Unmasking the Domestic Pollution Haven Effect: Evidence from China's Environmental Regulation

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ABSTRACT

The implementation of China's Two Control Zones (TCZ) policy has paradoxically increased total SO_2 emissions, deviating from its original aim of reduction. This paper investigates the unintended consequences of the policy, leveraging the quasi-natural experiment provided by the 10th Five-Year Plan that the central government imposes stringent pollution reduction mandates in TCZ cities. Using a difference-in-differences strategy, our analysis reveals that the TCZ policy has significantly raised SO_2 emissions in non-TCZ cities, with pollution spillovers concentrated near the regulation boundary and attenuating with distance. The domestic pollution haven effect (PHE) is particularly pronounced among state-owned firms, especially those affiliated with local bureaucrats (provincial, municipal, county, and township) and decentralized from upper to lower levels of government oversight. Furthermore, domestic investment is primarily responsible for the negative pollution externalities, while foreign investment does not exhibit the same sensitivity to environmental policy design. These findings serve as a cautionary tale for environmental decentralization, as the TCZ policy has inadvertently transformed non-TCZ cities into pollution havens, highlighting the necessity of aligning central and local government priorities and promoting inter-jurisdictional coordination to mitigate pollution spillovers and achieve sustainable economic development.

***Keywords*:** Pollution haven effect, Environmental regulation, Decentralization, Externalities
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1. Introduction

China has been the fastest-growing economy, reliant on low-cost natural resources and energy. The rapid expansion of heavy industries and accelerated urbanization over the past several decades have resulted in severe depletion of natural resources and environmental degradation (Chen, 2015; Greenstone et al., 2021). According to the 2022 China Ecological Environment Bulletin released by the Ministry of Ecology and Environment, 37.2% of the 339 cities in China fail to meet the requisite ambient air quality standards.[1] The World Health Organization's 2023 World Health Statistics report also presents that China's mortality rate due to air pollution (including indoor and ambient pollution) is 95.3 per 100 thousand people, significantly higher than the average rates in the Americas (31.1) and Europe (44.5).[2] Empirical evidence reaches a consensus that pollution has a detrimental effect on human capital, including reductions in life expectancy, cognitive performance, labor productivity, and mental health in China (Chen et al., 2013; Zhang et al., 2018; He et al., 2019; Chen et al., 2024).

In response to these adverse effects of pollution, the central government launched the Two Control Zones (TCZ) policy in 1998, specifically designed to limit sulfur dioxide (SO_2) emissions and curb acid rain in designated cities.[3] The policy underwent its preparation phase in the first two years (1998-1999) due to the absence of reduction mandates and the Asian Financial Crisis. Starting in 2000, the 10th Five-Year Plan marks a pivotal shift, as the central government formally imposes a 20% reduction target for SO_2 emissions in TCZ cities, enforcing stricter environmental regulations.[4] For the first time, the administrative enforcement empowered the central government to assign emission quotas to each province.[5] While the effectiveness of the TCZ policy in mitigating pollution remains inconclusive, recent empirical research indirectly supports its positive effect in reducing pollution. Evidence demonstrates that the TCZ policy drives away inbound foreign direct investment and reduces the infant mortality rate in TCZ cities, implying the deterrent effect of environmental regulation (Cai et al., 2016; Tanaka, 2015).

However, contrary to its intention of improving ambient air quality, implementing the TCZ policy was ultimately unsuccessful. Total SO_2 emissions escalated from 19.95 million tons in 2000 to 25.49 million tons in 2005, primarily driven by industrial emissions, with industrial SO_2 emissions alone contributing an additional 5.56 million tons between 2000 and 2005 (as shown in Fig. 1). Government reports validate these statistics, indicating that the 10th Five-Year Environmental Protection Plan targets were not entirely realized. SO_2 emissions saw a 27.8% increase compared to 2000, especially pronounced within the TCZ cities.[6] Furthermore, as shown in Fig. 2, firm-level data reveal a divergence in SO_2 emissions in non-TCZ and TCZ cities, with non-TCZ cities experiencing a steeper pollution trajectory since 2000.[7] This paradoxical trend suggests

[1] https://www.mee.gov.cn/hjzl/sthjzk/sthjtjnb/202312/t20231229_1060181.shtml
[2] https://www.who.int/publications/i/item/9789240074323
[3] http://www.gov.cn/zhengce/content/2010-11/22/content_5181.htm
[4] http://www.gov.cn/gongbao/content/2001/content_60699.htm
[5] Abatement requirements for each province are shown in the appendix Table A. 1.
[6] http://www.gov.cn/zwgk/2007-11/26/content_815498.htm
[7] Although the scatter plot shows a short dip in SO_2 emissions from 1998 to 1999, this reduction is not exclusive to TCZ cities; non-TCZ cities also experience a decline in emissions. Due to the unavailability of firm-level SO_2 emission data prior to 1998, our study is unable to definitively identify the cause of

that while stricter environmental regulations are introduced, they inadvertently trigger a substantial rise in total SO_2 emissions, particularly in non-TCZ cities. Nevertheless, the failure of environmental regulation characterized by the TCZ policy in 2000 remains underexplored.[8]

[Insert Fig. 1 here]

[Insert Fig. 2 here]

To fill this gap, this study aims to explore the causal relationship between the TCZ policy in the 10th Five-Year Plan and rising pollution emissions, focusing on the role of the central-local environmental decentralization system. China's policy outcomes are shaped by a hybrid governance model, in which the central government formulates policies, but their implementation is decentralized to local governments (Yao and Zhang, 2015). When the central government's and local officials' objectives diverge or multiple goals coexist, political and economic decentralization can dilute central control, undermining the effectiveness of centrally mandated policies. In this context, when the central government imposes stricter environmental regulations on TCZ cities, firms controlled by local governments are more likely to escape environmental regulations and exacerbate emissions in non-TCZ cities, driving the domestic pollution haven effect. By analyzing the failure of environmental regulations, this paper sheds light on the effectiveness of environmental regulations and the mechanisms that influence their outcomes.

This study builds on the existing literature about the Pollution Haven Effects (PHE) and the Pollution Haven Hypothesis (PHH). Copeland and Taylor (1994) pioneer this research by demonstrating that increased environmental standards in higher-income countries (North) cause a shift in pollution-intensive production toward lower-income countries (South). The PHE posits that the stringency of pollution regulations affects plant location and trade flows, while the PHH argues that reducing trade barriers causes pollution-intensive industries to shift from countries with stringent regulations to those with more lenient ones (Copeland and Taylor, 2004). Despite limited evidence supporting the PHH (Arik Levinson, 2009; Eskeland and Harrison, 2003; Shapiro and Walker, 2018), numerous studies have provided support for the existence of PHE (Levinson and Taylor, 2008; Hanna, 2010; Lin and Sun, 2016; Cherniwchan and Najjar, 2022).

Following this, an important extension of this literature is the concept of the domestic pollution haven effect, which posits that heterogeneous environmental regulation across different regions within a country can also result in the PHE. Kahn (2004) suggests that domestic pollution havens emerge at state and international borders, with significant differences in environmental regulations. Empirical research further substantiates this perspective, with a growing body of evidence demonstrating China's domestic pollution haven effects. These studies reveal that the spatial variation in the stringency of environmental regulations has caused polluting leakage to thy

this simultaneous decrease. We postulate that this decline may be linked to the Asian Financial Crisis, which leads to an economic slowdown and, consequently, a reduction in industrial activity and associated pollution levels.

[8] The TCZ policy refers to "The 10th Five-Year Plan for Acid Rain Control and SO_2 Pollution Prevention in the Two Control Zones." The policy document is available at the following government website: https://www.mee.gov.cn/gkml/zj/wj/200910/t20091022_172128.htm.

neighbor, the western provinces, and the Yangtze River's upstream, where regulations are more lenient (Cai et al., 2016; Chen et al., 2018; Wu et al., 2017).

This research also extends literature that considers decentralization as a critical economic factor, showing that while decentralization can enhance social welfare, it also generates adverse effects. For example, Jia et al. (2021) find that empowering local governments with higher political hierarchy fosters regional development. However, decentralization can magnify risks, such as corruption and transboundary pollution spillovers (Ferraz and Finan, 2008; Sigman, 2005). Lipscomb and Mobarak (2017) provide evidence of cross-border water pollution spillovers under decentralized management, even within the same governing state or federal. In China, He et al. (2020) show that the upstream-downstream gap in total factor productivity (TFP) and chemical oxygen demand (COD) emissions arose from the misalignment between the national policy goal and local bureaucratic incentives, with an estimated economic cost of more than 800 billion Chinese yuan. Fiscal decentralization has also intensified the urban-rural environmental enforcement gap, transforming rural areas into pollution havens (Zhang et al., 2023).

Different from existing literature, this study investigates the unintended consequences of the TCZ policy implemented during China's 10th Five-Year Plan. Although the policy enforces stricter environmental regulations in TCZ cities to curb SO_2 emissions and acid rain, it inadvertently created conditions for domestic pollution haven effects in non-TCZ cities. Taking this policy as a quasi-natural experiment, the time and spatial variations of the SO_2 reduction mandate provide an opportunity for implementing a difference-in-differences (DD) identification strategy. We examine the causal relationship between environmental regulation and pollution haven effect by drawing on comprehensive datasets from the Chinese Enterprise Pollution Database (CEPD) and the Chinese Industrial Enterprise Database (CIED).

The primary challenge in identifying the pollution haven effect of the TCZ policy lies in selecting appropriate comparable groups between non-TCZ and TCZ cities. Our study mitigates this issue by first employing a DD estimation at the firm level, comparing changes in SO_2 emissions between non-TCZ firms and their TCZ counterparts. We find that the environmental regulation has caused a significant increase in SO_2 emissions in non-TCZ cities. Additionally, we leverage the policy boundary to implement a spatial regression discontinuity (RD) design to estimate the causal effect of regulation on pollution spillover. The RD results indicate that northern firms (non-TCZ firms) exhibit higher SO_2 emissions than their southern counterparts (TCZ firms), particularly within a 40-kilometer radius of the policy boundary. Finally, we combine the two approaches above by estimating a boundary discontinuity difference-in-differences (BD-DID) regression to assess the impact of the TCZ policy on pollution emissions of firms located on both sides of the policy boundary. The BD-DID results reveal that the pollution haven effect concentrates on proximity to the regulation boundary, with the pollution spillover attenuating with distance.

This study makes four novel contributions to the existing literature. First, this paper reveals the causal link between environmental regulation characterized by the TCZ policy and the domestic pollution haven effect in China. While previous studies have demonstrated the effectiveness of environmental regulations in mitigating pollution, this paper challenges that perspective by unmasking the unintended

consequence of domestic pollution havens in a developing country. Stylized facts show that the total pollution emissions increase after implementing environmental regulations, primarily due to higher SO_2 emissions from non-TCZ cities. Through a series of comprehensive empirical analyses, this study demonstrates that the TCZ policy has exposed non-TCZ cities to higher pollution levels. Our study presents new empirical evidence on the effects of environmental regulations, confirming the existence of PHE in China.

Second, in terms of methodological contribution, our research employs several empirical strategies to address endogeneity problems and conducts a series of robustness checks to validate the findings. These analyses demonstrate that the observed pollution haven effect is driven by increased emissions from non-TCZ firms rather than emission reductions from TCZ firms. Specifically, we leverage the quasi-natural experiment provided by the TCZ policy and employ a difference-in-differences (DD) identification strategy to evaluate whether the policy has contributed to China's domestic pollution haven effect. The DD estimates capture the average policy effect of the TCZ policy. To strengthen causal inference, we implement a spatial regression discontinuity design, exploiting spatial discontinuities to estimate the effect of the TCZ policy on pollution. The RD estimates capture absolute emissions differences between non-TCZ and TCZ firms located near the policy boundary. Finally, we combine the DD and RD strategies into a boundary discontinuity difference-in-differences regression. These methods collectively reveal that regulatory discrepancies between non-TCZ and TCZ cities are the primary drivers of increased SO_2 emissions in non-TCZ cities.

Third, this study examines the mechanisms underlying the domestic pollution haven effect, emphasizing the role of environmental decentralization within China's central-local principal-agent system, offering insights into the failure of the TCZ policy. By extending the literature on decentralization and environmental regulation, our findings reveal that political decentralization exacerbates the PHE by fostering a misalignment between central and local government priorities. Specifically, local political incentives result in regulatory gaps that facilitate pollution spillovers, leading to increased SO_2 emissions in non-TCZ cities. These spillovers arise from the heterogeneous pollution reduction mandates, which mainly affect firms under local government jurisdiction and those decentralized from higher-level to lower-level government oversight.

Finally, this paper explores the domestic pollution haven effect of air pollution, specifically SO_2 emissions. While previous literature on the PHE has predominantly concentrated on water pollution—primarily due to its nature of flowing downstream—the PHE related to ambient air pollution has garnered less attention. Our findings demonstrate that similar to water pollution, regional disparities in environmental regulation give rise to the pollution haven effect for air pollution. In particular, these regulatory gaps have facilitated significant SO_2 leakage into non-TCZ cities, thereby exacerbating national SO_2 emissions.

The remainder of this paper is organized as follows: Section 2 provides the policy background and proposes research hypotheses. Section 3 describes our estimation strategy and the data. Section 4 reports empirical results. Section 5 explores underlying mechanisms and alternative explanations. Section 6 presents our conclusions.

2. Policy background and research hypothesis

2.1. Policy background

Acid rain and sulfur dioxide pollution pose severe threats to public health, corrode infrastructure, harm ecosystems, and cause considerable economic losses. These environmental issues have become formidable barriers to China's sustainable economic development. To mitigate these impacts and promote sustainability, the Chinese government incorporated the control of acid rain and SO_2 pollution into the amended Air Pollution Prevention and Control Law of the People's Republic of China (APPCL) in 1995. In January 1998, the State Council approved "The Official Reply of the State Council Concerning Acid Rain Control Areas and SO_2 Pollution Control Areas," which established Acid Rain Control Areas (ARCA) and SO_2 Pollution Control Areas (SPCA) in order to curb SO_2 emissions in the two control zones (TCZ) cities. The TCZ policy set two objectives: the short-term goal aimed to comply with industrial pollution standards by 2000, while the long-term goal sought to maintain SO_2 emissions at 2000 levels by 2010.[9]

During the 10th Five-Year Plan (FYP) period, China's total energy consumption was expected to grow significantly, leading to an increase of more than 900 thousand tons in SO_2 emissions in the TCZ cities. In response to this challenge, the central government, under the Outline of the 10th Five-Year Plan (2001–2005) for National Economic and Social Development, formulated the "10th Five-Year Plan for the Prevention and Control of Acid Rain and Sulfur Dioxide Pollution in the Two Control Zones." This regulation set ambitious goals to address the escalating environmental pressures. By 2005, it aimed to reduce SO_2 emissions by 20% compared to 2000 levels, alleviate acid rain pollution, and ensure that over 80% of cities met the national Class II air quality standards for SO_2 concentrations.[10] Specifically, the SO_2 emission control target for TCZ cities was set at 10.53 million tons by 2005, despite projections indicating that emissions would reach 14.1 million tons in these cities. To meet this target, the central government allocated specific reduction quotas to each province. Provincial SO_2 emission targets within the TCZ are listed in Table A. 1 in the appendix. The policy's scope and timeframe are outlined as follows:

[9] The objectives of the Two Control Zones (TCZ) policy are outlined as follows: By 2000, industrial so urces of SO_2 emissions were expected to meet emission standards, with a corresponding reduction in tot al SO_2 emissions. In key cities, including municipalities directly administered by the central governmen t, provincial capitals, special economic zones, coastal cities, and major tourist destinations, ambient air SO_2 concentrations were required to meet national environmental quality standards. Additionally, the d eterioration trend of acid rain within the control zones was to be alleviated. By 2010, total SO_2 emission s were to be maintained at the 2000 levels, with urban ambient air SO_2 concentrations meeting national air quality standards and a significant reduction in the area within acid rain control zones exhibiting a p H below 4.5, relative to 2000 levels. The policy document detailing these objectives is available on the official government website: https://www.gov.cn/zhengce/zhengceku/2010-11/22/content_5181.htm.

[10] The annual average SO_2 concentration standard is set at 60 μg/m³, which is considered the threshold for long-term air exposure without harming the population. In addition, the daily average concentration standard is 0.25 mg/m³, ensuring that short-term exposure does not result in acute health effects. The relevant document for China's 10th Five-Year Plan is available at the following government website: https://www.gov.cn/gongbao/content/2001/content_60699.htm.

Scope: The implementation scope of the TCZ policy during the 10th Five-Year Plan aligns with the areas designated by the State Council in January 1998 as Acid Rain Control Areas and SO_2 Pollution Control Areas, as shown in Fig. 3.

Baseline year: The baseline year for the policy is 2000.

Period: The policy was implemented from 2001 to 2005, aligning with the duration of the 10th Five-Year Plan.

The implementation of the TCZ policy exhibits several critical characteristics that reflect its socioeconomic and environmental significance. The TCZ policy encompasses 175 cities and regions, contributing approximately 67% of China's GDP. These regions include four centrally administered municipalities, 21 provincial capitals, and 11 of the nation's 16 coastal open cities. In terms of environmental pollution, China's total SO_2 emissions in 2000 amounted to 19.95 million tons, of which 13.16 million tons came from the TCZ (59.8% from the ARCA and 40.2% from the SPCA), representing 66% of national emissions. The ARCA in East and South China represent the fastest-growing economic regions, serving as gateways for international trade. Meanwhile, the SPCA covers most cities within the Bohai Economic Rim and industrial cities in central and western regions. As shown in Fig. 3, the ARCA are mainly concentrated south of the policy boundary, whereas the SPCA are north of the policy boundary.

[Insert Fig. 3 here]

2.2. Research hypothesis

The implementation of China's TCZ policy during the 10th FYP has paradoxically increased national-level SO_2 emissions, deviating from its original reduction target. This study aims to investigate the causal relationship between environmental regulation and the domestic pollution haven effect, with a particular focus on the role of environmental decentralization within the central-local government principal-agent political system. According to Fig. 4, the central government aims to achieve sustainable development through a dual focus on economic growth and environmental protection. In contrast, local governments tend to prioritize economic growth within their jurisdictions to enhance political promotion prospects (Jia, 2024). In this context, although the central government formulates stringent environmental regulations, the implementation of these policies is delegated to local governments. This decentralization grants local authorities considerable discretion in regulatory implementation. As a result, the effect of environmental policy in China is contingent upon the interaction between central design and local enforcement of these regulations.

Within the decentralized system, when the objectives of central and local governments are misaligned or when conflicting interests emerge, local authorities may strategically enforce environmental policies diverging from the central government's objectives, leading to noncompliance with regulations. The hierarchical administrative structure creates distinct behavioral patterns among firms affiliated with the central government compared to those overseen by local governments (including provincial, municipal, county, and township). Specifically, following the imposition of strict environmental regulations on TCZ cities after 2000, manufacturers in non-TCZ cities are likely to escape these regulations and emit more SO_2 emissions in non-TCZ cities

with less stringent enforcement. Pollution haven effects in non-TCZ cities can manifest in two forms:

On the one hand, heterogeneous pollution reduction mandates may facilitate the transfer of emissions from firms under local government jurisdiction, while firms under central government oversight are less likely to contribute to the pollution haven effect. This divergence stems from the differing priorities between central and local authorities. Central government-supervised firms align more closely with national policy goals due to stringent monitoring and information symmetry that prevent deviations from regulatory standards. Conversely, firms under local government oversight often prioritize local economic objectives, leading to higher emissions in areas with more lenient enforcement. On the other hand, environmental damage may be exacerbated in non-TCZ cities if firms undergo decentralization. This pollution haven effect arises when the oversight of firms shifts from the central government to local authorities (Huang et al., 2017), as local governments often prioritize short-term economic gains over environmental protection. Consequently, while environmental regulations designed to curb SO_2 emissions in TCZ cities are enforced, they may inadvertently exacerbate pollution emissions in non-TCZ cities rather than improving overall air quality in China. Therefore, we propose the following hypotheses:

Hypothesis 1. Environmental regulation characterized by the TCZ policy in 2000 may increase firm-level SO_2 emissions in non-TCZ cities through firms controlled by local governments, but it has no direct impact on SO_2 emissions from firms under central government oversight.

Hypothesis 2. Environmental regulation may increase firm-level SO_2 emissions among firms that have undergone decentralization from upper to lower government oversight, in contrast to those remaining under central government control.

[Insert Fig. 4 here]

3. Empirical strategy and data

3.1. Empirical strategy

As previously mentioned, following the implementation of TCZ policy in the 10th FYP, China's SO_2 emissions have increased rather than decreased. The primary goal of our empirical analysis is to identify and measure the sources of the increase in pollution emissions and to understand the reasons behind the paradoxical consequence. Taking this policy as a quasi-natural experiment, the time and spatial variations of the SO_2 reduction mandate of TCZ policy provide an opportunity for implementing a difference-in-differences (DD) identification strategy. This methodology enables us to investigate whether the TCZ policy results in China's domestic pollution haven effect. Specifically, the first difference arises from firms' SO_2 emissions between non-TCZ and TCZ cities, while the second difference derives from firms' SO_2 emissions before and after the regulation of TCZ policy during the 10th FYP. The DD estimation specification is presented in Equation 1:

$$Y_{it} = \alpha_0 + \beta non - TCZ_i \times Post_t + \boldsymbol{X}'_{it}\delta + \eta_i + \eta_c + \eta_{jt} + \mu_{it} \quad (1)$$

where the dependent variable, Y_{it} is an outcome (the logarithm of SO_2 emissions) of the firm i in the year t. $non - TCZ$ denotes the status with 1 if firms located in non-TCZ

cities and 0 referring firms located in TCZ cities. $Post_t$ is a dummy variable that equals 0 for all years before 2000 and 1 from 2000 onward. η_i are firm fixed effects accounting for unobserved time-invariant differences across firms, which allows us to estimate the treatment effect using the within-firm variation. η_c are city fixed effects capturing time-invariant characteristics such as geographic location or climate condition. η_{jt} are industry-by-year fixed effects capturing all yearly factors common to firms within the same industry in a year. $\boldsymbol{X}$ is a vector of baseline firm-level and city-level control variables (to be discussed later). μ_{it} denotes the error term. The standard error is clustered at the city-by-year to control for potential heteroscedasticity and serial correlation. Moreover, our main findings remain consistent when the standard error is clustered at the city level, city-by-industry level, industry-by-year level or firm level. β is the parameter of interest, which quantifies the impact of the TCZ policy on the pollution haven effect.

3.2. Data

The empirical analyses are based on a combination of multiple datasets, which provide comprehensive information on firms' pollution emissions, economic performance, and the socioeconomic conditions of cities from 1998 to 2005.

The firm pollution data is sourced from the Chinese Enterprise Pollution Database (CEPD) compiled by the Ministry of Ecology and Environment. Firms with pollutant emissions in the top 85% at the county level are required to submit detailed environmental data. This firm-level dataset provides detailed information on pollutant emissions, pollution abatement equipment, energy consumption, and other environmental performance data. These data have been increasingly utilized in recent studies to examine the impacts of Chinese central supervision, energy regulation, and tax merger policy on firms' environmental consequences (Zhang et al., 2018; Chen et al., 2020; Qi et al., 2022). Notably, research on the effects of environmental regulation on firms' pollution emissions is particularly pertinent to this study, reinforcing our confidence in the reliability of the CEPD (Wang et al., 2018; Fan et al., 2019; He et al., 2020). Since the 10th FYP explicitly mandated a 20% reduction in SO_2 emissions in the TCZ cities by 2005 compared to 2000 levels, this study uses SO_2 as the primary environmental pollution indicator for firms. For robustness checks, we also consider other pollution variables, such as chemical oxygen demand, industrial exhaust emissions, and industrial wastewater discharge, to assess the impact of environmental regulations on other environmental pollutants.

Our firm-level economic variables are sourced from the Chinese Industrial Enterprise Database (CIED) conducted by the National Bureau of Statistics of China. This survey encompasses non-state-owned industrial enterprises with annual sales exceeding 5 million RMB and all the state-owned industrial enterprises (SOEs), making it the most comprehensive and widely-used firm-level database in China. The CIED includes fundamental information about firms' characteristics, financial information, production, income statements, and cash-flow statements, such as inputs, outputs, sales, taxes, and profits. Representative studies using the CIED mainly concentrate on topics such as China's economic transition, trade liberalization, and economic growth (Song et al., 2011; Brandt et al., 2017; Hsieh and Klenow, 2009). Since the CEPD lacks firm-

level variables, we utilize the CIED to provide control variables, offering several advantages to our research: (1) The database contains information about the firm's location, enabling us to identify non-TCZ firms and TCZ firms, which is essential for performing the DD estimation; (2) The database provides detailed ownership information, facilitating the analysis of differential impacts of pollution spillover based on firm ownership structure; (3) The dataset also covers information on the firms' governmental affiliations, enabling an analysis of heterogeneity in treatment effects by considering these affiliations and whether the firms have experienced decentralization.

For this research, we merge the CEPD and CIED to identify non-TCZ and TCZ firms. First, given that the CEPD and CIED contain abnormal values, this study employs standardized data cleaning procedures suggested by Brandt et al. (2012) to preprocess the database before the empirical analysis.[11] Following this, we merge these two databases by using corporate legal entity codes, firm names, addresses, and telephone number codes that are common in both datasets to create a combined industrial-pollution panel dataset from 1998 to 2005. Finally, since the TCZ policy was implemented only in selected cities (as shown in Fig. 3), this policy categorizes cities into non-TCZ and TCZ cities. Therefore, firms in non-TCZ cities are identified as non-TCZ firms, while those in TCZ cities are classified as TCZ firms. This identification process is integral to the research design, as it underpins the empirical strategy used to generate reliable and valid conclusions.[12]

This study incorporates a comprehensive set of firm-level control variables that influence environmental pollution into the baseline regression model to estimate the policy's effects accurately. The data from the CIED includes firm age (and its squared term), capital-to-labor ratio, state ownership status, foreign investment status, and export status. Additionally, an auxiliary database utilized for city-level control variables is sourced from the China City Statistical Yearbook, provided annually by the National Bureau of Statistics of China. Detailed variable definitions and summary statistics are presented in Table A. 2 in the appendix.

4. Empirical Findings

4.1. Baseline results

4.1.1. Main results

This paper adopts the DD identification strategy to assess the environmental effects of the TCZ policy, and Table 1 presents the baseline results using firm-level panel data from 1998 to 2005 as the unit applied to Equation 1. All regressions control for year fixed effects and city-fixed effects. Columns 2 and 3 also include firm fixed effects and industry fixed effects in the main specification to replicate the regression.

[11] This study eliminates samples that lack data on total output, intermediate inputs, capital stock, or industrial value-added. Firms with missing employment data or fewer than eight employees are excluded, given that smaller firms have a higher likelihood of data misreporting. Additionally, observations with financial indicators inconsistent with generally accepted accounting principles are removed to ensure data accuracy.

[12] The identification of TCZ and non-TCZ cities is based on the document titled "The Official Reply of the State Council Concerning Acid Rain Control Areas and SO_2 Pollution Control Areas," which designates 175 TCZ cities.

The estimated coefficients are consistently positive and statistically significant at the 1% level, suggesting that the non-TCZ firms produced more SO_2 emissions than the TCZ firms—as would be expected since the non-TCZ cities could attract more pollution activities. In addition, considering that various factors may influence firms' pollution behavior, Column 4 includes controls for industry-by-year fixed effects to capture all yearly factors common to firms within the same industry. The coefficient of interest turns out to be 0.166 and statistically significant at the 1% level, which is close to the baseline result in Column 1.

Furthermore, to estimate the policy effects accurately, Column 5 of the baseline regression model controls for a set of firm-level variables that influence SO_2 emissions following established research. These variables include firm age and its squared term, the capital-labor ratio, state ownership, foreign investment status, and export status. Meanwhile, we further consider the impact of various city-level factors that may contribute to firms' SO_2 emissions. Column 6 includes a set of city-level control variables.[13] In sum, Columns 5 and 6 present the results after controlling for firm-level and city-level variables. Both estimates remain significantly positive at the 1% level, indicating that the findings are robust and not entirely driven by the inclusion of additional confounders, although the magnitude of the estimate in Column 6 is slightly smaller than that in Column 1. Based on the preferred estimate in Column 6, the average SO_2 emission increases by 14.3% following the implementation of the TCZ policy, equivalent to 44.75 thousand tons. These results suggest that the heterogeneous environmental regulation has caused a significant increase in firms' SO_2 emissions in non-TCZ cities where regulations are less stringent, as compared with TCZ cities.

[Insert Table 1 here]

4.1.2. Check on the pre-trends

The TCZ policy is an environmental regulation formulated by the central government, considering time-invariant factors such as geography, economy, and politics. If the non-random decision-making process correlates with unobserved variables, it may result in omitted variable bias. However, by incorporating firm fixed effects, city fixed effects, industry-by-year fixed effects, and control variables into the DD estimation, this paper mitigates the endogeneity problem caused by omitted variables. Additionally, identifying causal effects through DD estimation requires satisfying the parallel trends assumption: firms' SO_2 emissions in non-TCZ cities, absent policy intervention, should follow the same trend as those in TCZ cities. Therefore, we employ an event study analysis to investigate the pre-trends and verify the common trend assumption by replacing the regressor $non - TCZ_i \times Post_t$ in Equation 1 with $non - TCZ_i \times \eta_t$, η_t is a set of year dummy variables. This event study allows us to test whether the coefficients of the lead variables are statistically different from zero and estimate dynamic policy effects.

[13] The control variables employed in this study include GDP per capita, the share of secondary industry in GDP, annual precipitation, VAT payable by industrial enterprises above the designated size, total retail sales of social consumption goods, the proportion of the non-agricultural population, fixed asset investment as a share of GDP, foreign direct investment as a share of GDP, the number of industrial enterprises above the designated size, government budgetary expenditure, city population density, and the number of individuals employed in the city.

The analyses of the parallel trend assumption use firm-level data from 1998 to 2005, with the baseline year for the policy in 2000 serving as the reference year. Fig. 5 presents the estimated coefficients for the interaction terms: the black line displays the parallel trends test without control variables, and the red line represents the results incorporating control variables. Our findings indicate no significant differences in SO_2 emissions between non-TCZ and TCZ firms before the TCZ policy, regardless of whether control variables are included. After the environmental regulation, firms in non-TCZ cities exhibited significant increases in SO_2 emissions compared to TCZ cities. The DD estimation satisfies the parallel trends assumption, affirming the reliability and robustness of the methodology employed in this study.

[Insert Fig. 5 here]

4.2. Validity checks

In this subsection, we conduct two robustness checks to validate the reliability of our baseline results by using different identification strategies. To explicitly address potential confounding effects, we employ a spatial regression discontinuity (RD) design, leveraging spatial discontinuities to estimate the causal effect of regulation on pollution. As an additional robustness check, we combine the DD and RD estimation to implement a boundary discontinuity difference-in-differences (BD-DID) regression. This method evaluates the impact of the TCZ policy on SO_2 emissions by comparing firms located on either side of the policy boundary.

4.2.1. RD design

While the preceding analysis suggests that we capture the causal effect of environmental regulation on pollution, an endogeneity issue remains concerning: The previous estimation may not sufficiently resolve the potential confounding effects related to the assignment of non-TCZ and TCZ cities. To mitigate these confounding effects, we conduct a supplementary analysis focusing on policy boundary discontinuities. As shown in Fig. 6, a policy boundary creates variation in regulatory stringency between cities positioned north (19 non-TCZ cities) and south (30 TCZ cities) of the boundary. This spatial discontinuity serves as an exogenous variation to estimate the causal effect of regulation on pollution emissions, offering a robust approach to addressing potential bias.

[Insert Fig. 6 here]

We utilize the variation in distance to the nearest geographical threshold (policy boundary) as the running variable for implementing a spatial regression discontinuity design.[14] This empirical strategy is inspired by recent work exploiting discontinuities in regulation stringency to evaluate the effect of environmental regulation on firm productivity (He et al., 2020). However, in contrast to previous research, our study shifts the focus to air pollution spillovers, specifically emphasizing SO_2 emissions. By pooling all post-regulation observations, we rely on the recommended local linear approach to estimate the following Equation:

[14] The distance between a firm and the policy boundary serves as the running variable. We calculate the minimum distance from the county where each firm is located to the policy boundary using ArcGIS software.

$$Y_{it} = \alpha_1 North_{it} + \alpha_2 Dist_{it} + \alpha_3 North_{it} \cdot Dist_{it} + \eta_c + \eta_{jt} + \mu_{it} \quad (2)$$

where Y_{it} represents the SO_2 emission of firm i in the year t on either side of the boundary. $North_{it}$ is an indicator variable that equals 1 if firm i located north of the boundary and 0 otherwise. $Dist_{it}$ is the value of the running variable, which measures the distance between firm i to the closest policy boundary (negative if south and positive if north). Aligned with prior definitions, η_c denotes city fixed effects and η_{jt} represents industry-by-year fixed effects. Standard errors are clustered at the city by year level to deal with the potential spatial correlation of the error term, as suggested by Cameron and Miller (2015). Following Lee and Lemieux (2010), we estimate this nonparametric RD model with fixed effects using a two-step approach. First, we run an OLS regression of SO_2 emissions to absorb the industry-by-year and city fixed effects. Then, we apply the nonparametric estimations on the residualized SO_2 emissions.

We begin the empirical analysis by visualizing our main findings, adopting the approach proposed by Calonico et al. (2014). Fig. 7 presents the RD results by showing a binned scatterplot of SO_2 emissions (absorbing city fixed effects and industry-by-year fixed effects). Each dot denotes the average log SO_2 for firms, and their 95% confidence intervals are also presented. The RD plot for residual SO_2 emissions during the post-policy periods (2000–2005) reveals a sharp change in SO_2 emissions when moving from the left (south) to the right (north) of the threshold. Non-TCZ firms located north of the boundary exhibit significantly higher SO_2 emissions than TCZ firms situated south.

[Insert Fig. 7 here]

We now turn to using the bias-corrected local linear regressions approach to quantify the RD results using a triangular kernel.[15] Estimates from the local linear regression approach are presented in Table 2, Columns 1 – 4, corresponding to bandwidths of 20, 40, 60, and 80 kilometers. The different bandwidth ranges are shown in Fig. 8. The results of panel A show the TCZ policy's effect on SO_2 emissions by controlling for city fixed effects, while panel B presents the results by controlling for city fixed effects and industry-by-year fixed effects. Across all bandwidths, the coefficients remain consistently positive, indicating that northern firms (non-TCZ firms) exhibit higher SO_2 emissions than southern firms (TCZ firms), particularly within 40 kilometers of the policy boundary. As the bandwidth increases, the coefficients' magnitude and statistical significance decline, implying diminishing pollution spillover effects of the TCZ policy. However, we express caution when interpreting these estimates as they represent local effects and do not capture all samples in non-TCZ and TCZ cities.

[Insert Fig. 8 here]

[Insert Table 2 here]

4.2.2. BD-DD estimations

Despite the various specifications, the DD estimation could still have suffered from endogeneity issues, including omitted variables, measurement errors, and sample selection biases. If the TCZ policy is correlated with other unobserved factors affecting

[15] The results are consistent with our RD estimates when alternative kernel weighting methods are applied. The RD results using the epanechnikov and uniform kernels are presented in Table A. 3 and Table A. 4 in the appendix.

PHE that have not been considered, the benchmark regression model may yield biased results. As an alternative robustness check, we further combine the two approaches above and estimate a boundary discontinuity difference-in-differences (BD-DID) regression following Lu et al. (2019) to investigate the impact of the TCZ policy on pollution emissions of firms located on both sides of the policy boundary. This approach provides further control for any time-invariant differences in location characteristics among cities close to the boundary. In other words, TCZ cities near the boundary serve as counterfactuals for non-TCZ cities because they have similar geographical, anthropological, and socioeconomic characteristics (As shown in Fig. 6). The regression results of the BD-DD estimation are reported in Table 3. The coefficients of the interaction term in Columns 1–6 indicate that the TCZ policy increases the pollution emissions of firms in the non-TCZ cities.

[Insert Table 3 here]

Following a similar approach, we apply the BD-DID estimation to assess the effect of the TCZ policy on firms' SO_2 emissions within varying bandwidths along the boundary. Fig. 8 displays the distribution of samples within bandwidths of 20km, 40km, 60km, and 80km, while Fig. 9 presents the impact of the TCZ policy on pollution spillover within these respective distances. Our results confirm that the coefficients are small and statistically insignificant before 2000, but they become statistically significant and of greater magnitude from 2000 onwards, underscoring the pollution spillover effect induced by environmental regulations. This suggests that the TCZ policy generated significant pollution haven effects, particularly for firms in non-TCZ areas closer to the boundary. The pollution spillover effect also weakens as the distance from the policy boundary increases.

[Insert Fig. 9 here]

4.3. Other robustness checks

The previous robustness checks for RD and BD-DID estimations are based on a limited sample subset. This subsection extends the analysis by using a larger dataset and applying conventional robustness checks from multiple perspectives.

4.3.1. Non-target pollutants

The findings of our study reveal that the TCZ policy implemented during the 10th Five-Year Plan significantly increased SO_2 emissions from non-TCZ firms, contributing to a nationwide rise in SO_2 emissions. This raises the question of whether the domestic pollution haven effect observed for SO_2 is pollutant-specific or extends to other forms of environmental pollution. To explore this, we analyze the impact of environmental regulations on firms' chemical oxygen demand (COD), industrial exhaust emissions (IEE), and industrial wastewater discharge (IWD). Such estimations would enhance our understanding of the broader implications of environmental regulations on PHE. If the policy incentivizes local bureaucrats to target SO_2 emissions exclusively, we should not expect any PHE on non-targeted pollutants. The estimation results, reported in Table 4, show that none of the estimated coefficients for non-target pollutants are positive and statistically significant, suggesting that the SO_2-specific environmental regulations do not induce pollution haven effects for other pollutants.

[Insert Table 4 here]

4.3.2. Placebo test

To mitigate the potential endogeneity problem arising from unobservable factors, we conduct a placebo test on the estimated coefficients, following the methodologies in previous studies (Chetty et al., 2009; Ferrara et al., 2012; Li et al., 2016). By randomly sampling the interaction term of the core explanatory variables, we simulate a scenario of random TCZ policy assignment across cities. To enhance the identification power of the placebo test, this process is repeated 500 times, generating 500 sets of random samples. The DD estimation is then performed for each of these random samples, yielding 500 estimated coefficients representing the impact of the TCZ policy on pollution spillover effects. Under the random data-generation process, the placebo tests should have produced no significant estimates with a magnitude close to zero; otherwise, it would indicate a misspecification of the DD estimation. Fig. A1 presents the probability density distribution of the 500 estimated coefficients from the placebo tests, with SO_2 emissions as the dependent variable. The distribution of these estimated coefficients resembles an overall distribution with a mean of zero, and the coefficient of the core explanatory variable in the baseline results lies in the tail of this distribution. The placebo tests indicate that the baseline findings are not driven by random chance, further supporting our identification strategy.

4.3.3. PSM-DD estimation

In addition to our previous robustness checks, we apply a propensity score matching (PSM) strategy combined with the DD estimation to construct a matched sample from the observational data, ensuring that control variables are balanced and mitigating potential systematic differences in observable characteristics. This approach makes the firms affected by the TCZ policy more comparable to the unaffected firms, with TCZ firms used to estimate the counterfactual outcomes for non-TCZ firms. Firm characteristics and city features are used as matching criteria to perform 1:1 nearest-neighbor matching between firms in and outside TCZ cities. A logit model is then applied to calculate propensity scores, retaining only samples that meet the common support assumption. Re-estimating Equation 1 using the matched sample, the results in Table 5 consistently show positive and statistically significant estimates for SO_2 emissions across Columns 1–6 under the PSM-DD framework, reinforcing the study's credibility.

[Insert Table 5 here]

4.3.4. ARCA and SPCA Subsamples

The TCZ policy, as described in Section 2, is divided into Acid Rain Control Areas, located primarily south of the policy boundary, and SO_2 Pollution Control Areas, mainly situated to the north. This study explores whether the TCZ policy has led to heterogeneous environmental spillover effects between the two regions. To examine this, we divide the sample into two subregions based on whether the city is located north or south of the policy boundary, following the division criteria of the TCZ policy. In Table 6, Column 1 presents panel data from cities north of the policy boundary, while

Column 2 presents data from cities south of the boundary. The estimation results indicate that the policy has exacerbated pollution emissions from non-TCZ firms, particularly those located north of the policy boundary. Panel A (without covariate controls) and Panel B (with covariate controls) yield consistent findings, reinforcing the robustness of the results. These findings indicate that lenient enforcement of environmental regulations leads to substantial pollution emissions from firms outside the controlled cities, thereby contributing to a nationwide increase in SO_2 emissions.

[Insert Table 6 here]

4.3.5. Sample adjustment

To mitigate the potential influence of geographical features such as the Qinghai-Tibet Plateau and the Sichuan Basin on our estimation results, we refine our analysis by excluding these regions from the sample. Columns 3 of Table 6 remove samples from the Qinghai-Tibet Plateau, while Columns 4 exclude samples from Sichuan Province to evaluate the impact of the TCZ policy on pollution emissions. Panel A reports regression results without controlling for firm and city covariates, while Panel B presents results with these covariates included. The results show that the TCZ policy significantly increases SO_2 emissions from non-TCZ firms, even after accounting for sample adjustments. These robustness checks reaffirm the validity of our previous conclusions.

4.3.6. Alternative standard errors

Recognizing that different types of firms may exhibit correlation patterns not only within the city-by-year level but also across city-by-industry and year-by-industry levels, we assess the robustness of our baseline results by clustering standard errors at multiple levels. In Table 7, we cluster standard errors at the city level, city-by-two digit industry level, city-by-four digit industry level, year-by-two digit industry level, year-by-four digit industry level, and firm level, respectively. Our main findings remain consistent across all clustering levels, reinforcing the conclusion that the TCZ policy has induced the domestic pollution haven effect, contributing to a nationwide increase in SO_2 emissions.

[Insert Table 7 here]

5. Mechanisms

The preceding empirical analysis shows that the TCZ policy has resulted in higher pollution levels from non-TCZ firms between 2000 and 2005, supported by extensive empirical evidence. Within the central-local government principal-agent political system, while the central government has emphasized the importance of environmental protection and enacted policies to curb SO_2 emissions and mitigate acid rain, local governments have shown limited motivation to achieve these environmental targets. This misalignment stems from environmental decentralization since local governments primarily focus on achieving economic growth to secure political promotion. As a result, these environmental regulations may have inadvertently triggered the pollution haven effect, exacerbating nationwide pollution levels.

This section explores the mechanisms through which environmental decentralization generates the domestic pollution haven effect. We provide evidence

demonstrating that the political incentives of local politicians are key drivers behind our main findings. First, we examine the differential impacts of pollution spillover based on firm ownership. Next, we analyze heterogeneity in treatment effects across firms, considering their governmental affiliations and whether they have undergone decentralization. Furthermore, we evaluate the role of local leaders' long-term versus short-term goals in shaping the observed PHE. Lastly, we assess the relative contributions of domestic and foreign investment to the PHE.

5.1. Firm ownership structure

This subsection investigates whether the effect of pollution spillover varies according to firm ownership, providing insight into which type of firms predominantly drive the pollution haven effect. To investigate this, we analyze how the TCZ policy impacts pollution emissions across ownership structures, classifying firms as state-owned enterprises (SOEs), privately-owned enterprises (POEs), and foreign firms. These classifications are based on registration type, supplemented by firm control information and capital contributions.[16]

In Table 8, we re-estimate the DD strategy by firm ownership and find that SOEs primarily drive the increase in SO2 emissions. In contrast, the TCZ policy has no significant effect on the pollution spillover of privately-owned and foreign firms. A possible explanation is that SO_2 concentrated in a few SOEs-dominated industries. Specifically, SOEs hold a significant share in pollution-intensive industries such as state-owned petroleum and petrochemical enterprises. When environmental regulations are relatively less stringent, this leads to lower input costs for pollution-intensive products, enhancing the comparative advantage of pollution-intensive SOEs in non-TCZ cities. Consequently, this increases pollution emissions, turning non-TCZ cities into pollution havens for TCZ cities.

[Insert Table 8 here]

5.2. Subordinate relations and decentralization

This subsection investigates the heterogeneous effect of firms' governmental affiliations and decentralization status on pollution behaviors. The purpose of this mechanism analysis is two-fold. First, within China's hierarchical administrative structure, firms are subordinate to central, provincial, municipal, county, and township governments, resulting in differences in regulatory compliance and pollution outcomes. Firms affiliated with the central government typically exhibit stronger adherence to national policy objectives due to effective oversight and information symmetry. In contrast, firms under local government supervision often face weaker enforcement of environmental mandates, leading to higher emissions. We classify firms based on their governmental affiliations—central, provincial, municipal, county, and township—and

[16] Firm classification is conducted in three steps First, firms are categorized by their registration type: state-owned enterprises (SOEs) are classified under types 110, 141, 143, and 151; collective enterprises under types 120 and 142; privately-owned enterprises (POEs) under types 171–174; and foreign enterprises under types 300, 310, 320, 330, 340, 200, 210, 220, 230, and 240. Second, missing values are supplemented using firm control information. Finally, the classification process is completed by filling any remaining missing values based on the type with the largest share of paid-in capital.

conduct separate analyses for each category. Second, we investigate whether decentralization has influenced firms' pollution behaviors. Some firms have experienced decentralization, shifting oversight from central to local authorities, which hinders the central government's ability to monitor firms' pollution behaviors effectively. When firms are under the jurisdiction of local governments, their activities are more likely to align with local government priorities, which often emphasize economic growth over environmental protection, thereby exacerbating pollution levels.

Fig. 10 presents the pollution haven effects (treatment effects) of environmental regulations on non-TCZ firms affiliated with the central government and the differential effects for each group (provincial, municipal, county, and township). The results show that firms under central authority do not exhibit increased pollution emissions compared to TCZ firms. In contrast, firms under local governance demonstrate significant increases in SO_2 emissions, with estimated effects of 16.0%, 15.8%, 17.3%, and 22.8% for provincial, municipal, county, and township-affiliated firms, respectively. The analysis further reveals the critical role of decentralization in shaping pollution spillover effects. We find the pollution haven effects statistically distinguishable from the central effect, with a point estimate of 26.5 percentage points. In sum, pollution haven effects manifest in firms governed by local authorities and those decentralized from upper to lower government oversight. Although controlling for covariates reduces the sample size across firm categories, the findings in Fig. A2 remain consistent, confirming the robustness of these conclusions.

[Insert Fig. 10 here]

5.3. Long-term vs. short-term goals

Research on Chinese political meritocracy reveals that prefecture-level leaders in China are typically ineligible for promotion once they exceed the age of 56. This institutional feature creates distinct incentives for leaders based on their age. Leaders over 56, facing limited prospects for career advancement, are less motivated to prioritize long-term objectives, such as environmental improvement, which yield returns only over extended periods. In contrast, younger leaders (aged 56 or younger) still harbor political aspirations and are more likely to view excessive environmental pollution as a potential obstacle to promotion. To capture these divergent incentives, we categorize our sample based on the age of the city's mayor or party secretary. Leaders aged 56 or younger are classified as having long-term goals, balancing economic growth with environmental considerations, while those over 56 are assumed to focus on short-term goals, often prioritizing immediate economic gains.[17]

To investigate whether long-term or short-term goals drive the pollution haven effect under the TCZ policy, we analyze the heterogeneous impact of leaders' age on SO_2 emissions. Table 9 reports the regression results after categorizing the sample of firms. Columns 1 and 3 indicate that when the city's leaders have long-term goals, the TCZ policy does not lead to increased SO_2 emissions in non-TCZ cities, implying that environmental regulations do not induce the pollution haven effect, as leaders with long-term horizons balance economic growth with environmental considerations. However, Columns 2 and 4 show that the TCZ policy significantly increases SO_2

[17] The data on party secretaries and mayors in the cities is sourced from Yao and Zhang (2015).

emissions when the leaders have short-term goals. These findings suggest that the pollution haven effect in non-TCZ cities is primarily driven by leaders with short-term goals, who tend to overlook environmental considerations.

[Insert Table 9 here]

5.4. Domestic investment vs. foreign investment

This study examines whether non-TCZ cities, characterized by relatively lax environmental regulations, attract increased domestic and foreign investment, which may exacerbate the domestic pollution haven effect. The baseline regression model includes interaction terms with domestic and foreign investment variables to assess how different capital sources influence firms' pollution emissions. Domestic investment is measured by the ratio of fixed asset investment to GDP, while foreign investment is represented by the ratio of FDI to GDP. Table 10 presents the estimated impacts of these investments on SO_2 emissions. Columns 1 and 2 show that higher levels of domestic investment are associated with increased SO_2 emissions in non-TCZ cities, indicating that domestic capital contributes to the PHE. In contrast, Columns 3 and 4 show that foreign investment does not respond similarly to environmental regulations, with no evidence of the PHE. This may be explained by the positive spillover effects of FDI, such as the transfer of advanced technologies and management practices, which may enhance firms' pollution-reduction capacities and mitigate the risk of foreign investment contributing to the PHE. In Columns 5 and 6, when we include interaction terms for both domestic and foreign investment, the results continue to support the conclusion that domestic investment contributes to the PHE, while foreign investment does not exhibit the same sensitivity to environmental regulation.

[Insert Table 10 here]

6. Conclusion

China's rapid economic growth has been accompanied by significant environmental degradation, prompting the central government to implement the Two Control Zones policy to curb SO_2 emissions. However, the TCZ policy has failed to achieve its objectives, resulting in a rise in total SO_2 emissions, particularly in non-TCZ cities where emissions have increased since 2000. Despite this, the failure of the TCZ policy remains under-explored, and empirical investigations into its causes are limited. This study investigates the failure of the TCZ policy by examining the causal link between environmental regulation and the domestic pollution haven effect.

Estimating the causal relationship between environmental regulation and the domestic pollution haven effect requires addressing endogeneity concerns and investigating the mechanisms underlying the failure of the TCZ policy. To estimate this causal relationship, we treat the TCZ policy as a quasi-natural experiment and apply a difference-in-differences (DD) identification strategy, using spatial regression discontinuity (RD) and boundary discontinuity difference-in-differences (BD-DID) serving as supplementary methods to provide a robust analysis of how environmental regulation has contributed to the domestic pollution haven effect in China. Our findings reveal that the TCZ policy has led to increased SO_2 emissions in non-TCZ cities, where regulations are less stringent compared to TCZ cities. The RD results indicate that

northern firms (non-TCZ firms) exhibit higher SO_2 emissions than their southern counterparts (TCZ firms), particularly within a 40-kilometer radius of the policy boundary. Additionally, The BD-DID estimation shows that the pollution haven effect is most pronounced near the regulation boundary and diminishes as the distance from the boundary increases.

We attribute the failure of environmental regulations to China's environmental decentralization under the central-local governance system. In China's hierarchical administrative system, firms are affiliated with different levels of government and these affiliations heavily influence their behavior. While the central government emphasizes environmental protection, local bureaucrats prioritize economic growth, as GDP growth is crucial for political evaluations. Mechanism analysis indicates that the pollution haven effect exists only in state-owned firms in non-TCZ cities rather than in private-owned or foreign firms, and decentralized firms are primarily responsible for the pollution haven effect. Furthermore, domestic investment exacerbates the pollution haven effect, while foreign investment does not exhibit a similar sensitivity to environmental regulation.

This study identifies the transformation of non-TCZ cities into pollution havens as a direct consequence of environmental regulation, offering critical implications for future policy design. Standard approaches often concentrate on the impacts of regulation within targeted areas, overlooking significant spillovers to unregulated regions that threaten to derail national objectives. Our paper highlights the need for future environmental policies to account for both direct and indirect effects, particularly pollution spillover to unregulated regions. Additionally, this study underscores the importance of aligning the environmental priorities of central and local governments to prevent conflicting objectives and ensure consistency between policy formulation and implementation. Finally, we advocate for enhanced inter-jurisdictional coordination to mitigate pollution spillovers, minimize negative externalities, and advance sustainable development.

Declaration of Competing Interest

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

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Figures and Tables

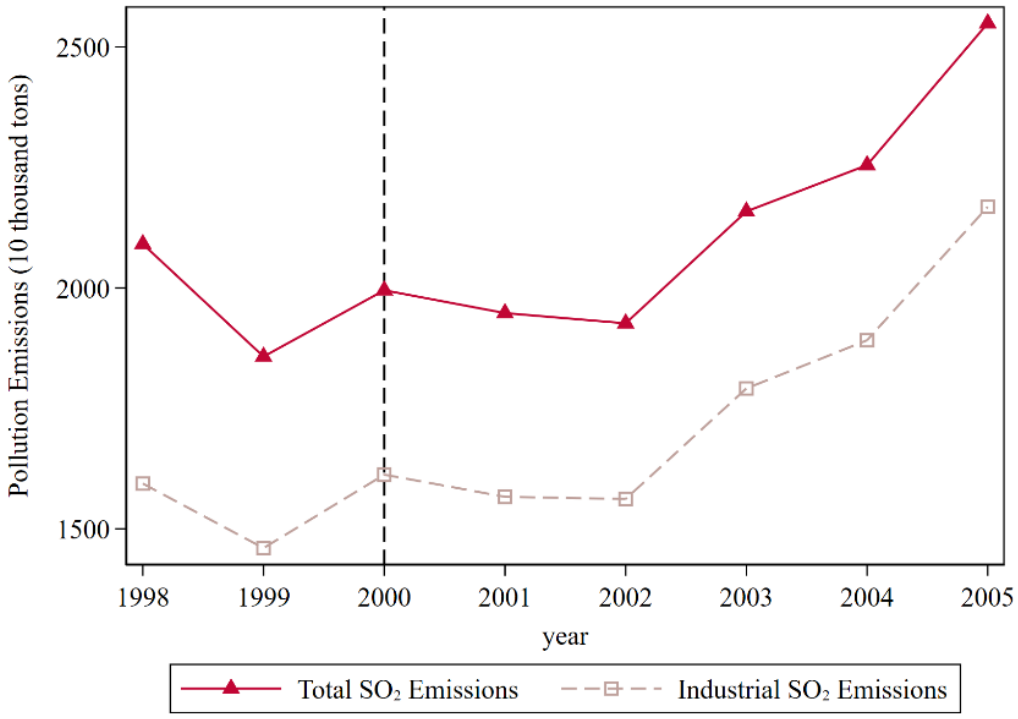


Fig. 1. Total SO_2 emissions and industrial SO_2 emissions trends in 1998–2005.

Notes: China Environment Yearbooks in various years.

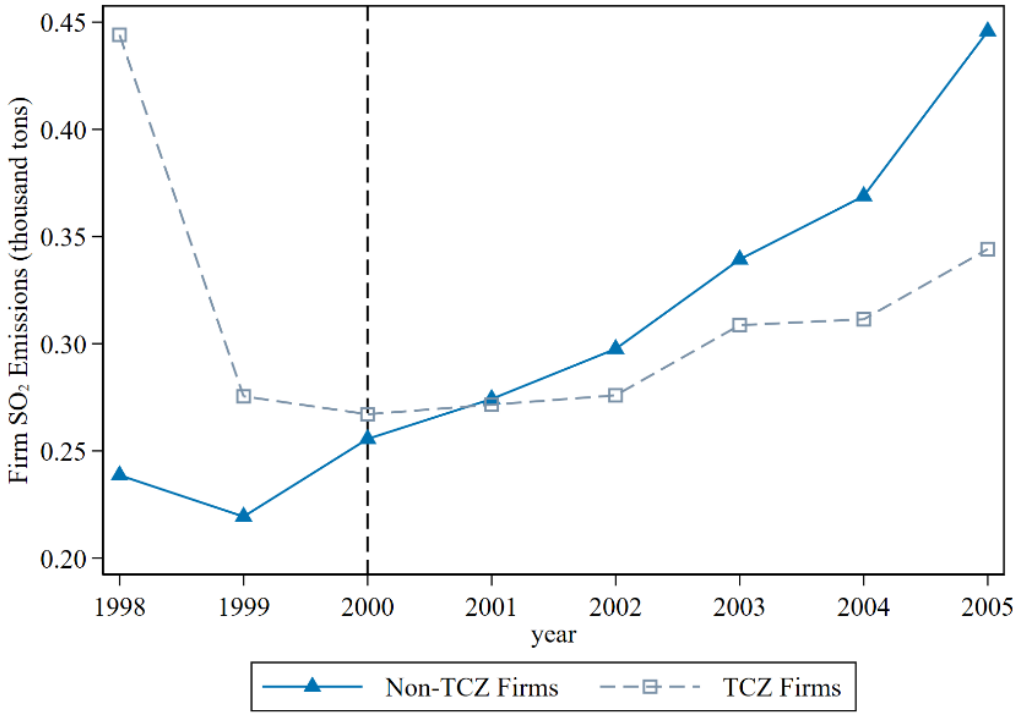


Fig. 2. Binned scatter plots of SO_2 emissions.

Notes: The firm-level data are sourced from the Chinese Enterprise Pollution Database (CEPD). The x-axis indicates the years before and after the implementation of the TCZ policy during the 10th Five-Year Plan, with the black vertical dash line marking the policy's introduction. The y-axis measures the average firm-level SO_2 emissions.

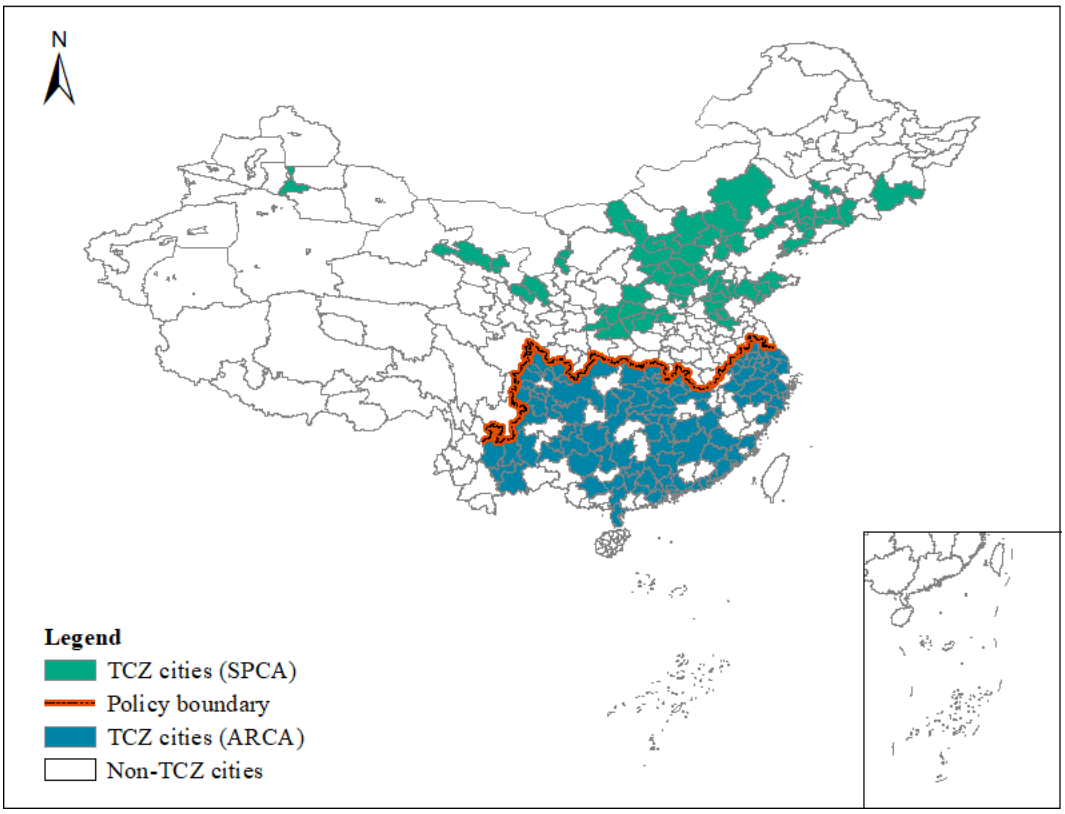


Fig. 3. Map of Two Control Zones.

Notes: This figure displays the spatial distribution of Two Control Zones. The areas marked in green denote the SO_2 Pollution Control Areas (SPCA), while the regions shaded in blue represent the Acid Rain Control Areas (ARCA). Within a relatively small geographical range, the red line marks the policy boundary, separating TCZ cities from non-TCZ cities and highlighting the distinct regulatory enforcement between the two areas.

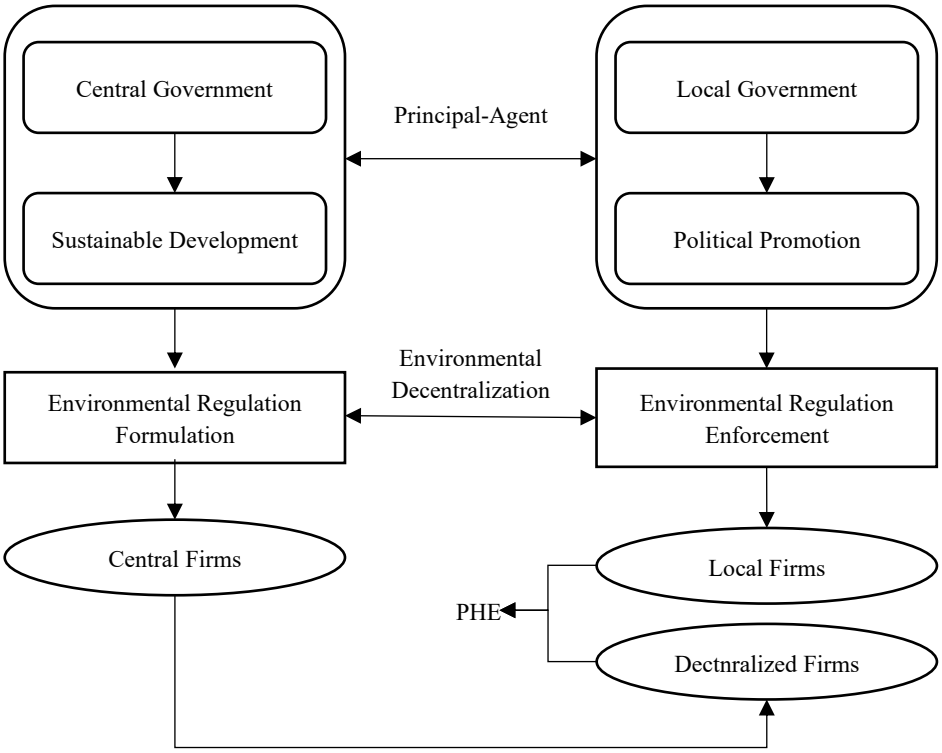


Fig. 4. Path diagram of the effect of environmental regulations on PHE.

Note: Drawn by the author.

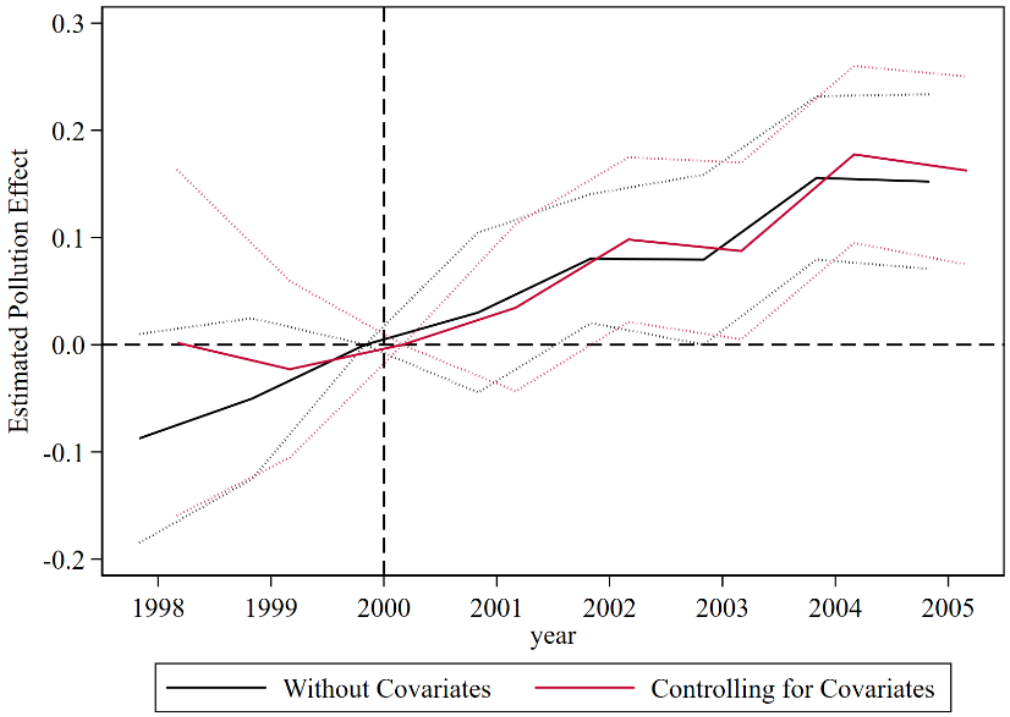


Fig. 5. Test for parallel trends of SO_2 emissions at the firm level.

Notes: The black line displays the parallel trends test without control variables, and the red line represents the results incorporating control variables. Any temporal trends are analyzed by comparing non-TCZ and TCZ firms. The plots connected by the solid line indicate changes in SO_2 emissions compared to 2000, conditional on firm, city, and industry-by-year fixed effects. The dashed lines represent the 95% confidence intervals where standard errors are clustered at the city by year level.

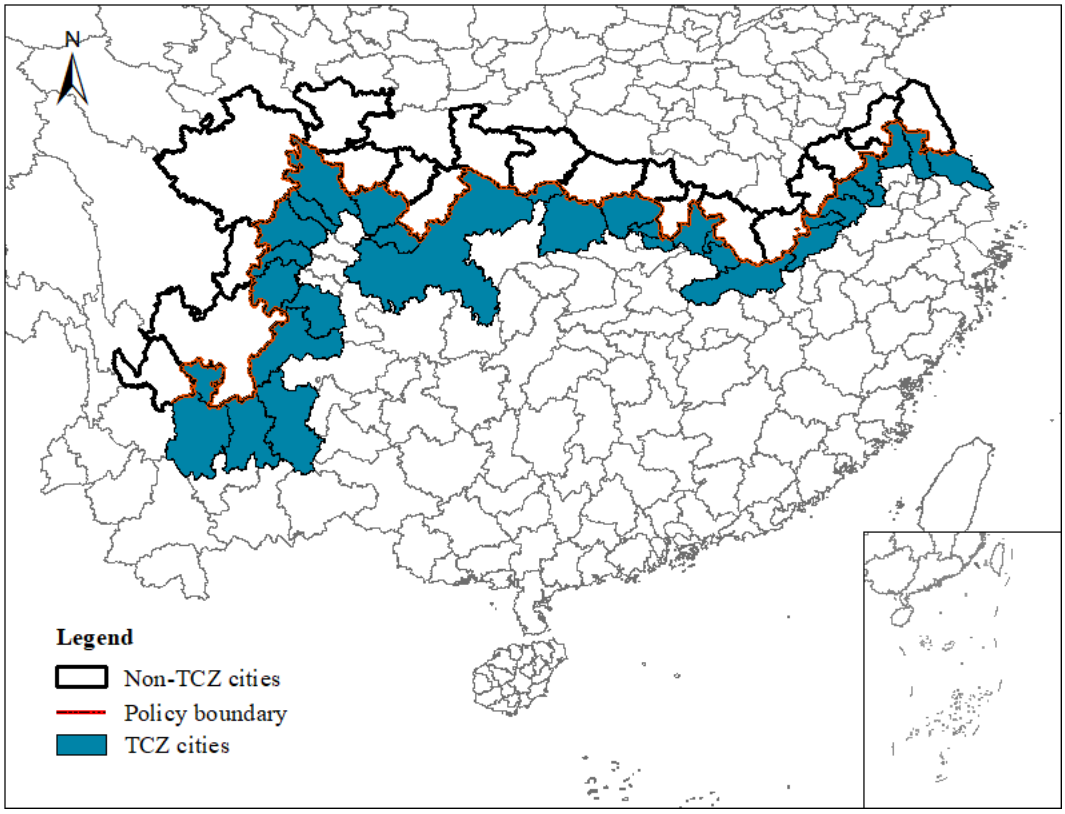


Fig. 6. Distribution of cities adjacent to the boundary.

Notes: This figure demonstrates the distribution of cities adjacent to the policy boundary, with 30 cities located south of the boundary and 19 cities to the north.

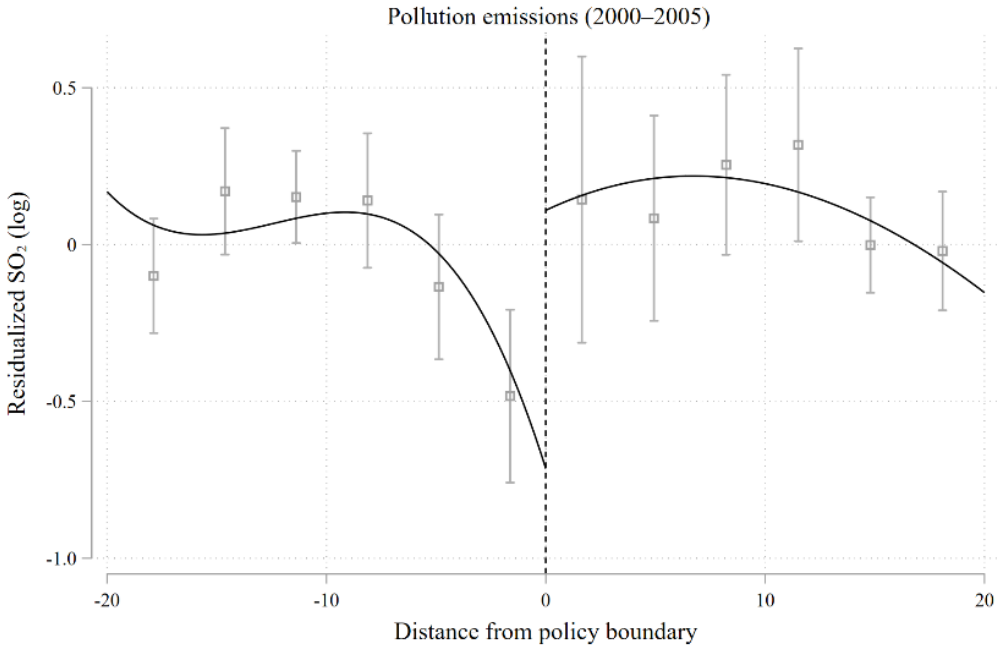


Fig. 7. Regression Discontinuity Plots.

Notes: This figure reports RD plots using the procedure suggested by Calonico et al. (2014). Industry-by-year and city fixed effects are absorbed before plotting the regression discontinuities. Robust standard errors are clustered at the city-by-year level. Error spikes represent 95% confidence intervals.

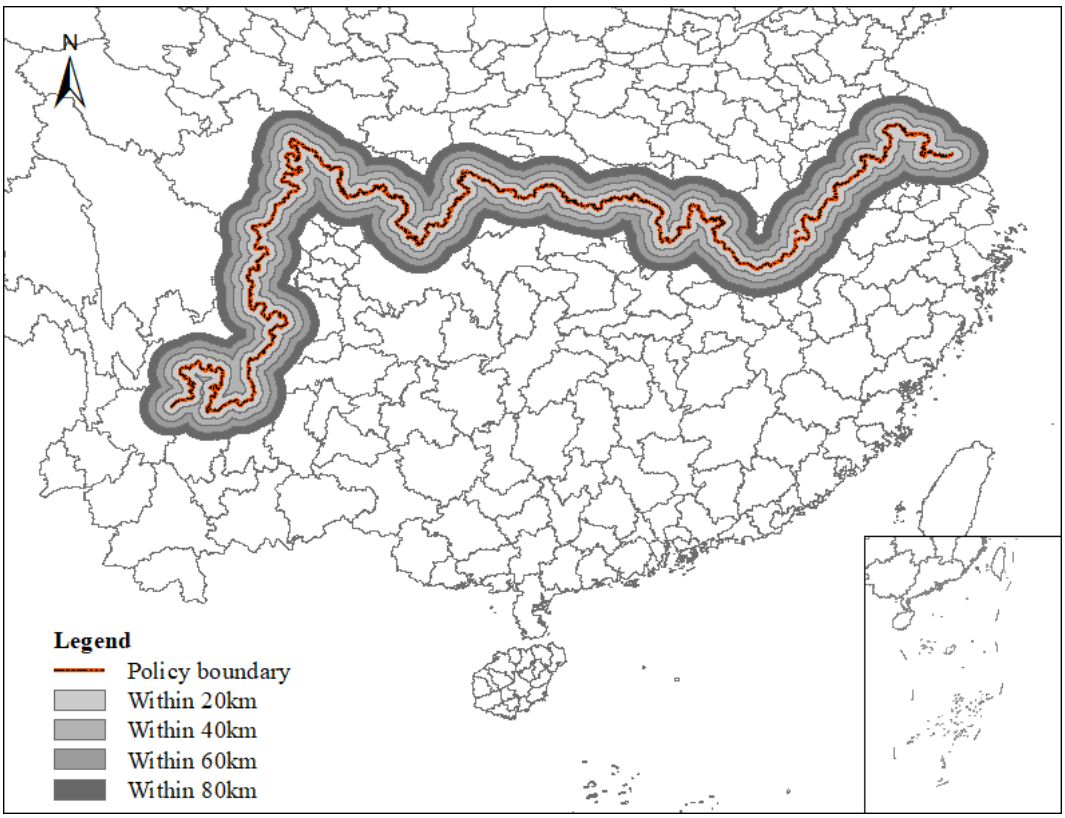


Fig. 8. Distribution of samples within various bandwidths.

Notes: This figure displays the distribution of samples within various bandwidths, with estimations considering different bandwidths of 20km, 40km, 60km, and 80km, respectively.

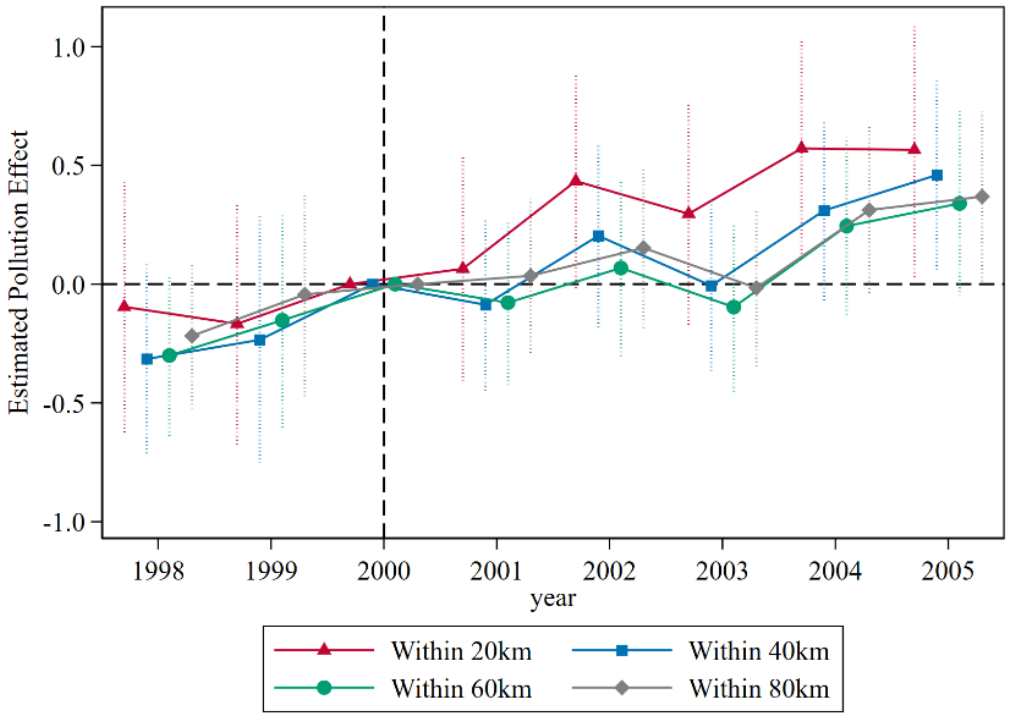


Fig. 9. Test for parallel trends of SO_2 emissions within different bandwidths.

Notes: This figure presents the estimation results within bandwidths of 20 km, 40 km, 60 km, and 80 km, respectively. The plots connected by the solid line indicate changes in SO_2 emissions compared to 2000, conditional on firm, city, and industry-by-year fixed effects. The dashed lines represent the 95% confidence intervals where standard errors are clustered at the city-by-year level.

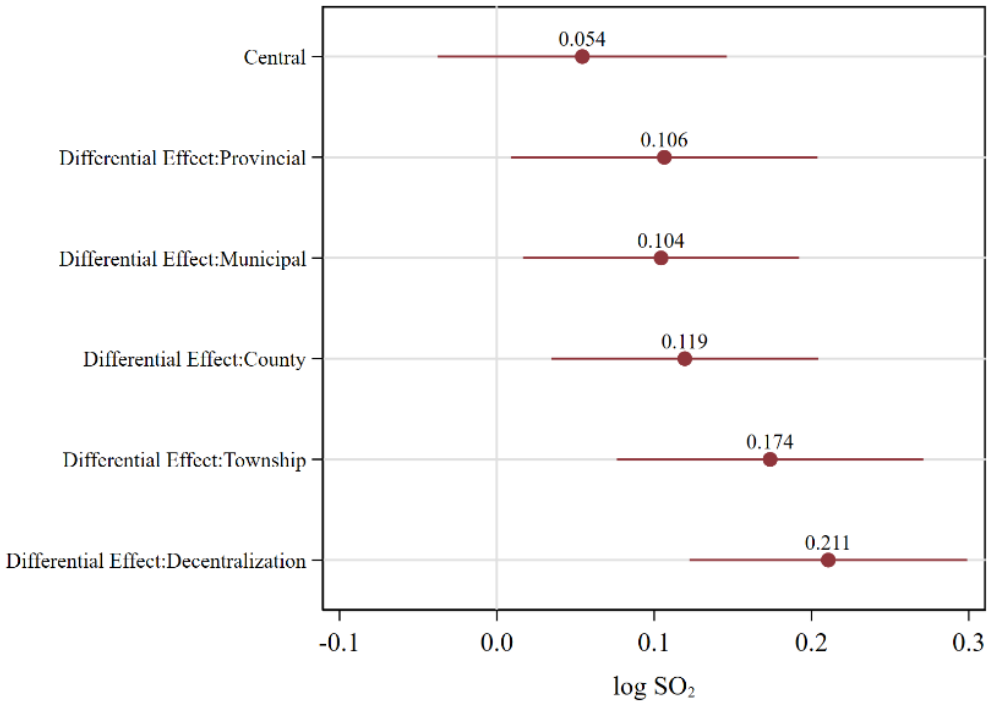


Fig. 10. Heterogeneous effects.

Notes: The sample is categorized by firms' governmental affiliations into five groups: central, provincial, municipal, county, and township. Decentralization refers to firms that have shifted from upper-level to lower-level government oversight. All regressions control year fixed effects, city fixed effects, firm fixed effects, and industry-by-year fixed effects. For the central group, we present the average treatment effect along with a 90% confidence interval (CI). We report the differential treatment effect for the other categories accompanied by a 90% CI. Standard errors clustered at the city-by-year level.

Table 1
Baseline estimation results.

	log SO2					
	(1)	(2)	(3)	(4)	(5)	(6)
Non-TCZ×Post	0.173***	0.161***	0.161***	0.166***	0.179***	0.143***
	(0.042)	(0.039)	(0.039)	(0.037)	(0.039)	(0.053)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	No	Yes	Yes	Yes	Yes	Yes
Industry FE	No	No	Yes	Yes	Yes	Yes
Industry-by-year FE	No	No	No	Yes	Yes	Yes
Firm Controls	No	No	No	No	Yes	Yes
City Controls	No	No	No	No	No	Yes
Observations	201345	183161	183161	183155	176086	149253
R-squared	0.081	0.803	0.803	0.805	0.805	0.812

Notes: All observations are at the firm-year level. Non-TCZ firms are those located in non-TCZ cities. Each Column represents a difference-in-differences specification. All regressions control for year fixed effects and city fixed effects. Columns 2–4 include controls for firm fixed effects, industry fixed effects, and industry-by-year fixed effects, respectively. Columns 5 and 6 further include firm-level and city-level control variables. Standard errors clustered at the city-by-year level are reported below the estimates. ***, **, * represent significance levels of 1%, 5%, and 10%, respectively.

Table 2
RD results.

	Within 20 km	Within 40 km	Within 60 km	Within 80 km
	(1)	(2)	(3)	(4)
Panel A: City FE absorbed				
RD in SO_2 (log)	5.194***	0.831**	0.350	0.254
	(1.899)	(0.397)	(0.262)	(0.246)
Bandwidth	3.003	7.461	13.69	18.17
Panel B: City FE + industry by year FE absorbed				
RD in SO_2 (log)	2.774*	0.872***	0.669***	0.665***
	(1.666)	(0.289)	(0.209)	(0.209)
Bandwidth	2.705	8.459	14.56	16.65
Observations	3544	7783	11301	14504

Notes: Each cell in the table represents a separate RD regression. The running variable is the distance between a firm and the closest policy boundary, where negative (positive) distance means firms are located to the south (north) of the policy boundary. Standard errors clustered at the city-by-year level are reported below the estimates. ***, **, * represent significance levels of 1%, 5%, and 10%, respectively.

Table 3
BD-DID results.

	log SO_2					
	(1)	(2)	(3)	(4)	(5)	(6)
Non-TCZ×Post	0.362***	0.323**	0.324**	0.333***	0.357***	0.174
	(0.115)	(0.126)	(0.126)	(0.115)	(0.116)	(0.173)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	No	Yes	Yes	Yes	Yes	Yes
Industry FE	No	No	Yes	Yes	Yes	Yes
Industry-by-year FE	No	No	No	Yes	Yes	Yes
Firm Controls	No	No	No	No	Yes	Yes
City Controls	No	No	No	No	No	Yes
Observations	32088	29097	29096	29086	28224	24651
R-squared	0.042	0.734	0.734	0.739	0.738	0.738

Notes: All regressions control for year fixed effects and city fixed effects. Columns 2–4 include controls for firm fixed effects, industry fixed effects, and industry-by-year fixed effects, respectively. Columns 5 and 6 further include firm-level and city-level control variables. Standard errors clustered at the city-by-year level are reported below the estimates. ***, **, * represent significance levels of 1%, 5%, and 10%, respectively.

Table 4

Non-target pollutants.

	log COD	log COD	log IEE	log IEE	log IWD	log IWD
	(1)	(2)	(3)	(4)	(5)	(6)
Non-TCZ×Post	-0.005	0.036	0.002	0.025	-0.054**	-0.025
	(0.046)	(0.058)	(0.019)	(0.026)	(0.025)	(0.031)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry-by-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm Controls	No	Yes	No	Yes	No	Yes
City Controls	No	Yes	No	Yes	No	Yes
Observations	158871	135022	190887	155691	194545	160928
R-squared	0.825	0.834	0.910	0.914	0.881	0.888

Notes: All regressions control year fixed effects, city fixed effects, firm fixed effects, and industry-by-year fixed effects. Columns 2, 4, and 6 include firm-level and city-level control variables. Standard errors clustered at the city-by-year level are reported below the estimates. ***, **, * represent significance levels of 1%, 5%, and 10%, respectively.

Table 5
PSM-DID.

	log SO_2					
	(1)	(2)	(3)	(4)	(5)	(6)
Non-TCZ×Post	0.142**	0.145***	0.145***	0.158***	0.162***	0.150***
	(0.062)	(0.054)	(0.055)	(0.053)	(0.052)	(0.052)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	No	Yes	Yes	Yes	Yes	Yes
Industry FE	No	No	Yes	Yes	Yes	Yes
Industry-by-year FE	No	No	No	Yes	Yes	Yes
Firm Controls	No	No	No	No	Yes	Yes
City Controls	No	No	No	No	No	Yes
Observations	152315	135699	135699	135691	135691	135691
R-squared	0.078	0.807	0.808	0.809	0.810	0.810

Notes: All regressions control for year fixed effects and city fixed effects. Columns 2–4 include controls for firm fixed effects, industry fixed effects, and industry-by-year fixed effects, respectively. Columns 5 and 6 further include firm-level and city-level control variables. Standard errors clustered at the city-by-year level are reported below the estimates. ***, **, * represent significance levels of 1%, 5%, and 10%, respectively.

Table 6
Sample adjustment.

	log SO_2			
	North	South	Without Plateau	Without Plateau and Sichuan
	(1)	(2)	(3)	(4)
Panel A: Without controlling for covariates				
Non-TCZ×Post	0.299***	0.097	0.163***	0.152***
	(0.052)	(0.068)	(0.037)	(0.035)
Observations	82180	95534	182511	173728
R-squared	0.862	0.852	0.854	0.860
Panel B: Controlling for covariates				
Non-TCZ×Post	0.265***	0.156	0.142***	0.134***
	(0.062)	(0.098)	(0.053)	(0.049)
Firm Controls	Yes	Yes	Yes	Yes
City Controls	Yes	Yes	Yes	Yes
Observations	67583	81644	149002	141252
R-squared	0.870	0.857	0.862	0.868

Notes: In Column 1, panel data is sourced from cities located north of the policy boundary, while Column 2 presents data from cities south of the boundary. Column 3 excludes samples from the Tibetan Plateau, and Column 4 further excludes samples from both the Tibetan Plateau and Sichuan Province. All regressions control for year fixed effects, city fixed effects, firm fixed effects, and industry-by-year fixed effects. Standard errors clustered at the city-by-year level are reported below the estimates. ***, **, * represent significance levels of 1%, 5%, and 10%, respectively.

Table 7
Alternative standard errors.

	log SO_2					
	(1)	(2)	(3)	(4)	(5)	(6)
Non-TCZ×Post	0.143**	0.143***	0.143***	0.143***	0.143***	0.143***
	(0.071)	(0.038)	(0.035)	(0.035)	(0.032)	(0.027)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry-by-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes
City Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	149253	149253	149253	149253	149253	149253
R-squared	0.862	0.862	0.862	0.862	0.862	0.862

Notes: In Columns 1–6, standard errors clustered at the city level, city-by-two digit industry level, city-by-four digit industry level, year-by-two digit industry level, year-by-four digit industry level, and firm level are reported below the estimates. ***, **, * represent significance levels of 1%, 5%, and 10%, respectively.

Table 8
Firm ownership structure.

	log SO2					
	State-owned		Private-owned		Foreign	
	(1)	(2)	(3)	(4)	(5)	(6)
Non-TCZ×Post	0.251***	0.164***	0.091	0.053	-0.002	-0.071
	(0.036)	(0.050)	(0.101)	(0.156)	(0.095)	(0.125)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry-by-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm Controls	No	Yes	No	Yes	No	Yes
City Controls	No	Yes	No	Yes	No	Yes
Observations	60964	44845	48560	42091	25759	23221
R-squared	0.882	0.890	0.845	0.852	0.878	0.882

Notes: In Columns 1–2, the panel data is restricted to the sample of state-owned firms; in Columns 3–4, the panel data is restricted to the sample of private-owned firms; in Columns 5–6, the panel data is restricted to the sample of foreign firms. All regressions control year fixed effects, city fixed effects, firm fixed effects, and industry-by-year fixed effects. Columns 2, 4, and 6 include firm-level and city-level control variables. Standard errors clustered at the city-by-year level are reported below the estimates. ***, **, * represent significance levels of 1%, 5%, and 10%, respectively.

Table 9

Long-term vs. short-term goals.

	log SO_2			
	Mayor, age<=56	Mayor, age>56	Secretary, age<=56	Secretary, age>56
	(1)	(2)	(3)	(4)
Panel A: Without controlling for covariates				
Non-TCZ×Post	-0.012	0.281***	0.067	0.260***
	(0.042)	(0.055)	(0.055)	(0.053)
Observations	85207	92301	89322	89247
R-squared	0.880	0.846	0.874	0.844
Panel B: Controlling for covariates				
Non-TCZ×Post	-0.012	0.298***	0.061	0.303***
	(0.053)	(0.088)	(0.064)	(0.096)
Observations	73513	70629	77533	67247
R-squared	0.886	0.855	0.880	0.852

Notes: The sample is categorized based on the city's mayor or secretary's age. Panel A presents our primary results without controlling for covariates, while Panel B provides the outcomes controlling for covariates as a robustness check. All regressions control year fixed effects, city fixed effects, firm fixed effects, and industry-by-year fixed effects. Standard errors clustered at the city-by-year level are reported below the estimates. ***, **, * represent significance levels of 1%, 5%, and 10%, respectively.

Table 10
Domestic investment vs. foreign investment.

	log SO_2					
	(1)	(2)	(3)	(4)	(5)	(6)
Non-TCZ×Post	0.021	0.034	-0.012	0.046	-0.051	-0.001
	(0.056)	(0.070)	(0.142)	(0.166)	(0.143)	(0.165)
Non-TCZ×Post×Domestic	0.004***	0.004**	--	--	0.003**	0.003**
	(0.001)	(0.002)	--	--	(0.001)	(0.002)
Non-TCZ×Post×FDI	--	--	0.013	0.008	0.007	0.003
	--	--	(0.016)	(0.018)	(0.016)	(0.018)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry-by-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm Controls	No	Yes	No	Yes	Yes	Yes
City Controls	No	Yes	No	Yes	Yes	Yes
Observations	170057	149253	149721	141017	149058	141017
R-squared	0.858	0.862	0.866	0.867	0.867	0.867

Notes: All regressions control for year fixed effects, city fixed effects, firm fixed effects, and industry-by-year fixed effects. Columns 2, 4, and 6 include firm-level and city-level control variables. Standard errors clustered at the city-by-year level are reported below the estimates. ***, **, * represent significance levels of 1%, 5%, and 10%, respectively.

Appendix A. Additional Figures and Tables

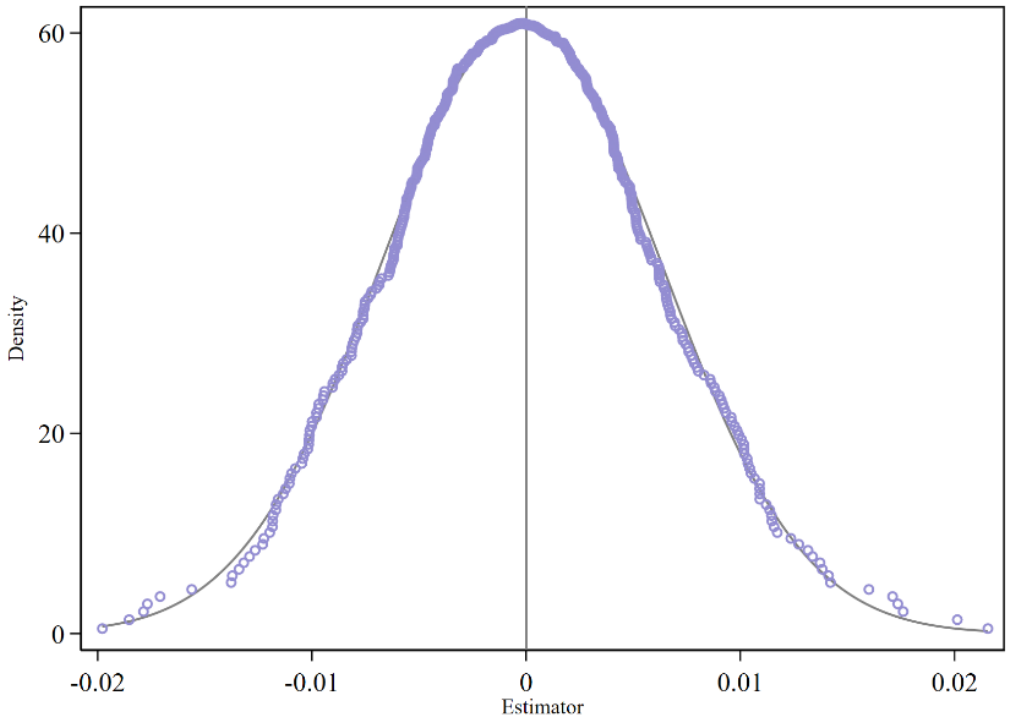


Fig. A1. Density of estimated coefficients from the placebo tests.

Notes: This figure presents the probability density distribution of the 500 estimated coefficients from the placebo tests, with SO_2 emissions as the dependent variable.

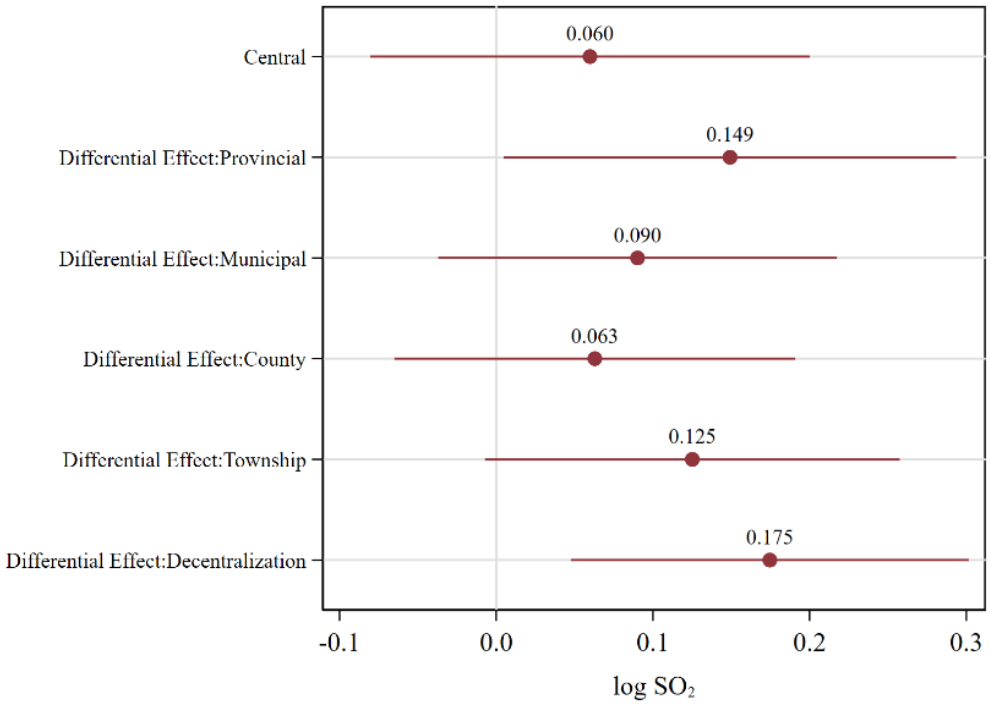


Fig. A2. Heterogeneous effects (controlling for covariates)

Notes: The sample is categorized by firms' governmental affiliations into five groups: central, provincial, municipal, county, and township. Decentralization refers to firms that have shifted from upper-level to lower-level government oversight. All regressions control for year fixed effects, city fixed effects, firm fixed effects, industry-by-year fixed effects, and control variables. For the central group, we present the average treatment effect along with a 90% confidence interval (CI). We report the differential treatment effect for the other categories accompanied by a 90% CI. Standard errors clustered at the city-by-year level.

Table A. 1
Provincial SO_2 emissions control targets (ten thousand tons).

Province	Reduction target	Total emissions in 2005
Beijing	4.59	17.00
Tianjin	5.14	20.50
Hebei	16.02	64.30
Shanxi	14.71	59.00
Inner Mongolia	7.20	28.60
Liaoning	11.00	44.00
Jilin	1.80	7.20
Shanghai	6.50	40.00
Jiangsu	20.00	80.00
Zhejiang	11.25	45.00
Anhui	2.90	11.40
Fujian	3.87	15.50
Jiangxi	3.30	13.30
Shandong	23.30	93.00
Henan	9.23	37.10
Hubei	8.01	32.20
Hunan	13.50	53.80
Guangdong	16.33	65.50
Guangxi	12.75	51.00
Sichuan	19.90	79.40
Chongqing	13.80	55.40
Guizhou	21.92	63.00
Yunnan	5.44	21.80
Shaanxi	4.71	18.70
Gansu	2.58	23.00
Ningxia	1.57	6.20
Xinjiang	1.88	7.30
Total	263.20	1053.20

Notes: China Environment Yearbooks.

Table A. 2
Summary statistics and description of variables.

Variables	Obs	Mean	Sd	Min	Max	Definition
SO_2 (log)	201350	10.008	2.202	0	21.503	SO_2 emissions (tons)
Age (log)	249218	2.391	1.074	0	5.670	The firm's age (year)
Age_squared (log)	249218	6.871	4.952	0	32.148	The squared term of a firm's age
KL (log)	249141	4.323	1.164	0.147	7.738	Capital-to-labor ratio
State-owned	253960	0.328	0.470	0	1	A dummy variable that equals 1 if the firm is state-owned and 0 otherwise
Foreign-owned	253960	0.173	0.379	0	1	A dummy variable that equals 1 if the firm is foreign-owned and 0 otherwise
Export	253957	0.280	0.449	0	1	A dummy variable that equals 1 if the firm engages in export activities and 0 otherwise
PGDP (log)	243853	9.394	0.739	7.015	11.807	GDP per capita (yuan)
Secondary_industry	237871	47.165	9.335	9.300	89.700	Secondary industry value added as a percentage of GDP (%)
Precipitation (log)	246607	6.705	0.796	1.687	7.916	Annual precipitation levels (mm)
Tax (log)	239356	12.238	1.262	4.890	15.293	The value-added tax (VAT) payable by industrial enterprises above the designated size (10,000 yuan)
Retail consumption (log)	243980	14.496	1.125	9.253	17.208	Total retail sales of social consumption goods (10,000 yuan)
Urbanization	242393	36.653	19.496	8.800	100	The non-agricultural population as a percentage of total population (%)
Investment	237550	33.273	12.801	11.914	83.934	Fixed asset investment as a percentage of GDP
FDI	236234	4.169	4.903	0	37.579	Foreign direct investment as a percentage of GDP (%)
Number of firms (log)	241960	6.831	1.244	0.693	11.760	The number of industrial enterprises in the city (%)
Fiscal (log)	246612	13.086	1.118	9.385	16.625	Fiscal budget expenditure (10,000 yuan)
Density (log)	237519	6.136	0.743	1.552	9.356	City population density (persons/km^2)
Number of employment (log)	239280	3.967	0.915	0.707	6.778	The number of employed persons (10,000)

Table A. 3

RD results: epanechnikov kernel.

	Within 20 km	Within 40 km	Within 60 km	Within 80 km
	(1)	(2)	(3)	(4)
Panel A: City FE absorbed				
RD in SO_2 (log)	5.171***	0.887**	0.152	5.171***
	(1.939)	(0.408)	(0.250)	(1.939)
Bandwidth	3.105	7.120	14.75	16.14
Panel B: City FE + industry by year FE absorbed				
RD in SO_2 (log)	2.775	0.907***	0.640***	0.615***
	(1.720)	(0.298)	(0.211)	(0.212)
Bandwidth	2.749	7.864	14.66	15.30
Observations	3544	7783	11301	14504

Notes: Each cell in the table represents a separate RD regression. The running variable is the distance between a firm and the closest policy boundary, where negative (positive) distance means firms are located to the south (north) of the policy boundary. Standard errors clustered at the city-by-year level are reported below the estimates. ***, **, * represent significance levels of 1%, 5%, and 10%, respectively.

Table A. 4

RD results: uniform kernel.

	Within 20 km	Within 40 km	Within 60 km	Within 80 km
	(1)	(2)	(3)	(4)
Panel A: City FE absorbed				
RD in SO_2 (log)	5.100**	0.514	0.056	0.090
	(2.047)	(0.546)	(0.265)	(0.266)
Bandwidth	2.433	5.099	14.08	12.44
Panel B: City FE + industry by year FE absorbed				
RD in SO_2 (log)	-0.379	1.392***	0.566**	0.540**
	(1.155)	(0.406)	(0.223)	(0.223)
Bandwidth	2.195	5.838	13.38	12.89
Observations	3544	7783	11301	14504

Notes: Each cell in the table represents a separate RD regression. The running variable is the distance between a firm and the closest policy boundary, where negative (positive) distance means firms are located to the south (north) of the policy boundary. Standard errors clustered at the city-by-year level are reported below the estimates. ***, **, * represent significance levels of 1%, 5%, and 10%, respectively.