm, 2006), rent-induced corruption (Burgess et al., 2012), decentralization borders (Lipscomb and Mobarak, 2016), and, especially, promotion incentives for local bureaucrats in the Chinese context (Zheng et al., 2014; Kahn et al., 2015; He et al., 2020).[4]

This study investigates the effect of the TCZ policy on mortality in Chinese cities and identifies the important role of political incentives. Taking advantage of the variation in the environmental regulation across cities and over time, we situate the quasi-experimental setting in a difference-in-differences (DID) framework based on a panel dataset containing 208 prefectural cities for 2001–2012. The treatment group is defined as those cities in which the whole domain is recognized as the TCZ, while the cities in which no area of the domain is recognized as part of the TCZ constitute the control group. While the TCZ policy was introduced in 1998, its implementation was unsuccessful as insufficient incentives were given to local officers for its enforcement. The central

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[1] Ebenstein et al. (2017) applied a regression discontinuity design to study the Chinese policy of providing winter heating in cities north of the Huai River while denying heat to the south. They found that the concentration of total suspended particles (TSP) in northern cities was 55% higher than that in southern cities, which increased cardiopulmonary mortality in northerners and eventually reduced the life expectancy by 5.5 years relative to that of southerners. Using detailed mortality data taken from China's Disease Surveillance Points System from 1999 to 2012, Ebenstein et al. (2015) showed that air pollution significantly slowed the decline in mortality caused by economic development. Using daily data, Wang et al. (2018) showed that the concentration of SO_2 in the air was positively correlated with mortality, both all-cause and cardiopulmonary, and provided empirical evidence that short-term exposure to SO_2 was harmful to people's health. Zhang et al. (2019) conducted a follow-up survey on representative samples of older Chinese adults from 2000 to 2011 and found that for every 10 $\mu g/m^3$ increase in cumulative SO_2 exposure, the odds of death increased by nearly 1%. Bombardini and Li (2020) found that the export expansion induced by tariff reductions in China led to an increase in infant mortality because of the increased local pollution concentrations.

[2] Since the mid- and late 20th century, various countries' governments have successively issued environmental regulations. The main purpose was to advocate energy conservation and emission reduction, to realize the dual goal of pursuing economic development and environmental protection.

[3] The CAAA sets clean air standards by limiting the highest concentrations of a variety of substances in the air, including SO_2 and TSP. Authorities inspected each county and imposed stricter supervision on nonattainment counties. For instance, there are emission ceilings for existing plants, and any substantial investment by a new or existing plant must be accompanied by the installation of the most advanced pollution abatement equipment in nonattainment counties.

[4] Zheng et al. (2014) pointed out that political promotions imposed pressure on local officials to tackle pollution issues. Kahn et al. (2015) found that China's environmental target responsibility system incentivized local governors to increase their effort to reduce water pollution at political boundaries, as local governors who sought to rise in the government's power structure recognized that high pollution levels would reduce their promotion chances. He et al. (2020) illustrated that, after the central government explicitly used water quality readings to help determine the promotion of local government officials, local governments would impose tighter regulations on upstream firms in a distorted manner to respond to the political incentives for pollution. In addition to the enforcement of environmental regulations, it has been shown in other areas that China's unique political system of performance-based bureaucratic promotion has exerted significant impacts, such as inter-jurisdictional tournament competition (Li and Zhou, 2005; Xu, 2011; Wu et al., 2013; Yao and Zhang, 2015), the top-down amplification of economic growth targets (Li et al., 2019), the sacrifice of the environment for economic pursuits (Jia, 2017; Zhang, 2021), government's window dressing behaviors in public education (Fang et al., 2020), and unreliable public government data on workplace safety (Fisman and Wang, 2017; Shi and Xi, 2018).

authority included the emissions quota in the performance evaluation system for all top local bureaucrats (city mayors and party secretaries) nationwide in 2006. This move facilitated strong political incentives for the local governments in TCZ cities to enforce the policy, owing to the more authoritarian emissions-reduction mandates in these cities. Therefore, we follow Chen et al. (2018) and declare the year 2006 and thereafter as the post-treatment period of the TCZ policy implementation.[5]

Our empirical evidence suggests that the TCZ policy in the post-2006 period significantly reduces the mortality rate in the treated cities relative to that in non-TCZ cities by 0.305‰. On average, it transforms into a 5.2% decrease in mortality in the TCZ cities.[6] Moreover, we show that the effect is particularly salient in the years when local officers are evaluated for political promotions and/or when they face stronger pressure for promotion,[7] thus further suggesting the important role of political incentives in determining the effectiveness of environmental regulation policies. Furthermore, we confirm that the TCZ policy reduces industrial SO_2 emissions instantaneously, while the accumulation of which eventually leads to a lagged reduction in mortality in the cities. Finally, we gauge the health benefits of the TCZ policy in terms of both the reduced mortality and lower incidence of disease, and estimate the health benefits to amount to 1.1 trillion yuan for the treatment period in our sample (i.e., 2006–2012), accounting for approximately 5.1% of GDP in 2006.

Our study contributes to several branches of the literature. First, we supplement empirical evidence on the effectiveness of environmental regulations in reducing mortality in developing countries. In this regard, the work that is most closely related to our study is Tanaka (2015), who also examines the effect of the TCZ policy on infant mortality. Using infant mortality data from the Chinese Disease Surveillance System, he finds a 20% reduction in infant mortality in TCZ cities relative to that in non-TCZ cities. However, given the examined period of 1991–2000, his study only captures the transient effect of the TCZ policy in 1998, and not its long-term effect.[8] However, owing to a lack of political incentives to enforce the TCZ policy in the early years of its implementation, there is considerable evidence of the ineffectiveness of the policy after 2000 (see Section 2 for a detailed discussion on this point). In particular, Chen et al. (2018) explicitly argue that the TCZ policy was not effectively enforced until the central government included the pollution emissions quota into the performance evaluation system for local officers in 2006. Therefore, this study more accurately estimates the impact of the policy over a relatively longer term.

Second, our study supplements the literature on what motivates local governments to enforce environmental regulation policies. We hold that the effectiveness of environmental regulation policies is primarily shaped by the political incentives faced by local bureaucrats. This fact is substantiated by three aspects: (1) the TCZ policy only became effective until political incentives were introduced by the central government in 2006; (2) the effect of the TCZ policy is most salient in the years of local bureaucrats' performance evaluation for promotion or demotion, while it is quantitatively smaller and statistically less significant in non-evaluation years; and (3) the effect is stronger in cities whose leaders are confronted with greater pressure for political promotion.

Third, we add to the limited but growing literature on the impacts of the TCZ policy in China. Most studies in this area have focused on the policy's impacts on cities' economic growth, exports, and foreign direct investment (Lu et al., 2012; Hering and Poncet, 2014; Cai et al., 2016; Chen et al., 2018). Our work extends these studies by examining the impacts of the policy on mortality, which appears to be its primary objective. In this respect, we also find that the TCZ policy reduces industrial SO_2 emissions in TCZ cities relative to those in non-TCZ cities by 19%, which reveals the mechanism of the impact of the TCZ policy on mortality. Furthermore, we quantify the health benefits of the TCZ policy in terms of a reduction in both mortality and disease incidence.

The remainder of the paper is organized as follows. Section 2 introduces the institutional background of the TCZ policy in China. Section 3 establishes the empirical framework and describes the data used. Section 4 presents the main empirical results, highlights the role of political incentives, and conducts a series of robustness checks and placebo analysis. Section 5 explores the mechanisms of the impact of the policy, while Section 6 evaluates the potential health benefits of the policy. Finally, Section 7 concludes the study.

2. Institutional background

SO_2 has been one of the main pollutants of China's atmosphere for a long time. Since the 1980s, annual SO_2 emissions in the country have increased rapidly, reaching 15.64 million tons in 1989 and 23.46 million tons in 1997.[9] SO_2 emissions not only threaten public health but also become the source of acid rain, and lead to serious damage to the ecological environment. According to the *China Environmental Bulletin*, in 1998, the annual pH level of the rainfall in more than half of all Chinese cities was lower than 5.6, and areas covered by acid rain accounted for more than 30% of the national territory. China had become the third largest acid rain area in the

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[5] See a detailed discussion on this point in the next section.

[6] Given that our dependent variable is the overall mortality rate in the cities, which contains all types of mortality including infant mortality and other mortalities that may be less sensitive and need time to respond to environmental pollution, this baseline estimate may be a mixture of contemporaneous and lagged effects of the TCZ policy.

[7] There might be a concern that this particularly salient effect in certain years may be confounded by the lagged effects of the policy. While we acknowledge that, given the lack of sensitive mortality data (such as infant mortality), we cannot fully rule out this possibility, we add a more detailed discussion in subsection 5.3 to highlight that our conclusion on the role of political incentives is supported by different attempts conducted in the current paper.

[8] As elaborated in Section 2 and Fig. 2, the TCZ policy did appear to reduce SO_2 when it was initially introduced in 1998; however, this reduction was only in effect for a very short time (i.e., 1998–2000); thus, Tanaka's (2015) findings are likely to capture this transient effect of the TCZ policy in 1998, rather than its long-run effect.

[9] Data are obtained from the *China Environmental Bulletin*, issued by the Ministry of Ecology and Environment of the People's Republic of China (1989 and 1997) (https://www.mee.gov.cn/xxgk2018/).

world, after Europe and North America.

As part of the policy responses to these serious problems caused by SO_2 pollution, the Chinese central government established the TCZ nationwide in 1998. That is, city areas with rainfall pH levels no higher than 4.5 were designated as acid rain control zones, whereas city areas with annual average SO_2 concentrations exceeding the national secondary standard[10] for the previous three years were designated as SO_2 pollution control zones.[11] Noteworthily, they are essentially areas with serious SO_2 pollution in nature: there is no difference between the two in terms of policy implementation. As depicted in Fig. 1, SO_2 pollution control zones are all distributed in northern China, while acid rain control zones are in southern China. This situation reflects the fact that under varying meteorological, topographical, soil, and other natural conditions, sulfur emissions mainly form SO_2 and acid rain in northern and southern China, respectively. Overall, the TCZ covers a total area of 1.09 million square kilometers and comprises 11.4% of the national territory, while the total SO_2 emissions in the TCZ accounted for 60% of the national total in 1998 (He et al., 2002).

Under the policy, TCZ cities are required to take measures to prevent acid rain and SO_2 pollution and implement stricter environmental regulations. These steps include measures that can effectively reduce SO_2 emissions in the short term, such as total SO_2 emissions control, production restriction or closure of high-sulfur coal mines, and prohibition of new coal-fired power plants. Meanwhile, the adoption of more sustainable development approaches is also encouraged, such as strengthening technological upgrading, speeding up the construction of coal washing and processing facilities, accelerating the construction of desulfurization facilities and those for industrial waste gas, and vigorously promoting cleaner production industries.[12] By implementing all these measures, the central authority hopes to reduce SO_2 in the short term while promoting resource conservation and comprehensive utilization in the long term.

In contrast to the policy design, at the onset of the TCZ policy implementation in 1998, the policy effect of reducing SO_2 emissions was only small and temporary. As visually presented in Fig. 2, total and industrial SO_2 emissions declined for a short period (1998–1999) when the TCZ policy was initially introduced; however, both indexes subsequently rose and reached the historically highest level in 2006. The ineffectiveness of the TCZ policy prior to 2006 has also been well documented by different sources. In particular, based on the TCZ policy progress report prepared by the State Environmental Protection Administration of China (SEPA) in 2004, there were 279 major SO_2 pollution abatement projects scheduled for implementation by the central government in the TCZ during the 10th Five-Year Plan of China (i.e., 2001–2005). They were expected to reduce SO_2 emissions by 3.037 million tons per year. However, by the end of 2004, only 77 projects had been completed, thus accounting for 28.3% of the total. The completed projects reduced SO_2 emissions by 0.5 million tons per year and met only 19% of the target; 93 projects (i.e., 34.2% of the scheduled projects) had not yet been launched. Another official document issued by the SEPA in November 2005 clearly stated that "… since the implementation of the TCZ policy, the situation of acid rain and SO_2 pollution in China is still severe. China's coal consumption soared from 1.25 billion tons in 2000 to 2 billion tons in 2005, and SO_2 emissions increased from 19.95 million tons in 2000 to 26.8 million tons in 2005. After 2000, the acidity of precipitation in China showed an overall increasing trend. Total areas covered by the heavy acid rain increased from 3.8% in 2002 to 6.8% in 2004, meaning a growth of 79%." All these reports point to the fact that the TCZ policy achieved few of its objectives in the early stages of implementation.

The unsuccessful practices of the TCZ policy led the central government to reconsider its strategy. Consequently, in 2006, the central government included, for the first time, emissions quotas for specific pollutants in local bureaucrats' performance evaluation system in *all* cities, covering both TCZ and non-TCZ cities. More specifically, the State Council announced explicitly that an accountability system had been established, and that the assessment of political performance would be considered as one of the bases for the selection, appointment, reward, and punishment of leading cadres, with environmental indicators listed as an essential part of the assessment content.[13] Most importantly, a one-vote veto on environmental protection was introduced into the performance evaluation system. It meant that if a local bureaucrat failed to meet the environmental targets, they would not be promoted regardless of other performance measures.

As this new administrative regulation was imposed on *all* local government leaders (i.e., city mayors and party secretaries) with the responsibility of meeting emissions targets set by the provincial and central governments for pollutants such as SO_2, all local governments carried out annual target management for planned indicators and regularly conducted and published environmental assessment outcomes across the nation. As depicted in Fig. 2, the total industrial SO_2 emissions in China reached a historical high of

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[10] According to the *National Standard of the People's Republic of China: Ambient Air Quality Standard (GB3095-1996)*, the limit of the national secondary standard set for the annual average SO_2 concentration is 0.06 mg/m^3.

[11] Included here are only the basic conditions for designating the two control zones. Considering the level of social development and economic bearing capacity of China, some additional conditions need to be met. The final acid rain control zones need to meet the following three conditions simultaneously: (1) The pH level of monitored precipitation is not greater than 4.5. (2) Sulfur settlement exceeds the critical load. (3) SO_2 emissions are large. Similarly, the final SO_2 pollution control zones need to meet the following four conditions simultaneously: (1) The annual average SO_2 concentration in ambient air in recent years exceeds the national secondary standard. (2) The daily average SO_2 concentration exceeds the national tertiary standard (daily average SO_2 concentration is no more than 0.25 mg/m^3). (3) SO_2 emissions are large. (4) The city acts as the basic control unit. State-level poverty-stricken counties are not included in the two control zones.

[12] For more detailed information, see *the Reply from the State Council on Relevant Issues Concerning Acid Rain Control Zones and Sulfur Dioxide Pollution Control Zones (National Letter [1998] No. 5)* released by the State Council on January 12, 1998. http://www.gov.cn/zhengce/content/2010-11/22/content_5181.htm.

[13] For more detailed information, see *Decision of the State Council on Implementing the Scientific Outlook on Development and Strengthening Environmental Protection (Guo Fa [2005] No. 39)*, released by the State Council on December 3, 2005. *http://www.gov.cn/zhengce/content/2008-03/28/content_5006.htm*.
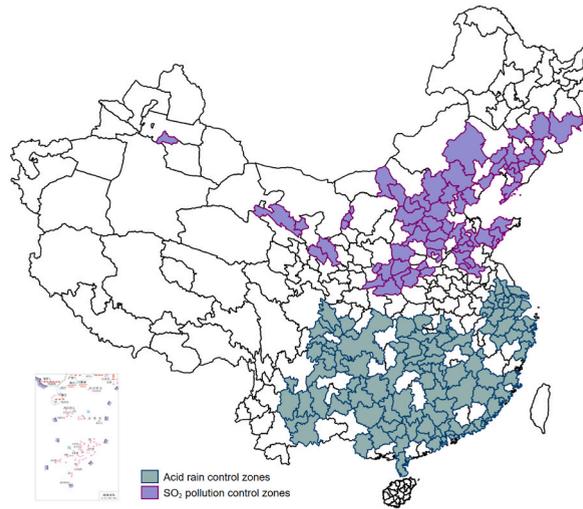
Fig. 1. The distribution of acid rain and SO$_2$ pollution control zones in China.
Source: Reply from the State Council on Relevant Issues Concerning Acid Rain Control Zones and Sulfur Dioxide Pollution Control Zones (National Letter [1998] No. 5)
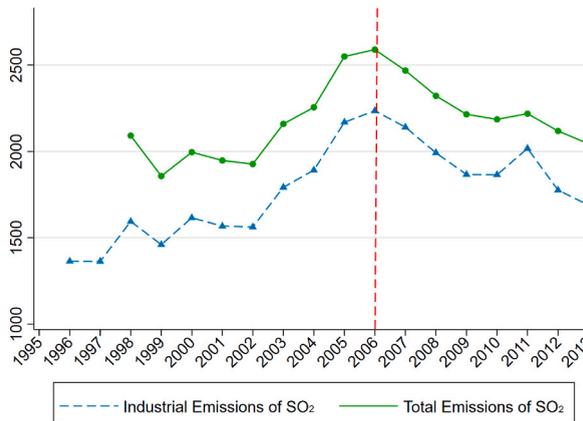

Fig. 2. The Time Trends of SO$_2$ Emissions. *Note:* The vertical line represents the year when the central authority included the emissions quota in the performance evaluation system for top local bureaucrats.
Source: China's Environmental Statistics Yearbook

22.35 million tons in 2006, and subsequently declined continuously, reaching 18.66 million tons in 2009, thus fulfilling the emissions reduction target set in the 11th Five-Year Plan (i.e., 2006–2010), a year ahead of schedule. Such an achievement indicates that the new administrative regulation has been successfully motivating *all* local bureaucrats toward stricter control of environmental pollution nationwide since 2006.[14] Given that the central authority stipulated a higher standard for pollutant emission in the originally designated TCZ cities in 1998, the bureaucrats in these cities faced stronger pressure and incentives to reduce pollutant emissions than those in non-TCZ cities in the post-2006 period.[15] Consequently, Chen et al. (2018) explicitly treat 2006 as the cut-off year for the actual implementation of the TCZ policy. We follow them for the empirical identification in this study.

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[14] Zhou (2007) pointed out that under China's political system, local bureaucrats only paid attention to indicators within the scope of the performance evaluation system due to promotion incentives, and ignored those outside the scope.

[15] The stronger pressure and incentives of the TCZ cities are evidenced by the fact that the emission quotas were more demanding in TCZ cities than elsewhere. To show this point, we manually collected the quotas of total SO$_2$ emissions allocated to each city in the 11th (2006–2010) and 12th (2011–2015) Five-Year Plans and calculated the targeted SO$_2$ emission reduction, which is measured by the difference between the target SO$_2$ emissions for that five-year period and the actual SO$_2$ emissions at the end year of the previous five-year period. We then run a regression to show whether the targeted SO$_2$ emission reduction varies between TCZ and non-TCZ cities. The results are reported in Table A2 of the Appendix, where we find the coefficient of TCZ_city to be significantly positive. This suggests that the TCZ cities were indeed allocated with higher emission reduction targets and therefore faced greater pressure and incentives than non-TCZ cities.

3. Empirical strategy

3.1. Econometric specification

Exploiting the quasi-experimental setting that arises from the strict implementation of the TCZ policy, we construct the DID framework to estimate the effect of the policy on mortality. Particularly, the regression model is set up as follows:

$$y_{it} = \alpha + \beta TCZ_i * Post_t + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{1}$$

where the dependent variable (y_{it}) is the mortality rate for city i in year t, which is measured as the proportion of annual deaths to the total population;[16] TCZ_i is an indication of the treated cities, which equals 1 if the entire domain of city i is designated as TCZ, and 0 otherwise.[17] $Post_t$ is a dummy variable that indicates the post-treatment period, and takes on a value of 1 for year 2006 and onward, and 0 otherwise.[18] X_{it} is a vector of time-varying covariates that affects mortality at the city level. μ_i is the time-invariant and city-specific effect for city i, λ_t is a set of year dummies, and ε_{it} is an i. i.d. error term. Meanwhile, to correct for the potential severely downward-biased standard errors produced by pervasive serial correlation in DID models, we follow Bertrand et al. (2004) and use Huber-White standard errors clustered at the city-level throughout the estimations.

Regarding the covariates, X_{it}, we include real GDP per capita, the share of secondary industry in GDP,[19] population density, food inflation,[20] government expenditure, and healthcare service condition. These variables have typically been found to be important for determining mortality. The first four control variables capture the effects of local economic development and demographic characteristics on mortality. Government expenditure, measured as the ratio of city expenditure to GDP, is included to reflect the overall public service provided by the governments. The total number of beds in hospitals and other healthcare institutions per million people is included to control for the general healthcare service condition in the cities. A detailed description of all the variables is provided in Table A1 of the appendix.

3.2. Data

We use an unbalanced panel dataset covering 208 prefectural-level cities between 2001 and 2012. Cities in Tibet and Qinghai are not included in the sample because of data availability; the four municipality cities of Beijing, Tianjin, Shanghai, and Chongqing are also excluded, as they are considered to be provincial-level jurisdictions rather than prefectural-level cities. The capital cities of the provinces are also excluded because of lack of comparability. Summary statistics for the key variables in the overall sample and subsamples for TCZ and non-TCZ cities are provided in Table 1.

Information on the annual number of deaths and total population figures (and hence the mortality rate) are derived from various issues of the *China Statistical Yearbook for Regional Economy* (compiled by the Department of Comprehensive Statistics and Department of Rural Survey of National Bureau of Statistics), which, regrettably, are available and comparable only for 2000–2012. The data on SO_2 emissions are obtained from various issues of the *China City Statistical Yearbook* (compiled by the Department of Urban Surveys National Bureau of Statistics), available from 2001 onward. The availability of data on these two variables together defines 2001–2012 as our sample period for the empirical analysis. The dummy variable that indicates the treatment status of the TCZ cities (i.e., TCZ_i) is manually sorted from the *Reply from the State Council on Relevant Issues Concerning Acid Rain Control Zones and Sulfur Dioxide Pollution Control Zones (National Letter [1998] No. 5)*.[21] Finally, we collect the retail price index for food at the provincial level from *China*

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[16] It is noted that our primary objective is to examine the overall health and well-being effect of the TCZ policy. In this regard, infant or child mortality may be more sensitive to environmental pollution than overall mortality. Regrettably, panel data on infant or child mortality at the city level are not available in China after 2000, which is the main reason for selecting the overall mortality rate as our key dependent variable in this paper. Nevertheless, overall mortality covers various types of mortality, including infant mortality and other mortalities that may be less sensitive and take time to respond to environmental pollution. This implies that changes in infant mortality can also be reflected in the measure of overall mortality and the contemporaneous effects of the TCZ policy on infant mortality, if any, may therefore be mixed with the delayed effects of the policy on other types of mortality.

[17] Since the dependent variable (mortality rate) corresponds to the statistical data of the prefectural cities as a whole, to make our estimation more accurate, we delete the samples of prefectural cities in which the TCZ policy has only been implemented in some regions. Therefore, the cities in our treatment group are samples with citywide implementation of the TCZ policy, while those in the control group are samples with citywide non-implementation of the TCZ policy. The geographic distribution of our sample cities is depicted in Figure A1 of the appendix.

[18] Our strategy is not a traditional DID setting, but a DID in the mechanical sense. Remarkably, our identification is based on the fact that while political incentives were provided to all local bureaucrats nationwide for environmental protection in 2006 and afterward, the TCZ cities faced much stronger incentives and pressures to reduce pollution because of the original requirements of the TCZ policy, which has become part of the criteria for their political promotions now.

[19] According to the National Economic Classification (GB/T 4754-2011), China's secondary industry refers to the mining industry (excluding mining auxiliary activities), manufacturing industry (excluding metal products, machinery, and equipment repair), electricity, heat, the gas and water production and supply industry, and construction industries.

[20] We add the retail price index for food to the model to track the inflation of necessities. Regrettably, price indexes are not available at the city level in China; thus, we use data at the provincial level instead.

[21] It is a government document with national legal force, released by the State Council on January 12, 1998. http://www.gov.cn/zhengce/content/2010-11/22/content_5181.htm.

Table 1
Summary statistics.

Variables	Full Sample			TCZ Sample			Non-TCZ Sample		
	Obs	Mean	S.D.	Obs	Mean	S.D.	Obs	Mean	S.D.
Mortality rate	2920	5.65	1.88	1087	5.82	1.67	1833	5.55	1.99
TCZ	2940	0.37	0.48	1092	1.00	0.00	1848	0.00	0.00
GDP per capita	2923	2.59	3.94	1090	3.39	5.10	1833	2.12	2.96
Secondary industries	2927	45.98	13.27	1090	49.93	10.04	1837	43.64	14.36
Population density	2929	350.82	313.14	1091	496.43	338.54	1838	264.39	261.20
Food inflation	2940	135.12	33.31	1092	134.28	32.06	1848	135.61	34.03
Government expenditure	2901	0.18	0.19	1083	0.13	0.09	1818	0.21	0.22
Healthcare	2469	2777.40	1317.25	1091	2891.06	1412.57	1378	2687.41	1229.67
Retirement	2676	0.20	0.40	1092	0.19	0.39	1584	0.21	0.40
Term_2nd	2676	0.07	0.26	1092	0.05	0.23	1584	0.09	0.28
ProvParty_p1	2676	0.21	0.41	1092	0.21	0.41	1584	0.21	0.41
Birth rate	2922	12.45	29.84	1091	13.12	48.17	1831	12.05	6.23
SO$_2$	2462	45174.25	39468.16	1088	54525.75	41523.15	1374	37769.28	36096.15
Hospitals	2469	61.01	76.79	1091	61.50	95.40	1378	60.62	58.00
Doctors	2469	1561.45	905.88	1091	1658.96	1066.62	1378	1484.24	746.14

Note: TCZ sample refers to the cities where their whole domains were classified as two control zones in 1998. Non-TCZ sample refers to those cities where none of their domains were included in the two control zones in 1998.

Statistical Yearbook (compiled by the National Bureau of Statistics). Data for all the other variables are obtained at the prefectural city level from various issues of the *China City Statistical Yearbook*, except for those on the number of births, which are provided by the *China Statistical Yearbook for Regional Economy*.

4. Empirical results

4.1. Baseline results

Table 2 documents the main estimation results for our baseline Specification (1). We perform the basic DID estimation without adding any control variables in Column (1), and find the estimated coefficient of *TCZ*Post* to be negative and statistically significant at the 5% level. This result is consistent with our expectation of the effectiveness of the environmental regulation. Columns (2)–(4) subsequently add a battery of city-level covariates, including economic and demographic characteristics, food inflation, government expenditure, and healthcare service condition, to the specification. As shown, the implementation of the TCZ policy has a persistent, negative, and statistically significant effect on mortality rate. Quantitatively, based on the estimate obtained in Column (4), the strict implementation of the TCZ policy has reduced TCZ cities' mortality rate by 0.305‰ relative to that of non-TCZ cities. Evaluated at the average mortality rate of the TCZ sample (i.e., 5.82‰, see Table 1), it translates into a 5.2% reduction in mortality ((0.305/5.82) × 100% = 5.2%). Overall, our core results in Table 2 point to the effectiveness of the TCZ policy in reducing mortality rates in the period when the policy was under strict implementation.[22]

Along with TCZ policy, most of the control variables appear to have statistically significant effects on mortality. Particularly, higher levels of real GDP per capita, government spending, and healthcare service conditions are all found to be important contributors for public health and hence a lower level of mortality. Population density also has negative and significant coefficients, which indicates that people are concentrated more in well-developed cities and hence exhibit lower mortality rates. Nevertheless, while food inflation is expected to have a positive effect on mortality, we find its associated coefficient to be negative and statistically significant. A potential explanation is that under a certain threshold, food inflation may also serve as an indicator of economic development; thus, a higher level of the variable may capture the effect of economic development.

4.2. Event-study estimation

The validity of our main results in Table 2 relies on the identification assumption that the average mortality for the TCZ and non-TCZ cities would have evolved in parallel in the absence of the TCZ policy. More concretely, only if the premise that the mortality across the two groups of cities is approximately comparable prior to the TCZ policy implementation is satisfied can the DID approach be used to eliminate the intrinsic difference between the two groups and identify the pure policy effect. To confirm this point, Fig. 3 compares the average mortality trend in TCZ cities with that in non-TCZ cities for the analyzed period. As shown, mortality rates in TCZ

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[22] It is noted that the DID estimate should be interpreted as the average treatment effect of the policy, which can be thought of as a weighted average effect of the contemporaneous and lagged effects of the policy. Hence, the DID estimate itself does not necessarily reflect the contemporaneous effect of the policy on mortality only. As a matter of fact, in our subsequent analyses, we find evidence that the strict implementation of the TCZ policy may help reduce SO$_2$ emissions contemporaneously, and as a result of lower cumulated exposure to air pollution, mortality has eventually decreased (with a time-lag effect).

Table 2
The impact of the TCZ policy on mortality.

	(1)	(2)	(3)	(4)
TCZ*Post	−0.280**	−0.303**	−0.311**	−0.305**
	(0.136)	(0.138)	(0.137)	(0.136)
GDP per capita		−0.036**	−0.041***	−0.032**
		(0.015)	(0.016)	(0.016)
Secondary industries		−0.008	−0.009	−0.009
		(0.010)	(0.010)	(0.010)
Population density		−0.001*	−0.001*	−0.002**
		(0.001)	(0.001)	(0.001)
Food inflation		−0.022**	−0.021**	−0.021**
		(0.010)	(0.010)	(0.010)
Government expenditure			−0.812*	−0.789*
			(0.419)	(0.418)
Healthcare				−0.000*
				(0.000)
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	2429	2429	2429	2429
Adjusted R-squared	0.354	0.357	0.358	0.358

Note: The dependent variable is the mortality rate in prefectural cities. Robust standard errors are reported in parentheses and clustered at the city level. *, **, and *** denote significance at the confidence levels of 10%, 5%, and 1%, respectively.
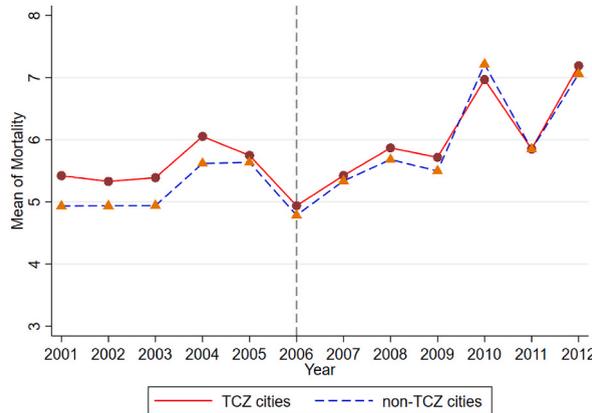

Fig. 3. The Time Trends of Average Mortality in TCZ and non-TCZ Cities, *Note:* The vertical line represents the year when the central authority included the emissions quota in the performance evaluation system for top local bureaucrats.
Source: China Statistical Yearbook for Regional Economy

cities were persistently higher than and parallel to those in non-TCZ cities prior to the treatment period (i.e., 2006), which suggests that the assumption of parallel trends for the two groups holds. The difference between the two groups started to narrow down after 2006, thus indicating the treatment effect of the TCZ policy.

Furthermore, we follow the existing literature and conduct an event-study estimation (e.g., Jacobson et al., 1993):

$$y_{it} = \alpha + \beta_k \sum_{k=-5}^{4} TCZ_i * Post_k + \beta_j TCZ_i * Post_{j\geq5} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{2}$$

where we replace the TCZ implementation dummy from Specification (1) with a series of dummies ($TCZ_i * Post_{k,j}$) that indicate the period relative to the policy implementation in city i. For instance, $TCZ_i * Post_{-2}$ refers to two years prior to policy implementation while $TCZ_i * Post_{j\geq5}$ refers to more than five years following policy implementation. The omitted time category is $k = -2$; thus, the estimated effects, β_k, are relative to the two periods prior to policy implementation. The reason for choosing this period as the benchmark period, rather than using $k = -1$, is that the corresponding year for the latter period (i.e., $k = -1$) is 2005, which is the ending year of the 10th Five-Year Plan; we are interested in exploring the policy effect in those ending years of the Chinese Five-Year Plans when local officers were confronted with the strongest political incentives to enforce central policy (discussed in detail in the next subsection). All the other variables are the same as those in Specification (1).

Panel A of Fig. 4 plots the estimated coefficients on the dummies in Specification (2), together with the associated 95% confidence intervals. The point estimates in the pre-implementation period suggest that there was no pre-trend for mortality between the TCZ and
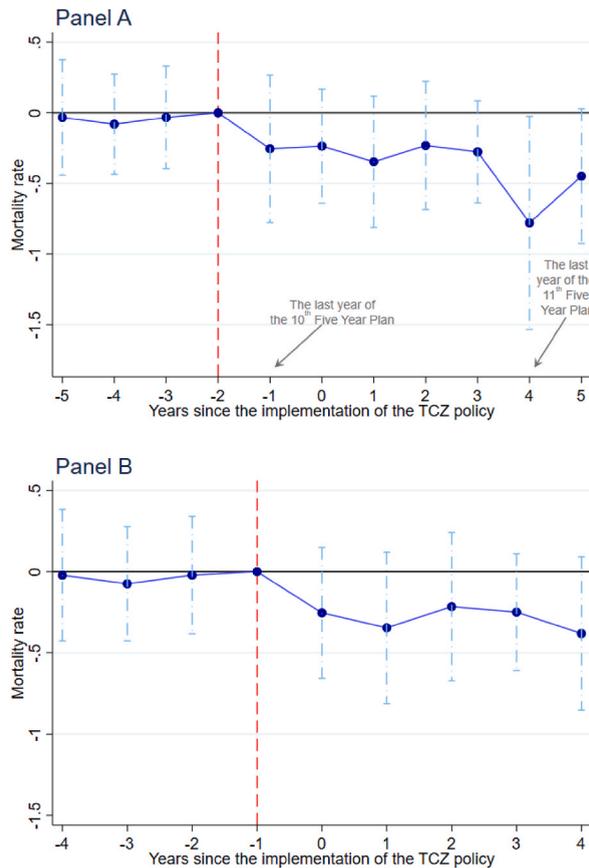
Fig. 4. Dynamic Effect of the TCZ Policy on Mortality. *Note:* The figure plots the coefficients and associated 95% confidence intervals from esti-mating the leads and lags of the policy effects, where the dependent variable is mortality rate. Panel B excludes the ending years of Five-Year Plans (i.e., 2005 and 2010) from the regression sample for estimations.
Source: Authors' calculations based on the estimates of Specification (2)

non-TCZ cities, thereby validating our identification assumption that TCZ implementation is exogenous to mortality. Noteworthily, the decline in the estimate for the time period, $k = -1$, as evidenced in the next subsection, is likely to be driven by the strong political incentives faced by local officers in the ending years of the Five-Year Plans. To rule out this potential confounding effect of the political incentives, we exclude the ending years of the Five-Year Plans (i.e., 2005 and 2010) from the regression sample and re-conduct the event-study estimation. Panel B of Fig. 4 depicts the new estimation results, which show sharper indications of a common trend be-tween the treated and control cities in the pre-reform period and a more consistent effect of the TCZ in reducing mortality.

4.3. Further evidence on the role of political incentives

We further explore the role of the political incentives faced by local bureaucrats in shaping the effectiveness of the TCZ policy. As stressed in Section 2, the TCZ policy became effective only after the SO_2 emissions quota was incorporated as one of the key aspects for evaluating local bureaucrats' performance in 2006. This demonstrates the role of political incentives in motivating local bureaucrats to implement central policy. To further validate the role of political incentives, we provide several additional supporting evidence.

First, considering the point estimates in the event-study estimations in Panel A of Fig. 4, it is notable that β_4, which corresponds to the policy effect in 2010, is the most quantitatively salient. As the last year of the 11th Chinese Five-Year Plan, 2010 was a year in which local bureaucrats faced political evaluation for their performance over the previous five years; it was the first time that the SO_2 emissions targets for local bureaucrats underwent real evaluation after 2006. This fact implies that in the years when political in-centives become even stronger, the TCZ policy effect also tends to strengthen, thus confirming that political incentives play an important role in determining the effectiveness of the TCZ policy.[23] Similarly, the estimated coefficients for β_{-1}, which correspond to the cases in the last years of the 10th Five-Year Plan, also declined sharply. It suggests that in the pre-treatment period, the local

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[23] In subsection 5.3, we provide a more detailed discussion on how this aspect of political incentives effect may be confounded by the potential lagged effect of the TCZ policy.

bureaucrats in the TCZ cities still paid some attention to their environmental performance when they were evaluated politically.[24] However, this incentive appears to be much lower prior to the incorporation of the emission quotas into the performance evaluation system in 2006.

Second, we explore the personal characteristics of the top local bureaucrats to capture the heterogeneity of the political incentives they face. Particularly, under the current Chinese institutional system, local bureaucrats face mandatory retirement at a certain age, and are generally barred from serving more than two consecutive terms.[25] Zhou (2007) pointed out that local governance in China was akin to a political tournament in which local bureaucrats were entitled to a final opportunity for promotion when they approached retirement age or were in their second term: If a local bureaucrat performed sufficiently well to win the tournament and successfully proceeded to the next round, the retirement age and official career would be extended; however, if the person failed in the ultimate competition, they would be eliminated, which would mean an abrupt end to their tenure and a complete loss of future opportunities. Consequently, being closer to retirement age and being in one's second term have become critical points for local bureaucrats as they face stronger political incentives to perform better and win the "last fight" (Zhou et al., 2015). Therefore, we use both the age and the term of tenure of the top local bureaucrats to conduct an additional analysis to capture their political incentives.

More specifically, we add a new dummy variable to Specification (1) that indicates the relative strength of the political incentives faced by local bureaucrats and interact it with the existing treatment variable (i.e., $TCZ_i * Post_t$) to identify the role of political incentives. This new dummy variable takes on alternative forms. The first one is an indicator variable for whether the city mayor faced retirement pressure; we use 53 years as the cut-off age, as suggested by Yu et al. (2016).[26] The variable equals 1 when the mayor of city i is over 53 years old in year t, and 0 otherwise (denoted $Retirement_{it}$).[27] The second one is an indicator variable for whether the city mayor is in their second term in office: if true, the variable equals 1; otherwise, it equals 0 (denoted $Term\_2nd_{it}$). The new estimation results are reported in Table 3. As shown, Columns (1)–(4) suggest that the effect of the TCZ policy in reducing mortality tends to be stronger in cities whose mayors are closer to retirement age and in their second term (i.e., the significant and negative estimated coefficients of the variables, $TCZ*Post*Retirement$ and $TCZ*Post*Term\_2nd$, respectively). This result further confirms our conjecture on the role of political incentives in shaping the effectiveness of the TCZ policy.

Finally, since our story is about making promotions contingent on achieving certain environmental standards, it is sensible to predict that local bureaucrats are likely to make a stronger effort to reduce pollution (and hence, mortality) in the year before a possible promotion. To explore this point, we introduce a dummy for the year before a possible promotion for city mayors into Specification (1) and expect to find a negative estimated coefficient for this variable.[28] By the nature of the Chinese political institution, each tenure for city mayors is 5 years; however, the actual appointment and possible turnover of city leaders are also subject to provincial governments' decisions, particularly those of the Provincial Committee of the Community Party of China (CPC). Since the Congress of the CPC is the most important political event for the provinces, and one in which new provincial leaderships are elected from the incumbent city leaders, we use the year of the Provincial Congress of the CPC as the targeted year for a possible promotion for city leaders.[29]

The estimation results in Table 4 indicate that the estimated coefficient of the dummy for the year before a possible promotion for city mayors is negative and statistically significant, which provides further support for the fact that political incentives for local leaders matter in the enforcement of environmental regulation policies.

4.4. Robustness and placebo tests

To check the robustness of our results, we conduct a series of sensitivity and placebo analyses.

Balanced sample. Since our sample for the baseline estimations is not strictly balanced, it may raise the concern that our results are confounded by the composition of cities in the sample. Therefore, we restrict the sample to a balanced panel. The estimates in Column (1) of Table 5 indicate that, on average, the strict implementation of the TCZ policy has reduced the mortality rate of TCZ cities by 0.314‰ relative to that of non-TCZ cities, which is quite close to the baseline estimate in Table 2.

Subsample analysis. One of the potential concerns with our estimations is that some other events related to mortality occurred during the sample period, which may confound our baseline estimate. A notable event in this category is the *Wenchuan* earthquake that occurred in 2008. It caused huge losses in some cities and led to an abnormally significant increase in the death rate. In Column (2) of

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[24] Note that the TCZ policy was initially implemented in 1998, however evidence shows that it was not strictly enforced by local governments before 2006, the year the emissions quota was included by the central authority in the performance evaluation system for top local bureaucrats.

[25] The retirement age varies by governmental hierarchy: the higher the administrative level, the older the retirement age.

[26] Using the spatial measurement method, Yu et al. (2016) calculate that municipal mayors are generally eligible for their last promotion opportunity when they are around 53 years old.

[27] We focus on city mayors' political incentives rather than party secretaries' for the analysis because, according to the regulations of the State Council, specified in its document "*Mayor's Statement of Responsibility for Environment-protecting Objectives,*" city mayors were the primary responsible leaders for achieving environment-protecting targets, and bore all the possible consequences for lack of achievement.

[28] We thank a referee for raising this insight, which guides the analysis here.

[29] We manually collect the data on the years of Provincial Congress of the CPC from the official websites of provincial governments and the public media.

Table 3
Political incentives and the effects of the TCZ policy.

	(1)	(2)	(3)	(4)
TCZ*Post*Retirement	−0.388*	−0.435**		
	(0.202)	(0.210)		
TCZ*Post*Term_2nd			−0.622**	−0.578*
			(0.307)	(0.316)
TCZ*Post	−0.207†	−0.232†	−0.249*	−0.282**
	(0.146)	(0.143)	(0.137)	(0.137)
Retirement	0.099	0.123		
	(0.102)	(0.103)		
Term_2nd			0.319	0.292
			(0.264)	(0.263)
Controls	No	Yes	No	Yes
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
F-tests	4.50**	5.03***	4.14**	4.07**
Observations	2429	2429	2429	2429
Adjusted R-squared	0.355	0.359	0.355	0.359

Note: The dependent variable is the mortality rate in prefectural cities. Controls include real GDP per capita, the share of secondary industry in GDP, population density, food inflation, government expenditure, and healthcare service condition. "F-tests" indicates an F-test for the joint significance of the coefficients between TCZ*Post and its interaction terms. Robust standard errors are reported in parentheses and clustered at the city level. *, **, and *** denote significance at the confidence levels of 10%, 5%, and 1%, respectively. † denotes joint significance at the confidence level of 5% or below.

Table 4
The effect of the possible political promotion.

	(1)	(2)
TCZ*Post	−0.246*	−0.272*
	(0.139)	(0.139)
ProvParty_p1	−0.292***	−0.285**
	(0.111)	(0.110)
Controls	No	Yes
City FE	Yes	Yes
Year FE	Yes	Yes
Observations	2429	2429
Adjusted R-squared	0.349	0.352

Note: The dependent variable is the mortality rate in prefectural cities. "ProvParty_p1" is a dummy variable indicating the year before a possible promotion for city mayors. Controls include real GDP per capita, the share of secondary industry in GDP, population density, food inflation, government expenditure, and healthcare service condition. Robust standard errors are reported in parentheses and clustered at the city level. *, **, and *** denote significance at the confidence levels of 10%, 5%, and 1%, respectively.

Table 5, we exclude the 10 hardest-hit cities from the sample and re-estimate the model.[30] The result shows that the coefficient of the TCZ reform remains negative and statistically significant, thus suggesting no apparent effect of the earthquake on the results obtained.

Addressing the spillover effect concern. Another common concern related to pollution is the spatial spillover effect. The stricter environmental regulations implemented in TCZ cities may motivate local polluting enterprises to migrate to non-TCZ cities, aggravating pollution and increasing mortality in non-TCZ cities. If this is the case, our baseline estimate is likely to be over-estimated. To address this concern, we examine whether mortality rates differ significantly between the non-TCZ cities that are adjacent to TCZ cities and those that are not. The working hypothesis here is that the spillover effect is more likely to be local, and that the polluting enterprises tend to relocate to the areas surrounding the original TCZ cities. More specifically, we restrict the regression sample to non-TCZ cities and falsify the TCZ policy effects in non-TCZ cities that are adjacent to TCZ cities for year 2006 and onward. Column (3) of Table 5 displays the new estimation results based on the restricted sample. We find that mortality rates were not significantly different between the two groups of non-TCZ cities, thereby indicating no apparent existence of the spillover effect of the TCZ policy.

Controlling for provincial time trends. To further consider the potential unobserved, time-varying effects for different regions, we add to the model the quadratic time trend variables for each province (i.e., the interaction terms between the province-specific dummy

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[30] According to the *Overall Plan for Post Wenchuan Earthquake Recovery and Reconstruction*, issued by the State Council in 2008, 10 cities were designated as earthquake disaster areas: Chengdu, Deyang, Mianyang, Guangyuan, Ya'an, Aba Tibetan and Qiang Autonomous Prefecture, Longnan, Gannan Tibetan Autonomous Prefecture, Hanzhong, and Baoji.

Table 5
Robustness checks: Alternative subsamples and specifications.

	Balanced sample	Earthquake	Spillover	Time trend
	(1)	(2)	(3)	(4)
TCZ*Post	−0.314**	−0.313**	0.063	−0.409***
	(0.145)	(0.139)	(0.188)	(0.122)
Controls	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	No
Prov FE*t	No	No	No	Yes
Prov FE*t^2	No	No	No	Yes
Observations	2129	2348	1352	2429
Adjusted R-squared	0.359	0.354	0.317	0.366

Note: The dependent variable is the mortality rate in prefectural cities. "Balanced sample" refers to the subsample that is strictly balanced; "Earthquake" refers to the subsample that excludes the 10 most hard-hit cities in the Wenchuan earthquake from the sample; "Spillover" refers to the estimation that restricts the regression sample to non-TCZ cities and falsifies the treatment variable; "Time trend" indicates that we add to the model the quadratic time trend variables for each province (i.e., the interaction terms between the province-specific dummy variables and the quadratic time trend). Controls include real GDP per capita, the share of secondary industry in GDP, population density, food inflation, government expenditure, and healthcare service condition. Robust standard errors are reported in parentheses and clustered at the city level. *, **, and *** denote significance at the confidence levels of 10%, 5%, and 1%, respectively.

variables and the quadratic time trend). The estimation result in Column (4) of Table 5 does not challenge our main finding on the mortality-reducing effect of the TCZ policy implementation, either in terms of estimated magnitude or of statistical significance level.

Sample selection. Sample selection may bias the DID estimates if the TCZ cities exhibited different time trends, in terms of mortality, to those of the non-TCZ cities. Although this concern is, to a large extent, mitigated by the facts presented in Figures 3 and 4, we further address this issue in two dimensions. First, we restrict our estimation to a subsample containing only the marginally treated and marginally untreated cities. For this, we first calculate the average value of SO$_2$ emissions for each city prior to the strict implementation of the policy (i.e., 2001–2005). We then use the mean (median) values of this variable, separately for the treated and untreated cities, as the cut-off points, and define those cities with average SO$_2$ emissions between these two cut-off points as the marginal treatment sample. Figure A2 in the appendix documents the pre-trends of industrial SO$_2$ emissions for both the treated and untreated cities using the full and marginal samples, respectively. As shown, the average SO$_2$ emissions for the treated and untreated cities practically overlap in the marginal treatment sample, regardless of whether the mean or median is used as the selection criterion. Our new estimation results in Columns (1) and (2) of Table 6, based on this comparable subsample, are consistent with those of the baseline estimations.

Second, another typical approach to dealing with the sample selection issue is to combine propensity score matching (PSM) with DID estimations. Specifically, we first calculate the probability that a city is subject to the TCZ policy, using the covariates in the pre-treatment period (i.e., 2001–2005).[31] Each treated city is then matched with "identical" but non-treated cities, alternately using one-to-one nearest neighbor matching, kernel matching, and radius matching approaches. Having obtained a matched control group of cities, the treatment effect of the TCZ policy is estimated under the DID framework. As shown in Columns (3)–(5) of Table 6, the PSM-DID estimates are persistently negative and statistically significant, confirming the robustness of our baseline results.

Placebo tests. We further conduct placebo tests along two dimensions to assess the validity of our empirical design. First, relying on the pre-treatment sample period (i.e., 2001–2005), we randomly select a year and falsify it as the treatment year, and then re-conduct the DID estimations. If there were no differential trend between the TCZ and non-TCZ cities, and the previously detected result captured the real policy effect, this hypothetical year of policy implementation and the falsified treatment variable would have no apparent effect on mortality. The results in Columns (1)–(4) of Table 7, where we alternatively use the middle years, 2002 and 2003, as the hypothetical years of policy implementation, are consistent with this expectation.[32] Second, we use the cities' birth rates as "placebo" dependent variables and expect the TCZ policy to have no significant effect. Our logic here is that if there were unobserved and time-varying factors in driving the detected policy effect in TCZ cities, then these factors would affect not only the mortality rate but also other related demographic indicators such as birth rates. The results reported in Columns (5) and (6) of Table 7 suggest a positive but statistically insignificant effect of the TCZ policy on city birth rates, thus confirming that the detected decline in mortality in our baseline estimation is a result of the TCZ policy implementation rather than of other unobserved, time-varying factors.

5. Mechanism analysis

Thus far, we have confirmed, in many respects, that the strict implementation of the TCZ policy brought about a decline in

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[31] These covariates are the same as those included in our baseline specification, that is, real GDP per capita, the share of secondary industry in GDP, food inflation, population density, government expenditure, and healthcare service condition.
[32] The results remain the same when we use other years (i.e., 2001 and 2004) as the hypothetical years of policy implementation. These results are reported in Table A3 of the appendix.

Table 6
Robustness checks: Further correcting sample selection.

	Marginal (Mean)	Marginal (Median)	PSM (1v1)	PSM (Kernel)	PSM (Radius)
	(1)	(2)	(3)	(4)	(5)
TCZ*Post	−1.115***	−0.420*	−0.312**	−0.277*	−0.290*
	(0.372)	(0.216)	(0.154)	(0.155)	(0.155)
Controls	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	448	646	1742	2397	2398
Adjusted R-squared	0.433	0.435	0.343	0.356	0.355

Note: The dependent variable is the mortality rate in prefectural cities. Columns (1) and (2) present estimations by restricting the regression sample to two marginal samples. Specifically, after calculating the average value of SO_2 emissions for each city before the strict implementation of the policy (i. e., 2001–2005), we use the mean (median) values of this variable, separately for the treated and untreated cities, as the cut-off points, and define the cities with average SO_2 emissions between the two cut-off points as the marginal sample. Columns (3)–(5) report the PSM-DID estimates, using one-to-one nearest neighbor matching, kernel matching, and radius matching approaches, respectively. Controls include real GDP per capita, the share of secondary industry in GDP, population density, food inflation, government expenditure, and healthcare service condition. Robust standard errors are reported in parentheses and clustered at the city level. *, **, and *** denote significance at the confidence levels of 10%, 5%, and 1%, respectively.

Table 7
Placebo tests.

	Falsified treatment year				Birth rate	
	(1)	(2)	(3)	(4)	(5)	(6)
TCZ*Post2002	−0.060	−0.060				
	(0.133)	(0.139)				
TCZ*Post2003			−0.117	−0.103		
			(0.161)	(0.167)		
TCZ*Post					3.562	3.559
					(2.567)	(2.649)
Controls	No	Yes	No	Yes	No	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1014	998	1014	998	2406	2389
Adjusted R-squared	0.491	0.494	0.492	0.494	0.010	0.007

Note: The dependent variable in Columns (1)–(4) is the mortality rate, while the dependent variable in Columns (5)–(6) is the birth rate. "Falsified treatment year" indicates that we use year 2002 or 2003 as the falsified treatment year and the regression sample period is 2001–2005. "Birth rate" indicates that we use the birth rate as the dependent variable to conduct the placebo analysis. Controls include real GDP per capita, the share of secondary industry in GDP, population density, food inflation, government expenditure, and healthcare service condition. Robust standard errors are reported in parentheses and clustered at the city level. *, **, and *** denote significance at the confidence levels of 10%, 5%, and 1%, respectively.

mortality. In our particular context, this public health gain is most naturally attributed to improved environmental quality. We supplement this assertion with quantitative evidence and, simultaneously, rule out improved healthcare service conditions as an alternative explanation.

5.1. Eliminating the improved healthcare service conditions as an explanation

Typically, a potential explanation for the decline in mortality is the improvement of local healthcare service conditions. To eliminate it as a potential explanation for the previously detected results, we rely on three commonly used indicators, i.e., the number of beds in hospitals and health centers per million people, the number of hospitals and healthcare institutions per million people, and the number of doctors per million people, to quantify the healthcare service conditions of the cities and use them as the dependent variables in the estimations. As shown in Table 8, the implementation of the TCZ policy does not exert a statistically significant effect on either the number of hospital beds or doctors, while it appears to slightly reduce, rather than increase, the number of hospitals and healthcare institutions in TCZ cities compared to that in non-TCZ cities. Overall, we believe that the implementation of the TCZ policy did not bring about an improvement in healthcare service conditions in TCZ cities, and thus eliminate it as an explanation for our findings.

5.2. Reducing SO_2 pollution as the working mechanism

The direct target of the implementation of the TCZ policy is to reduce SO_2 emissions, which, in turn, should generate the most direct and significant effect on mortality. As one of the major pollutants in the atmosphere, SO_2 can naturally form sulfate aerosols and sulfite

Table 8

Mechanism analysis: Eliminating the improved healthcare service conditions as an explanation.

	Beds		Hospitals		Doctors	
	(1)	(2)	(3)	(4)	(5)	(6)
TCZ*Post	108.254	56.834	−14.621**	−14.822*	117.404	32.083
	(78.513)	(63.004)	(7.062)	(8.080)	(79.372)	(63.152)
Controls	No	Yes	No	Yes	No	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2442	2442	2442	2442	2442	2442
Adjusted R-squared	0.857	0.885	0.602	0.604	0.710	0.746

Note: The dependent variables are noted at the top of each column. "Beds," "Hospitals," and "Doctors" refer to the number of beds in hospitals and health centers per million people, the number of hospitals and healthcare institutions per million people, and the number of doctors per million people, respectively. Controls include real GDP per capita, the share of secondary industry in GDP, population density, food inflation, and government expenditure. Robust standard errors are reported in parentheses and clustered at the city level. *, **, and *** denote significance at the confidence levels of 10%, 5%, and 1%, respectively.

Table 9

Mechanism analysis: The impact of SO_2 emissions.

	SO_2		Mortality		
	(1)	(2)	(3)	(4)	(5)
TCZ*Post	−0.196**	−0.190**	−0.276**	−0.261*	−0.249*
	(0.079)	(0.078)	(0.135)	(0.134)	(0.145)
SO_2 Emissions			0.018		
			(0.070)		
One-period lagged SO_2 Emissions				0.034	
				(0.084)	
Two-period lagged SO_2 Emissions					0.196**
					(0.094)
Controls	No	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	2462	2413	2400	2214	2026
Adjusted R-squared	0.825	0.826	0.358	0.344	0.333

Note: The dependent variable in Columns (1)–(2) is SO_2 emissions (in logarithmic form), while the dependent variable in Columns (3)–(5) is the mortality rate. Controls include real GDP per capita, the share of secondary industry in GDP, population density, food inflation, government expenditure, and healthcare service condition. Robust standard errors are reported in parentheses and clustered at the city level. *, **, and *** denote significance at the confidence levels of 10%, 5%, and 1%, respectively.

particles, which cause severe respiratory diseases in humans. In addition, SO_2 is harmful to the nervous system and can reduce the activity of biological enzymes, thus leading to bronchial contraction and abnormal changes in the heart rhythm, which seriously endanger the health of cardiovascular and respiratory systems (Nowak et al., 1997; Tunnicliffe et al., 2001).[33]

To corroborate this working mechanism, we first re-estimate Specification (1) using industrial SO_2 emissions (in logarithmic form) as the dependent variable. The results in Columns (1) and (2) of Table 9 illustrate that the TCZ policy significantly reduces industrial SO_2 emissions in TCZ cities and quantitatively reduces these emissions by 19 percentage points relative to those of non-TCZ cities.

Subsequently, we add SO_2 emissions to the baseline Specification (1) to test whether the mortality effect of the TCZ policy is mitigated by the inclusion of SO_2 emissions. If our hypothesized mechanism holds, we expect a significant positive effect of SO_2 emissions on mortality and a weakened direct effect of the TCZ policy on mortality. As shown in Column (3) of Table 9, we find a positive but statistically insignificant effect of the contemporaneous SO_2 emissions on mortality. Subsequently, considering the potential time-lagged effect of SO_2 emissions on reducing mortality, we use the lagged values of SO_2 emissions in the baseline DID specifications in Columns (4)–(5) of Table 9. We find the estimate for the two-period lagged value of SO_2 emissions to be quantitatively

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[33] Air pollution may also affect mortality through its impact on traffic safety. Sager (2019) finds that air pollution can reduce drivers' safe driving performance and increase traffic deaths by damaging drivers' cognitive abilities or making them more aggressive or impatient.

larger (positive) and statistically significant, while that of the TCZ variable is statistically less significant.[34] The combination of these results confirms the mechanism by which the TCZ policy reduces mortality by cutting SO_2 emissions.

5.3. Further discussion

As a further step to establish the link between the TCZ policy and an instant effect of SO_2 emission reduction, and then a lagged effect on overall mortality, we conduct the event-study estimations to capture the dynamic effects of the TCZ policy, alternately using SO_2 emissions and mortality as the dependent variables. The results in Table 10 indicate that the TCZ policy reduced the SO_2 emissions immediately in the treated cities, while the effect of the TCZ policy on mortality was only statistically more significant and qualitatively larger after four years of its strict implementation.

It should be noted that the lagged effect of the policy itself is not concerning, as it may reflect that the decline of the overall mortality rate is driven more by the types of mortality that take time to respond to environmental pollution. Also, this lagged effect itself does not deny the potential existence of the contemporaneous effect of the policy on the more sensitive types of mortality (such as infant mortality).[35] However, there could be a concern that our assumed higher and more instant effectiveness of the TCZ policy around the years with stronger political incentives may be confounded by the delayed effect of the policy, particularly for the argument of the contemporaneous lower mortality in the last year of the Five-Year Plan (i.e., 2010) in Fig. 4. To fully address this concern, it would be ideal to employ the more sensitive type of mortality (e.g., infant mortality) as the dependent variable and re-examine the event-study estimates. Unfortunately, this data is not available at the prefectural city level and hence preventing us from conducting such an analysis.

Nevertheless, we believe that to a large extent, our assertion on the role of political incentives in shaping the effectiveness of the TCZ policy should not be affected by this lagged effect confounder. Firstly, our identification strategy revealed that while the TCZ policy was announced in 1998, it only became effective until political incentives were introduced by the central government in 2006. Thus, the baseline result of the paper itself is evidence of the role of political incentives.[36] Secondly, the estimates in Fig. 4 and Table 10 show that the decline in mortality was exceptionally low in 2010 and paradoxically rebounded after 2010[37]; if the mortality drop in 2010 was entirely attributed to the lagged effect induced by the continued decline in SO_2 emissions, we may expect a continued decline in mortality after 2010 rather than a rebound. It is for this reason that we suspect a role played by the strong political incentive induced by the evaluation year of the Five-Year Plan. Thirdly, since overall mortality includes all types of mortality, it is possible that local bureaucrats may have targeted to reduce lethal pollution and significantly improve the sensitive portion of overall mortality for better political performance in the evaluation year, leading to a relative instantaneous effect in the years with stronger political incentives. Lastly, the effect of political incentives is also grounded by our analysis of the personal characteristics of local bureaucrats. We have shown that the effect of TCZ policy in reducing mortality tends to be stronger in cities whose mayors are closer to retirement age and in their second terms, respectively. Additionally, we utilize the information of the year before a possible promotion for city mayors and find that the promotion incentives for local leaders matter in the enforcement of the TCZ policy. All these results speak to an independent effect of political incentives, going beyond the delayed effect of the policy.

6. Evaluating health benefits of the TCZ policy

We calculate the health benefits of the TCZ policy to gain insight into its welfare implications. First, we quantify the health benefits of the TCZ policy in terms of reduced mortality. According to the estimates obtained above, the mortality rate reduced by 0.305‰ annually in TCZ cities in the post-2006 period. As China has a population of 1.4 billion and the TCZ cities account for approximately 42% of the national population, the strict implementation of the TCZ policy is expected to save 179,340 lives (1,400,000,000 × 42% × 0.305‰ = 179,340). Regarding the valuation of 702,000, in 1997 yuan, of a statistical life estimated by the World Bank (1997), the annual economic value of the TCZ's life-saving effect amounts to 125.90 billion in 1997 yuan (179,340 × 702,000 = 125.90 × 10^9).[38]

Second, we gauge the health benefits of the TCZ policy in terms of disease incidence. The results in Column (2) of Table 9 indicate that the TCZ policy reduced SO_2 emissions by 19%; based on the sample mean of 45,174.25 tons (see Table 1), this translates into an annual decrease of 45,174.25 × 19% = 8583.11 tons. As the calculations of health damage from SO_2 pollution in the literature are generally based on the concentration of the pollutant in the air, measured in ug/m³, we convert the pollution magnitude of our

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[34] Following Zhang et al. (2019), we also calculate the cumulative measure of SO_2 emissions as an alternative measure of air pollution to identify the effect. The results are reported in Table A4 of the appendix, where we find our results to be consistent. Additionally, we calculate the weighted average of SO_2 emissions in all other cities (weighted by the inverse distance between two cities) for each city in a given year, and add this weighted average variable to our baseline specification, along with the SO_2 emissions for the city itself, to eliminate concern about the confounding effect from a transboundary movement of SO_2 emissions. The estimation result is reported in Table A5 of the appendix, where we do find SO_2 emissions in both local cities and the "neighboring" cities to positively affect mortality, providing evidence of the robustness of our analysis.

[35] Changes in infant mortality can be reflected in the measure of overall mortality, and the contemporaneous effect of the policy on infant mortality, if any, may be mixed with the delayed effect on other types of mortality.

[36] Given the persistent increase of SO_2 emissions between 1998 and 2006 (see Fig. 2) and the long-time gap between these two years, the baseline result of the paper is less likely to be an indication of the lagged effect stemming from the enforcement of the same policy in 1998.

[37] The absolute value of the estimate for year 2010 (i.e., 0.78) is 1.7 times larger than that for year 2011 (i.e., 0.449).

[38] Indeed, different age groups have different life expectancies and productivities, and hence different values of statistical life (VSLs). Due to a lack of detailed data, our calculation only focuses on total mortality and uses a constant VSL.

Table 10
Dynamic effects of the TCZ policy on SO_2 emissions and mortality.

	SO_2	Mortality
	(1)	(2)
5 years before	−0.081	−0.033
	(0.077)	(0.208)
4 years before	−0.033	−0.081
	(0.070)	(0.180)
3 years before	−0.024	−0.033
	(0.056)	(0.184)
1 year before	−0.039	−0.255
	(0.066)	(0.265)
Year of implementation	−0.190**	−0.236
	(0.080)	(0.205)
1 year after	−0.188**	−0.347
	(0.089)	(0.236)
2 years after	−0.226**	−0.232
	(0.095)	(0.230)
3 years after	−0.228**	−0.277
	(0.099)	(0.183)
4 years after	−0.155	−0.780**
	(0.111)	(0.382)
5 and more years after	−0.301**	−0.449*
	(0.130)	(0.242)
Controls	Yes	Yes
City FE	Yes	Yes
Year FE	Yes	Yes
Observations	2413	2429
Adjusted R-squared	0.825	0.357

Note: The dependent variables in Columns (1) and (2) are SO_2 emissions (in logarithmic form) and mortality rate in prefectural cities, respectively. Controls include real GDP per capita, the share of secondary industry in GDP, population density, food inflation, government expenditure, and healthcare service condition. Robust standard errors are reported in parentheses and clustered at the city level. *, **, and *** denote significance at the confidence levels of 10%, 5%, and 1%, respectively.

estimates. Using city-level data on SO_2 emissions in China, Chen et al. (2018) calculated that a reduction of 5564 tons in SO_2 emissions was equivalent to a reduction of 4.1 μg/m3 in SO_2 air concentration. We applied a simplified linear approximation to their results and concluded that an annual reduction of 8583.11 tons of SO_2 emissions would decrease the SO_2 concentration in the air by 6.32 μg/m^3 (8583.11 × 4.1/5564 = 6.32). A World Bank report (World Bank, 1997) also showed that the dose-response cases to a 1 μg/m^3 increase in SO_2 concentration per million population were 10,000 for chest discomfort and 5 for respiratory symptoms. Therefore, an annual reduction in SO_2 concentration of 6.32 μg/m^3 would result in approximately 37.18 million fewer cases across China (6.32 × 1,400,000, 000 × 42% × (10,000 + 5)/1,000,000 = 37.18 × 10^6). According to Ho and Jorgenson (2003), the value per case was 9.8 in 1997 yuan; thus, the TCZ policy has saved at least 364.36 million in 1997 yuan (37.18 × 10^6 × 9.8 = 364.36 × 10^6) annually in medical bills.

In summary, our quantitative calculation indicates that the implementation of the TCZ policy yields annual health benefits of 126.26 billion in 1997 yuan (125.90 × 10^9 + 364.36 × 10^6 = 126.26 × 10^9) in terms of both reduced mortality and reduced disease incidence, which is equivalent to 134.57 billion in 2006 yuan.[39] Using the discount rates of 3% and 7%, as recommended in EPA's Guidelines for Preparing Economic Analyses (EPA, 2000) and OMB Circular A-4 (OMB, 2003), we calculate the total cumulative health benefits of the strict implementation of TCZ policy in our sample period (i.e., 2006–2012) to be 1.03 trillion (134.57 × $\sum_{t=1}^{7}(1 + 3\%)^{t-1}$ = 1,031.14 billions) and 1.16 trillion (134.57 × $\sum_{t=1}^{7}(1 + 7\%)^{t-1}$ = 1,164.57 billions) in 2006 yuan, respectively. Considering China's GDP in 2006, the total health benefits of the TCZ policy account for approximately 4.8%–5.4% of GDP in 2006.

7. Concluding remarks

This study provides evidence of the effectiveness of environmental regulations in reducing mortality in developing countries. For the purpose, we take advantage of a quasi-experimental setting for empirical identification based on a panel dataset of 208 Chinese prefectural cities for 2001–2012. Our empirical results suggest that the examined environmental regulation policy, the TCZ policy, significantly reduces mortality in the treated cities relative to that in the non-treated cities by 0.305‰ in the period when the policy is strictly enforced. This result is shown to be robust to different confounding factors. Furthermore, we highlight, in several respects, the

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[39] 100 yuan in 1997 = 106.58 yuan in 2006.

importance of political incentives in ensuring the effectiveness of the policy implementation. Finally, we shed some light on the mechanism through which the TCZ policy exerts an impact on mortality, and gauge the health benefits of the TCZ policy.

Our findings have two relevant policy implications. First, our results add to the literature by providing evidence of the effectiveness of environmental regulations from the world's largest developing country. Since environmental problems have become a global challenge, especially for developing countries, the policy practices in the Chinese context have broader implications for other countries dealing with the same issues. Second, we explicitly reveal the importance of political incentives for local bureaucrats in ensuring policy effectiveness, especially in countries with relatively weak institutions and monitoring systems. It delivers an important message that the implementation of environmental regulations itself is not sufficient to guarantee policy effectiveness in developing countries: an appropriate mechanism to induce the right political incentives for local bureaucrats is essential. In this regard, designing better environmental regulation policies in accordance with their political systems is among the key aspects for consideration by policy-makers in many countries.

Finally, we note a limitation of the current paper that in the absence of detailed data on different types of mortality, we are not able to disentangle the contemporaneous effect of the policy from its delayed effect, which limits the precise estimation of the political incentives effect. Nevertheless, this caveat suggests that with more detailed data on pollution-sensitive mortality or different empirical settings, further studies can move the research in this area forward by identifying the contemporaneous effect of environmental regulation policy and more precisely determining the effect of political incentives.

Disclosure statement for Yongzheng Liu

Disclosure statement for xiaoge zhang

I hereby declare that I have no relevant or material financial interests that relate to the research described in this paper.

Data availability

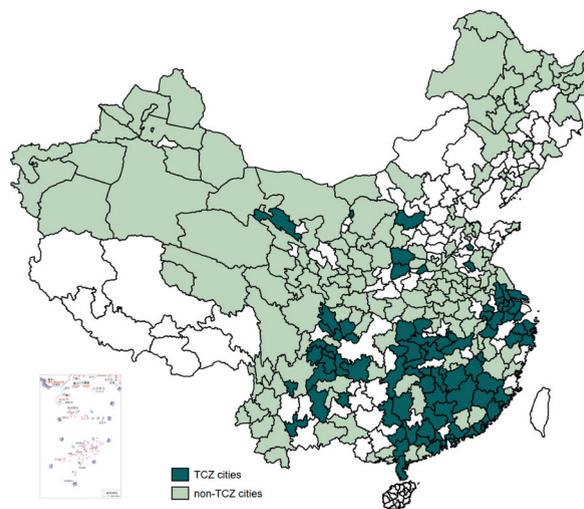Data will be made available on request.

Appendix

Fig. A1. The Distribution of Sample Cities, *Note:* TCZ cities refers to the cities where the whole domains were classified as two control zones in 1998. Non-TCZ cities refers to those cities where none of their domains were included in the two control zones in 1998.
Source: Reply from the State Council on Relevant Issues Concerning Acid Rain Control Zones and Sulfur Dioxide Pollution Control Zones (National Letter [1998] No. 5)
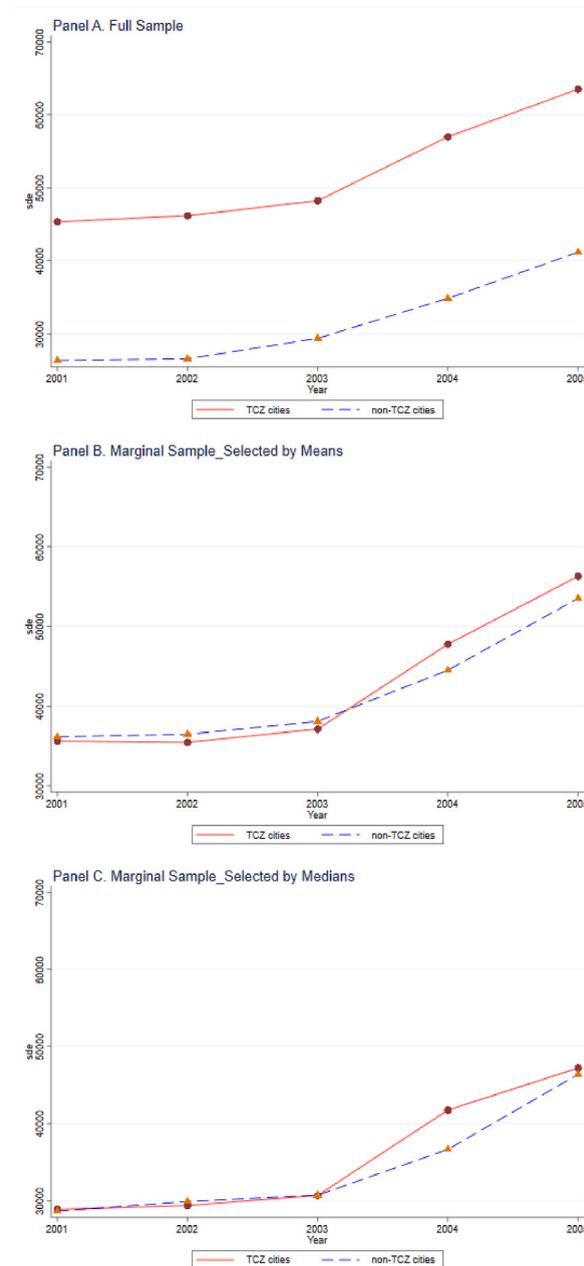
Fig. A2. The Pre-trends of Industrial SO_2 Emissions in Marginal Treated and Marginal Untreated Cities

Note: Panels B and C use two marginal samples to depict the time trends. Specifically, we calculate the average value of SO_2 emissions for each city before the strict implementation of the policy (i.e., 2001–2005), and use the mean (median) values of this variable separately for the treated and untreated cities as the cut-off points; then we define the cities with average SO_2 emissions between the two cut-off points as the marginal sample. Source: China Statistical Yearbook for Regional Economy

Table A1

Variable Definitions and Data Sources

Variables	Definition	Data sources
Mortality rate	The number of annual deaths divided by total population (‰)	*China Statistical Yearbook for Regional Economy*
TCZ	= 1 if the TCZ policy is implemented citywide; = 0 if the TCZ policy is not implemented in any regions of the city	*Reply from the State Council on Relevant Issues Concerning Acid Rain Control Zones and Sulfur Dioxide Pollution Control Zones (National Letter [1998] No. 5)*
GDP per capita	Real GDP per capita (10,000 yuan)	*China City Statistical Yearbook*
Secondary industries	The share of secondary industry in total GDP (%)	*China City Statistical Yearbook*
Population density	The ratio of the population to the area (persons/km^2)	*China City Statistical Yearbook*
Food inflation	Food inflation rate at the provincial level (price in 1999 = 100)	*China Statistical Yearbook*
Government expenditure	The ratio of city fiscal expenditure to GDP (%)	*China City Statistical Yearbook*
Healthcare (Hosbeds)	The number of beds in hospitals and healthcare institutions per 1 million people	*China City Statistical Yearbook*
Retirement	= 1 if the city mayor is over 53 years old and 0 otherwise	*Public information from the prefecture-city government's bulletins*
Term_2nd	= 1 if the city mayor is serving in the second term and 0 otherwise	*Public information from the prefecture-city government's bulletins*
ProvParty_p1	= 1 if it is the year before the province holds the People's Congress of the Communist Party of China and 0 otherwise	*Hand-collected from the official websites of local governments and the news media*
Birth rate	The number of annual births divided by total population (‰)	*China Statistical Yearbook for Regional Economy*
SO$_2$	The industrial emission of SO$_2$ (tons)	*China City Statistical Yearbook*
Hospitals	The number of hospitals and healthcare institutions per 1 million people	*China City Statistical Yearbook*
Doctors	The number of doctors per 1 million people	*China City Statistical Yearbook*

Table A2

SO$_2$ Emissions Quotas in TCZ and Non-TCZ Cities

	(1)	(2)	(3)	(4)
TCZ_city	1.022***	0.835***	0.866***	0.741**
	(0.265)	(0.314)	(0.244)	(0.295)
Controls	No	Yes	No	Yes
Province FE	No	No	Yes	Yes
FYP FE	No	No	Yes	Yes
Observations	1293	1167	1293	1167
Adjusted R-squared	0.047	0.064	0.178	0.220

Note: The dependent variable is the targeted SO$_2$ emission reduction in the 11th and 12th Five-Year Plans, which is measured by the difference between the target SO$_2$ emissions for that five-year period and the actual SO$_2$ emissions at the end year of the previous five-year period. TCZ_city is an indication of the treated cities, which equals 1 if the entire domain of the city is designated as TCZ, and 0 otherwise. Control variables include real GDP per capita, the share of secondary industry in GDP, population density, food inflation, government expenditure, and healthcare service condition. Province FE and FYP FE capture fixed effects for each province and each Five-Year Plan period, respectively. Robust standard errors are reported in parentheses and clustered at the city level. *, **, and *** denote significance at the confidence levels of 10%, 5%, and 1%, respectively.

Table A3

Robustness Checks: Alternative Placebo Years

	(1)	(2)	(3)	(4)
TCZ*Post2001	−0.092	−0.077		
	(0.147)	(0.147)		
TCZ*Post2004			−0.270	−0.197
			(0.235)	(0.234)
Controls	No	Yes	No	Yes
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	998	998	998	998
Adjusted R-squared	0.491	0.494	0.492	0.494

Note: The dependent variable is the mortality rate in prefectural cities. In Columns (1)–(2) and Columns (3)–(4) we use 2001 or 2004 as the falsified treatment year, respectively, and the regression sample period is 2001–2005. Controls include real GDP per capita, the share of secondary industry in GDP, population density, food inflation, government expenditure, and healthcare service condition. Robust standard errors are reported in parentheses and clustered at the city level. *, **, and *** denote significance at the confidence levels of 10%, 5%, and 1%, respectively.

Table A4

Robustness Checks: Cumulative Measures of SO$_2$ Emissions

	(1)	(2)	(3)	(4)	(5)	(6)
TCZ*Post	−0.270**	−0.251*	−0.252*	−0.225	−0.200	−0.199
	(0.134)	(0.132)	(0.145)	(0.141)	(0.139)	(0.154)
Cumulative sum of SO$_2$ emissions	0.100					
	(0.172)					
One-period lag of cumulative sum of SO$_2$ emissions		0.203				
		(0.180)				
Two-period lag of cumulative sum of SO$_2$ emissions			0.364*			
			(0.210)			
Cumulative average of SO$_2$ emissions				0.125		
				(0.161)		
One-period lag of cumulative average of SO$_2$ emissions					0.240	
					(0.175)	
Two-period lag of cumulative average of SO$_2$ emissions						0.363*
						(0.204)
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2400	2214	2026	2329	2142	1952
Adjusted R-squared	0.358	0.344	0.332	0.354	0.340	0.330

Note: The dependent variable is the mortality rate in prefectural cities. In the first three columns, we calculate the cumulative SO$_2$ emissions and their lagged values by the cumulative summation method and add the logarithmic form of these variables to the specification. More precisely, we calculate the sum of the cumulative SO$_2$ emissions for each city in a specific year since 2001. The last three columns use the cumulative average instead of the cumulative summation. Controls include real GDP per capita, the share of secondary industry in GDP, population density, food inflation, government expenditure, and healthcare service condition. Robust standard errors are reported in parentheses and clustered at the city level. *, **, and *** denote significance at the confidence levels of 10%, 5%, and 1%, respectively.

Table A5

Robustness Checks: SO$_2$ Emissions in Other Cities

	(1)	(2)
TCZ*Post	−0.172	−0.192
	(0.144)	(0.147)
Two-period lagged SO$_2$ Emissions	0.193**	0.180*
	(0.093)	(0.096)
Two-period lag of weighted average of SO$_2$ Emissions in other cities	2.609**	2.036*
	(1.212)	(1.229)
Controls	No	Yes
City FE	Yes	Yes
Year FE	Yes	Yes
Observations	2039	2026
Adjusted R-squared	0.333	0.333

Note: The dependent variable is the mortality rate. The weighted average of SO$_2$ emissions in other cities (in logarithmic form) is the average of SO$_2$ emissions from all other cities in each city in a given year weighted by the inverse distance between the two cities. Controls include real GDP per capita, the share of secondary industry in GDP, population density, food inflation, government expenditure, and healthcare service condition. Robust standard errors are reported in parentheses and clustered at the city level. *, **, and *** denote significance at the confidence levels of 10%, 5%, and 1%, respectively.

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