Unwanted Fresh Air: Evidence from Coal-Fired Power Plants Closures in China*

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Abstract

Amid the rapid global energy transition, understanding the impact of power plant retirements is critical for effective policy-making. This study examines the effects of power plant closures on air quality and economic outcomes in China, leveraging quasi-experimental variation from these closures. We find that closures reduce PM2.5 levels and increase land prices but also lead to a significant and progressively larger decline in light intensity, particularly in more distant areas. The negative economic effects are substantial, suggesting that the benefits of cleaner air come at a high economic cost, outweighing the gains in land value. We identify slow capital adjustment as a key mechanism, with capital reallocating away from regions with retired plants, likely due to the energy industry's central role. Areas farther from closures experience sharper economic declines and greater vulnerability to negative shocks, underscoring the need for government compensation. These findings enrich the understanding of the energy industry's exit, especially from the economic perspective.

Keywords: Air pollution, Coal-fired power plants, Land price, Nighttime light, Capital adjustment, Geographical heterogeneity

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1 Introduction

In recent decades, the global energy sector has undergone rapid transformation, increasingly focusing on environmental protection and sustainability. Within this transformation, the power industry plays a crucial role. Therefore, studying the potential impacts of the changes in power plants is of significant policy importance for the energy transition. As a traditional and widely-used method of power generation (Ye, Lin and Tukker, 2019; Chen et al., 2019), coal-fired power plants have drawbacks such as non-renewable fuel sources and pollution emissions. This makes them a primary target in the power sector's transformation. This paper focuses on China, the largest developing country in the world, to examine the environmental and economic consequences of closing coal-fired power plants.

Previous studies on the effects of power plant closures have primarily focused on air pollution (Adhvaryu et al., 2023; Li and Jin, 2024), health outcomes (Hao et al., 2007; Fan, Gao and Tang, 2023), and student performance (Komisarow and Pakhtigian, 2022; Duque and Gilraine, 2022). In the context of developing countries, however, the energy industry plays a crucial role in local economic development, making it essential to consider the economic consequences of these closures. If reductions in air pollution brought by plants closures come at the cost of economic downturns, then this fresh air may not be welcome by local residents. This issue is further compounded by China's unique "equal share" power dispatch system (Kahrl, 2016), under which older, inefficient power plants are still tasked with significant energy production. This system ensures that these outdated plants continue to play an important role in the local economy. We are concerned that the closure of coal-fired power plants may lead to a decline in local economic activity, capital outflows, and ultimately a reduction in air pollution. This article does not provide direct identification results for this conjecture, only some indicative evidence. Nighttime light intensity offers a valuable proxy for assessing the level of economic activity in a region, helping us better understand the economic consequences of coal-fired power plant closures.

The "Let Small Ones Go" scheme, introduced by China in 1999 and reinforced in 2007, offers a valuable opportunity for identification. The aim of this policy was to shut down small, inefficient generators and promote larger, high-efficiency ones to improve power generation efficiency and environmental quality. To assess the impact of coal-fired power plant closures on air quality and nighttime light intensity within a 30 km radius, we applied a staggered difference-in-differences (DID) identification method.

The findings are striking. While plant closures reduced PM2.5 levels and increased land prices, they also led to a notable decline in light intensity, highlighting the substantial economic costs of achieving cleaner air. This study demonstrates that such closures alleviate pollution-related negative externalities, driving up nearby land prices. However, the economic shock caused by firm exits outweighs the gains from higher land values, leading to the negative effects on economic activities. By decomposing the impact on light intensity into extensive and intensive margins, we find that closures not only reduced the geographic area illuminated by nighttime lights but also diminished the intensity of the lights themselves. These results underscore the negative aggregate economic impacts of power plant retirements.

Our event study reveals a growing impact on both air quality and light intensity over time. We suggest that slow capital adjustment is a key mechanism driving this trend, as capital reallocates away from regions with decommissioned plants gradually. Using firm exit as proxies for regional capital adjustments, we find that the number of exiting firms remained relatively stable in the first three years. This is likely because firm owners wait for the depreciation of installed capital before contracting or shutting down their local operations (Dix-Carneiro and Kovak, 2017). However, this does not imply that the improvement in air quality is without value. Cleaner air can serve as a catalyst for transforming the regional industrial structure, shifting from energy-intensive industries to less energy dependent ones.

We conducted a heterogeneous analysis of the above results based on geographic distance to retired power plants. We divide the sample into two groups — 'close' and 'distant' — using a 10km threshold. Within 30km of the retired plants, we do not observe significant heterogeneous treatment effects on air quality. Regarding economic outcomes, we find that the 'close' group experiences larger capital outflows but smaller negative shocks to economic activity. This suggests that areas closer to the retired plants may have more diverse industrial compositions and greater resilience, allowing them to recover more quickly from the closures. In contrast, upstream and downstream firms in the 'distant' group face worsening conditions, with progressively larger negative effects. This may be due to their more monotonous industrial structure, which makes them more vulnerable. Our heterogeneous analysis has important policy implications, highlighting the need for greater compensation for the 'distant' group.

Our research contributes to the existing literature in three significant ways. First, this is the first study to use nighttime light intensity as a proxy to assess the economic impact of coal-fired power plant closures, thereby supplementing the literature on the social and economic consequences of such shutdowns. While previous studies have primarily examined the effects on housing prices (Bauer, Braun and Kvasnicka, 2017), fiscal revenues (Haller, Haines and Yamamoto, 2017), and unemployment rates (Yamamoto, 2022), our study leverages 24 years of nighttime light data to investigate the long-term effects of plant closures on local economic development. And we emphasize that China's unique equal-share power dispatch system underpins the critical economic role of old, inefficient power plants, leading to significant economic repercussions when they are retired.

Second, we highlight the negative consequences of plant closures in China, a perspective that has been less explored in the literature. Previous studies have mostly focused on the positive effects of coal-fired power plant closures, such as improvements in agricultural productivity (Cao and Ma, 2023), air quality (Ma et al., 2017; Hao et al., 2007), housing prices, and health outcomes

(Li and Jin, 2024). Our findings extend this understanding by showing that plant closures result in the slow reallocation of capital away from regions where plants have been retired, underscoring the broader economic consequences of these shutdowns.

Third, we examine the effects of plant closures on fertility rates, thereby contributing to the literature on human capital through a quantity dimension (Hao et al., 2007; Fan, Gao and Tang, 2023; Komisarow and Pakhtigian, 2022; Duque and Gilraine, 2022). Our findings suggest that previous studies that focus solely on the quality dimension of human capital may underestimate the overall impact of closures on human capital.

Our paper proceeds as follows. Section II describes the institutional context of phasing out of coal-fired power plants in China. Section III describes the data sources, measures of main dependent variables, and empirical strategy. Section IV presents (i) our main results for closures' effects on regional air quality and economic activities, (ii) a wide array of robustness tests, (iii) mechanisms that could explain the effects of closures of plants, (iv) heterogeneous analysis based on geographic distance to retired power plants, and (v) impact of closures on human capital in terms of quantity. Section V concludes.

2 Institution Background

In this section, we introduce the China's power system and power dispatching system. We then introduce the policy of closing specific coal-fired power plants named "Let Small Ones Go" Scheme.

2.1 Power System and Power Dispatching System in China

China's electricity system, the second largest in the world after the U.S., serves as the backbone of its economic growth (Kahrl, Williams and Hu, 2013; Wang et al., 2019). Prior to 2002, the entire sector—encompassing power generation, transmission, distribution, and sales—was owned and managed by the state grid company, operating as a monopoly. However, the State Council's 2002 Electric Power System Reform Scheme dismantled this monopoly, restructuring it into smaller companies responsible for either power generation, distribution, or engineering services, with the aim of establishing a competitive power market (State Council of China, 2002).[1]

Unlike most countries, which dispatch generators based on a "merit order" system according to the marginal cost of production, grid operators in China follow an "equal shares" approach (Kahrl, 2016). Under this system, operating hours are distributed equally among coal-fired generators, regardless of their age, size, or efficiency. In contrast, the merit order system prioritizes the dispatch of generators based on fuel costs, giving preference to more fuel-efficient units, which

[1] See https://www.ndrc.gov.cn/xwdt/xwfb/200507/t20050708_958393.html

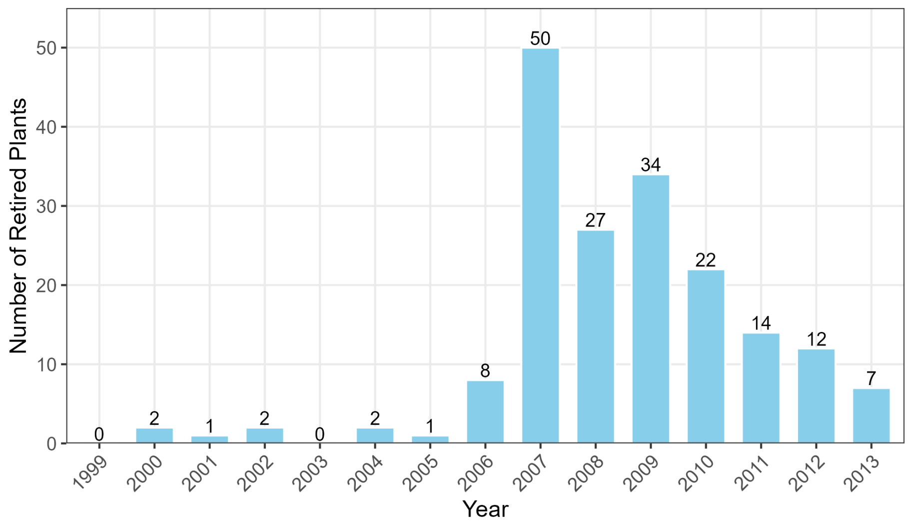


Figure 1: Number of Coal-Fired Power Plants Retired from 1999 to 2013

Sources: Longitudinal data from Global Energy Monitor. The retirement year for each power plant is determined by the earliest year among its individual units.

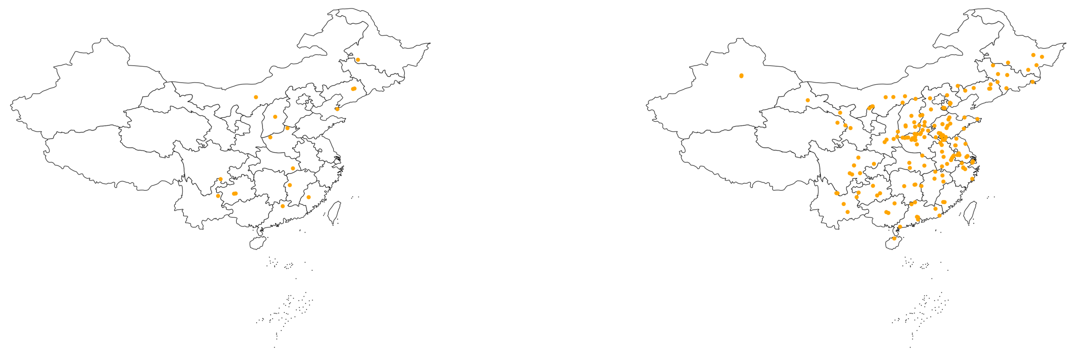
are allocated more operating hours.

As China's electricity sector expanded, the economic inefficiencies of the "equal shares" system became increasingly apparent. This approach not only exacerbated pollution by allocating more operating hours to less fuel-efficient, high-emission generators, but it also hindered progress by allowing older, inefficient power plants to maintain a significant role in local economic development. These outdated plants were effectively shielded from being replaced by newer, more efficient generators.

2.2 "Let Small Ones Go" Scheme

In 2020, the thermal power sector accounted for approximately 68% of China's total electricity generation, with around 90% of that electricity produced from coal burning (Chen et al., 2019; Ye, Lin and Tukker, 2019). This heavy dependence on coal has significant environmental implications, especially as China faces the dual pressures of meeting its 2060 Carbon Neutrality goal and aligning with the global 1.5°C target set by the Paris Agreement (Fan, Gao and Tang, 2023). Phasing out coal power has thus become a critical challenge for the nation.

One key strategy to address this challenge has been the closure of coal-fired power plants. The Chinese central government initiated the Let Small Ones Go Scheme in 1999 and reinforced it in 2007. This policy aimed to replace inefficient small power plants with larger, more efficient ones while restricting the development of new small units. Under this scheme, the construction of large coal-fired power generator units was approved, with capacities 1.2 to 1.6 times that of the



(a) 1999-2006: + 16 plants

(b) 2007-2013: + 166 plants

Figure 2: Spatial Distribution of Coal-Fired Power Plants Retired from 1999 to 2013
Sources: Longitudinal data from Global Energy Monitor. The retirement year for each power plant is determined by the earliest year among its individual units.

small plants they were intended to replace.

Furthermore, as illustrated in Figures 1 and 2, the wave of coal-fired power plant closures before 2006 was significantly weaker than the wave after the policy reinforcement in 2007. This shift was largely driven by the tight electricity supply and increased demand around 2000. In such an environment, shutting down plants was likely more challenging, and regions with retired plants may not be exogenous, as they could have other unobservable factors influencing electricity supply. To address these potential endogeneity concerns, we focus solely on plants retired after 2007. Given the sufficient number of observations, we do not expect to lose significant variation for identification. Figure 2 also proposes that Chinese government retired coal-fired power plants in an almost spatially random manner.

3 Data

3.1 Data Source

Our data on coal-fired power plants during this period is sourced from the Global Energy Monitor.[2] This dataset contains comprehensive and detailed information on the geographical coordinates and operational status of coal-fired power plants, which facilitates subsequent geographic-level identification and helps avoid sample selection bias. In detail, this dataset provides geographic information on both retired and active power plants, along with details on the operational status of individual generator units (e.g., operational, retired, canceled, or under development), as well as their start year, retirement year, capacity, and ownership. For the purposes of our analysis, we define a plant as "retired" if at least one of its generator units has been de-

[2]See https://globalenergymonitor.org/projects/global-coal-plant-tracker/

commissioned, with the retirement year marked as the year in which the first unit was retired. Our working sample includes 182 retired plants.

The data for our outcome variable primarily comes from satellite observations. Satellite data has several advantages, such as broad spatial coverage and the ability to provide continuous observations over extended periods. These features are particularly useful for better identifying micro-geographical patterns. Additionally, compared to traditional survey-based data collection methods, satellite data is non-invasive and allows for large-scale data acquisition without interfering with the observed area. Furthermore, the observations provided by satellite data are highly objective and consistent, avoiding biases or errors that may arise from human judgment or operational mistakes.

We measure air quality using satellite observation dataset, High-resolution and High-quality Ground-level PM2.5 Dataset (Wei, 2021) for China.[3] Its main scope covers the entire China region, with a spatial resolution of 1 km and a temporal resolution of days, months, and years, measured in $\mu g/m^3$ since 2000. We calculate the average annual PM2.5 concentration at the regional level, resulting in approximately 8,000 observations from 2000 to 2021. To assess changes in air quality around retired plants, we focus our analysis on areas within a 30 km radius of these decommissioned facilities.

As a result of fresh air, the asset value in the area is reflected by land prices, which are obtained from the China Land Market Network.[4] We crawled all the auction notices from 2000 to 2023, containing information on land prices, land size, locations, and other relevant details. Since the observations are based on government records, both the land price and land size are accurate, eliminating any measurement error. Additionally, the use of web scraping ensures that our dataset is comprehensive. To enhance our analysis, we utilized the land address to call the Gaode API and obtain the longitude and latitude coordinates, enabling us to perform a micro-geographical analysis. All land prices have been standardized by land size, providing a measure of the land price per hectare.

We study economic consequences using nighttime light intensity data from National Oceanic and Atmospheric Administration's (NOAA) National Geophysical Data Center (NGDC). Its spatial resolution is 0.87km from 2000 to 2023. Similarly, we calculate the average annual light intensity at the regional level. And both the extensive margin and the intensive margin are considered simultaneously.

To investigate the mechanism of slow capital adjustment, we use Data of Chinese industrial enterprises to construct the variables of firm entry and firm exit. However, this dataset don't contain the latitude and longitude of the firm which are obtained by calling the API of Gaode App. Then we can calculate average annual firm entry and firm exit at the regional level identical

[3]See https://data.tpdc.ac.cn/zh-hans/data/6168e75d-93ab-4e4a-b7ff-33152e49d0bf.
[4]See https://www.landchina.com.

Table 1: Descriptive Statistics

Variable	(1) All	(2) Dist<30	(3) 30<Dist<60
Panel A. Closures of plants			
Retired year	2008.808		
	(1.831)		
Retired capacity	5.467		
	(0.668)		
New capacity	6.513		
	(0.768)		
Observations	248,698		
Panel B. Nighttime light intensity			
Extensive margin	0.637	0.748	0.528
	(0.324)	(0.301)	(0.308)
Intensive margin	13.407	18.670	8.179
	(15.024)	(17.766)	(9.010)
Observations	244,738	122,160	118,484
Panel C. Air Quality			
PM2.5	53.282	53.485	53.102
	(18.206)	(18.502)	(17.934)
Observations	244,738	122,160	118,484
Panel D. Capital Adjustment			
Firm entry	7.506	5.918	9.042
	(22.183)	(18.019)	(25.479)
Firm exit	6.370	5.137	7.562
	(14.178)	(12.021)	(15.898)
Observations	158,670	78,015	80,655
Panel E. Asset Value			
Land Price	2151.066	2520.551	1602.77
	(85076.64)	(9850.545)	(91594.31)
Observations	134,669	60,809	71,327

Notes: 182 retired coal-fired power plants. Column (1) includes observations within 60km of retired plants. Column (2) and (3) split samples into two subsets, based on the distance of observations to retired plants. See the text for description for all measures.

to the previous steps.

Table 1 presents summary statistics for this and other main dependent variables throughout the paper. One concern is that the capacity of new power generators is larger than the capacity of old and inefficient ones, which may confound our identification of the closure effect of coal-fired power plants. In that way, we control plants current capacity of operating generators to partial out this confounding factor. Another concern is that China faced significant electricity supply constraints around 2000, which could introduce selection bias for plant closures before 2007. Fortunately, the number of plants retiring prior to 2007 is small, as shown in Figures 1 and 2, so this issue is unlikely to affect our results, even though we directly exclude these plants from our analysis.

3.2 Identification

To measure the effects of closures of coal-fired power plants on several regional outcomes, we estimate the following staggered and continuous difference-in-difference two-way fixed effect equations:

$$Y_{it} = \alpha_i + \beta Closure_{it} + X_{it}'\phi + \lambda_t + \epsilon_{it} \tag{3.1}$$

$$Y_{it} = \alpha_i + \beta Closure_{it} \times Capacity_i + X_{it}'\phi + \lambda_t + \epsilon_{it} \tag{3.2}$$

where, for both equations (3.1) and (3.2), the variable Y_{it} is the value of an outcome such as air quality and light intensity in region i in year t. $Closure_{it}$ is an indicator equal to 1 if year t is larger than the retired year in region i. X_{it} is control variable, especially including the plants current capacity of operating power generators. α_i and λ_t are the region and year fixed effect. For equation (3.2), we implement a continuous DID where $Capacity_i$ represents the treat intensity, which is the capacity of the retired power generators. Our key variable are $Closure_{it}$ and $Closure_{it} \times Capacity_i$, and our parameter of interest β measures the change in the dependent variables after the closures of nearest coal-fired power plants and how much this effect changes(causal response) as the capacity of retired power generators changes.

One concern is that regions with any retired plants might be affected by other operational or retired power plants simultaneously, especially the new power plants encouraged by the policy. To address this problem, we restrict our sample to be within 30km and add the control of plants current capacity.

However, due to the issue of negative weights in staggered adoption, applying the TWFE estimator may lead to errors. Therefore, we directly estimate the following event study to analyze the dynamic effects of plant closures:

$$Y_{it} = \alpha_i + \sum_{k \neq -1} \beta_k \tau_{itk} + X_{it}' \phi + \lambda_t + \lambda_{dt} + \epsilon_{it} \tag{3.3}$$

where $RetireYear_i$ is the year when plants in region i were retired, and the τ_{itk} equals to 1 if the period is k, which means $\tau_{itk} = \mathbf{1}\{t - RetireYear_i = k\}$. We include distance-by-year fixed effects λ_{dt} to account for different trends, as the energy industry is typically located at the center of industrial estates, and greater distances may correspond to poorer areas, which could exhibit different trends compared to those located closer. Our interest coefficient β_k measures the effects of closures in each period k. In our event study figure, we plot the estimated coefficient and the 95% confidence interval.

To better explore the heterogeneous treatment effects(HTE) based on geographical distance, we grouped the observations by the distance from each grid to the coal-fired power plant and estimated the dynamic group-specific treatment effects(GTE) using the following equation:

$$\begin{aligned} Y_{it} =& \alpha_i + \sum_{k \neq -1} \beta_{1k} \tau_{itk} \times \mathbf{1}\{dist_i \leq d\} + \sum_{k \neq -1} \beta_{2k} \tau_{itk} \times \mathbf{1}\{dist_i > d\} \\ &+ X_{it}' \phi + \lambda_t + \lambda_{dt} + \epsilon_{it} \end{aligned} \tag{3.4}$$

where d is the threshold used to group observations. Our interest coefficient β_{1k} and β_{2k} measure the separate treatment effects of closures on nearby and distant groups, respectively, in each period k.

4 Results

4.1 Main Results

We begin by examining the impact of closures on air quality and their corresponding effect on nearby asset values, which may be influenced by pollution sources. However, land prices only reflect one aspect of economic consequences. To gain a broader perspective, we analyze the aggregated effects on regional economic activities, using nighttime light as a proxy variable. Next, we provide evidence supporting the existence of long-term effects, as well as geographical spillover effects.

4.1.1 Effects on Air Quality

First, we check the effects on air quality. Table 2 shows the results of estimating (3.1) and (3.2) for regional air quality. All coefficient estimates for the treatment are statistically significant at a high 1% level and negative, indicating that closures of coal-fired power plants make regional

Table 2: Regional Air Quality

VARIABLES	(1) Log PM2.5	(2) Log PM2.5	(3) Log PM2.5	(4) Log PM2.5	(5) Log PM2.5	(6) Log PM2.5
Closure	-0.0067***	-0.0093***	-0.0093***			
	(-5.0384)	(-6.8650)	(-6.8638)			
Closure × Capacity				-0.0009***	-0.0013***	-0.0013***
				(-3.7583)	(-5.1330)	(-5.1298)
Observations	2,462,782	2,462,782	2,462,782	2,462,782	2,462,782	2,462,782
R-squared	0.9722	0.9723	0.9723	0.9722	0.9723	0.9723
Grid FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Control	NO	YES	YES	NO	YES	YES
Dist×Year FE	NO	NO	YES	NO	NO	YES

Notes: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Dependent variable is natural log of yearly PM2.5 from 2000 to 2021. Variable capacity is the retirement capacity of power plants. Regression sample includes observations within 30km of retired plants. All regressions control grid FE and year FE. Standard errors are clustered at grid level.

PM2.5 content decline significantly. Since the policy aimed to shut down smaller power generation units and establish larger, more efficient ones, columns 2 and 5 add the control of plants total capacity to partial out the effect of the new established units. Coefficients in column 2 and 5 don't change their signs and presents a larger effect and have higher statistical significance, which proves that establishing new power generation units will lead to our underestimation of the policy effect. The coefficient estimate of -0.0093 in column 2 indicates that region within 30km of retired plants experienced a 0.93 percentage point proportional decline in PM2.5 content after the closures of plants. And the coefficient estimate of -0.0013 in column 5 indicates that for every 10 percentage point proportional increase in the retirement capacity of power plants, closures will result in an additional 1.3 percentage point proportional decline in PM2.5 content. To prevent issues arising from different trends in various geographic locations, we control for distance-by-year fixed effects in columns 3 and 6. The results remain robust.

To verify whether the policy meets the requirements of quasi natural experiments and investigate the dynamic effects, we estimated (3.3) and present the results of the event study in Figure 3. Figure 3 provides the evidence that our treatments satisfy the parallel trend assumption. The growing effect of closures on air quality is a striking feature of Figure 3. It indicates that the declining effects on air quality may not only come from the plants themselves, but also rely on the exits of other energy dependent enterprises which can also bring massive air pollution. And we will provide some evidence about this channel in section C.

4.1.2 Effects on Land Price

Previously, our focus was primarily on the consequences of PM2.5 levels, often overlooking their impact on economic outcomes. Pollution is a classic example of a negative externality, which

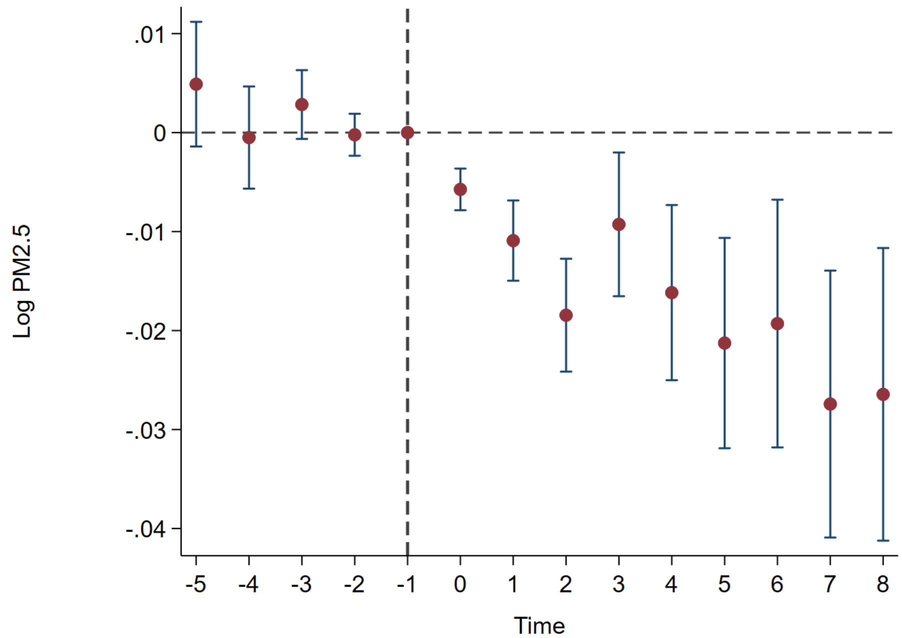


Figure 3: Dynamic Effects on Air Quality

Notes: This figure presents the period coefficients for 5 years before and 9 years after plant closures. A full set of controls, grid, year, and distance-by-year fixed effects are included. Standard errors are clustered at grid level.

may suppress the value of nearby assets. In this section, we concentrate on land prices, as they represent a key component of governments' income.

Table 3 presents the results of estimating equations (3.1) and (3.2) for regional asset value. All coefficient estimates for the treatment are statistically significant at the 1% level and positive, indicating that the closure of coal-fired power plants significantly increases nearby land prices. The coefficient estimate of 0.0921 in column 1, panel A, shows that regions within 30 km of retired plants experienced a 9.21 percentage point increase in land price per hectare following the closures. Additionally, the coefficient estimate of 0.0146 in column 1, panel B, suggests that for every 10 percentage point increase in the retirement capacity of power plants, closures result in an additional 14.6 percentage point increase in land price per hectare. Land appreciation is not an unexpected outcome. A possible explanation is that the presence of coal-fired power plants creates a negative externality on nearby assets due to air pollution. Once the plants are closed, this externality disappears, leading to an increase in land prices.

Table 3 also illustrates the geographical spillover effects on asset value. Different distance thresholds are used in each column, and the regression samples are determined based on their proximity to the retired plants and the chosen threshold. Both panel A and panel B reveal the geographical spillover effects on land prices. The effects are stronger for lands closer to the plants, which aligns with the interpretation that air pollution is more intense in areas nearer to the plants.

Table 3: Asset Value and Geographical Spillover Effects

	(1)	(2)	(3)	(4)
VARIABLES	log land price	log land price	log land price	log land price
Panel A. Staggered DID				
Closure	0.0921***	0.0804***	0.0801***	0.0473***
	(4.3840)	(4.5977)	(5.1958)	(3.3953)
Observations	1,920,035	3,564,709	5,794,029	8,603,977
R-squared	0.6661	0.6440	0.6349	0.6304
location FE	YES	YES	YES	YES
Control	YES	YES	YES	YES
Dist#Year FE	YES	YES	YES	YES
Dist Threshold	30km	40km	50km	60km
Panel B. Continuous DID				
Closure×Capacity	0.0146***	0.0135***	0.0139***	0.0092***
	(3.7142)	(4.1859)	(4.9102)	(3.6110)
Observations	1,920,035	3,564,709	5,794,029	8,603,977
R-squared	0.6660	0.6440	0.6349	0.6304
location FE	YES	YES	YES	YES
Control	YES	YES	YES	YES
Dist#Year FE	YES	YES	YES	YES
Dist Threshold	30km	40km	50km	60km

Notes: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Dependent variable is natural log of land price per hectare from 2000 to 2023. Variable capacity is the retirement capacity of power plants. Regression sample includes observations from plants at different distance thresholds. Standard errors are clustered at grid level.

To test the parallel trends assumption and investigate dynamic effects, we estimate equation (3.3) and present the results of the event study in Figure 4. Consistent with the air quality findings, the effects on land prices exhibit a growing pattern, suggesting that plant closures can lead to a persistent increase in government income. This evidence indicates that plant closures might have a positive impact on regional economic development, driven by the increase in asset values associated with improved air quality.

4.1.3 Effects on Economic Activities

So far, we have found that the closure of power plants leads to a reduction in PM2.5 levels and an increase in land prices. These results suggest that closures have positive effects on both the environment and the economy. However, land prices represent only one aspect of the economic consequences. The exit of energy firms not only signals the elimination of negative externalities but also the loss of employment opportunities and tax revenues. Kuznets Curve tell us that the relationship between environment and economic development is inverted U-shaped. It implies that the improvement of air quality might be based on the slowdown of the economic development. Then the fresh air might be costly and unwanted. To assess the broader impact on economic activities, we use nighttime light as a proxy variable and investigate its effects.

Figure 5 shows the results of estimating (3.3) for regional nighttime light level. All coefficient

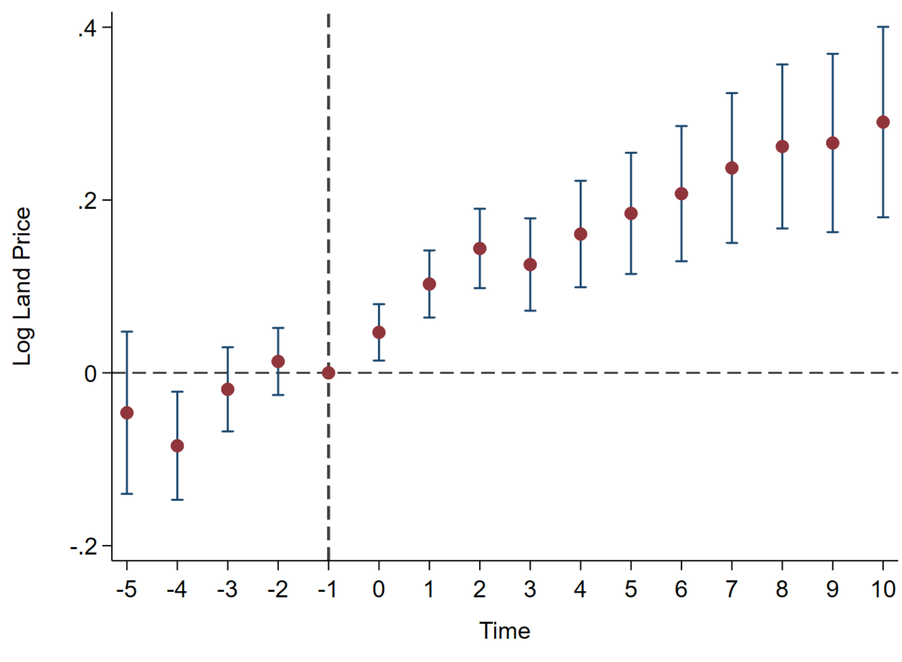


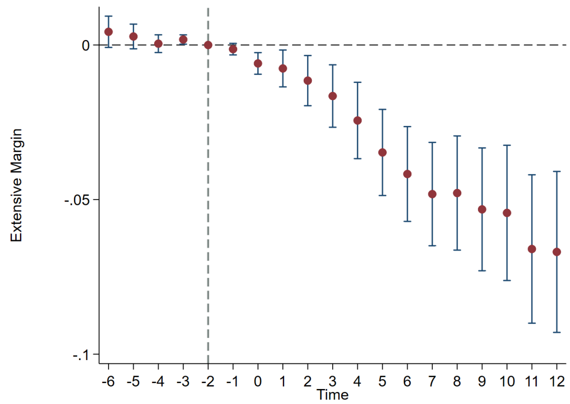
Figure 4: Dynamic Effects on Land Price

Notes: This figure presents the period coefficients for 5 years before and 10 years after plant closures. A full set of controls, grid, year, and distance-by-year fixed effects are included. Standard errors are clustered at grid level.

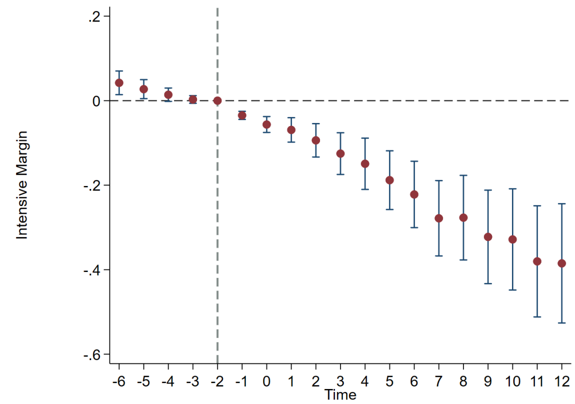
estimates after closures are statistically significant at a high 5% level and negative, indicating that closures of coal-fired power plants make regional nighttime light level decline significantly. Here, we separate the effects into two margins: the extensive margin, which measures the share of the area with any nighttime light coverage, and the intensive margin, which captures the intensity of nighttime light. Figure (5a) shows that closures of plants lead to a nearly 4 percentage point proportional decline in the share of area that has any nighttime light coverage. These evidence indicates that on the extensive margin, the closures of coal-fired power plants have a significant negative economic impact.

Beyond the extensive margin, closures of plants also lead to decrease in the intensive margin of light intensity. Figure (5b) demonstrate this using the nighttime light intensity as the dependent variable, which suggests that regional light intensity declines approximately 20 percent after the closures. Both the extensive and intensive margin results suggest that the closure of coal-fired power plants leads to a decline in local economic activity, indicating that the negative impact of firm exit outweighs the positive effects of eliminating externalities.

For parallel trend assumption, figure 5 proposes that there is no significant pre-trend both for extensive margin and intensive margin. Consistent with the effects on air quality, there are also growing and long-run effects on economic activities, which level off after 11 periods. It indicates that the special and important position of energy industry in the local economic activities.



(a) Dynamic Effects on Extensive Margin



(b) Dynamic Effects on Intensive Margin

Figure 5: Regional Economic Activities

Notes: This figure presents the period coefficients for 6 years before and 13 years after plant closures. Dependent variable is the extensive and intensive margin of nighttime light intensity. A full set of controls, grid, year, and distance-by-year fixed effects are included. Standard errors are clustered at grid level.

Together, these results are surprising, particular the effects on economic outcomes. Conventional wisdom from the literature studying the closures of plants mostly focus on the positive consequences like air pollution and health outcomes. However, the results here provide the evidence that these fresh air and healthy body are very costly, accompanied by the cost of decreasing economic activities. These results enrich our understanding of the exit of the energy industry, from the perspective of economic outcome. The remainder of the paper focuses on studying and explaining these surprising results.

4.1.4 Robustness

In this section, we present robustness checks on the parallel pre-trend assumption, removing outliers, clustering at different levels, and varying the distance threshold to select the sample.

Negative weights.-Since the retirement of plants is a staggered adoption, early treated observations in late periods will face negative weights issue when there is heterogeneous treatment effect. (Callaway and Sant'Anna, 2021) proposed an approach to address this problem. They only use never-treated or not-yet-treated as control groups to estimate the ATT and plot event study. Here, we follow their approach to implement CSDID as a robustness check.

Different distance threshold.-One challenge is that an operational plant may be located within 30km of various retired plants, resulting in a multiple-treatment issue. To mitigate this concern, we test several different distance threshold from 10km to 60km to select our sample. Consistent with baseline results, estimated coefficient values have changed in magnitude, but all remain statistically significant.

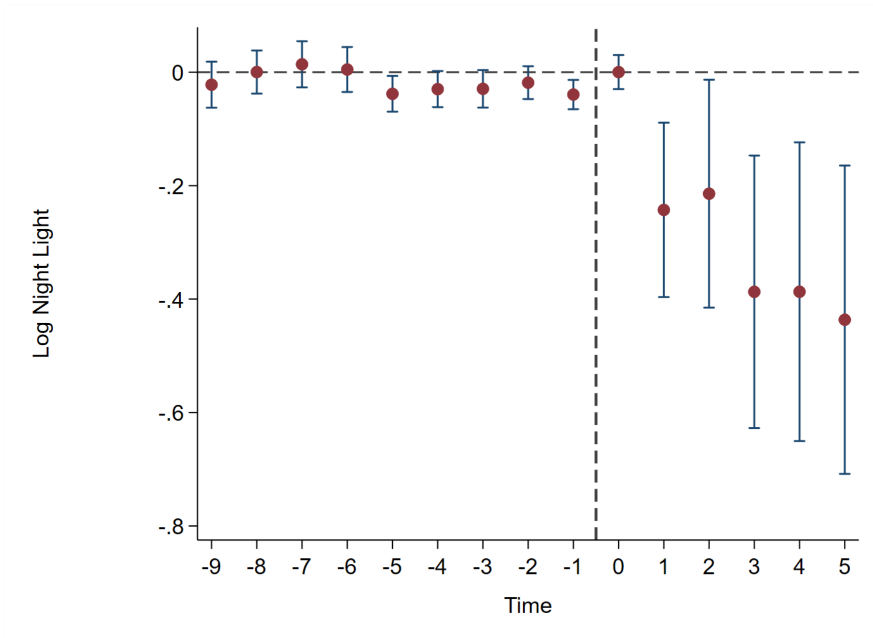


Figure 6: Robustness: Negative Weights

Notes: A full set of controls, grid and distance by year fixed effects are included. Standard errors are clustered at region level. The point estimate and confidence interval of the event effect are both obtained from CSDID.

Table 4: Robustness: Different Distance Threshold and Geographical Spillover Effects

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Log PM2.5	Log PM2.5	Log PM2.5	Log PM2.5	Log PM2.5	Log PM2.5
Panel A. Staggered DID						
Closure	-0.0103***	-0.0094***	-0.0093***	-0.0090***	-0.0088***	-0.0086***
	(-4.2626)	(-5.5952)	(-6.8638)	(-7.8087)	(-8.7193)	(-9.5650)
Observations	267,498	1,083,010	2,462,782	4,445,253	7,054,143	10,331,065
R-squared	0.9719	0.9723	0.9723	0.9719	0.9719	0.9719
location FE	YES	YES	YES	YES	YES	YES
Control	YES	YES	YES	YES	YES	YES
Dist#Year FE	YES	YES	YES	YES	YES	YES
Dist Threshold	10km	20km	30km	40km	50km	60km
Panel A. Continuous DID						
Closure×Capacity	-0.0015***	-0.0014***	-0.0013***	-0.0012***	-0.0012***	-0.0012***
	(-3.3178)	(-4.3560)	(-5.1298)	(-5.6105)	(-6.3768)	(-7.0900)
Observations	267,498	1,083,010	2,462,782	4,445,253	7,054,143	10,331,065
R-squared	0.9719	0.9723	0.9723	0.9719	0.9719	0.9719
location FE	YES	YES	YES	YES	YES	YES
Control	YES	YES	YES	YES	YES	YES
Dist#Year FE	YES	YES	YES	YES	YES	YES
Dist Threshold	10km	20km	30km	40km	50km	60km

Notes: *** p<0.01, ** p<0.05, * p<0.1. Dependent variable is natural log of yearly PM2.5 from 2000 to 2021. Variable capacity is the retirement capacity of power plants. Regression sample includes observations from plants at different distance thresholds. Standard errors are clustered at grid level.

Parallel pre-trend assumption.-To complete this robustness check, we estimate equation (3.3) for our main dependent variables and plot figures of event study, along with the 95% confidence intervals. Figure 3, 4 and 5 provide evidence for the validity of this assumption.

Remove outliers.-To address potential bias from outliers, we exclude the points with yearly PM2.5 level and other dependent variables in the top and bottom 1%. Our baseline results indicate that our inference is not affected by outliers.

4.2 Mechanism

As an energy industry, power plants play an important role in local economic development. The exit of the energy industry is likely to lead to the collapse of agglomeration economies, resulting in a long run effect. In this section, we consider capital adjustment as one main channel that might explain the before results.

With the closures of coal-fired power plants, local economies will lose their energy advantages in industrial development, leading to the exit of energy dependent enterprises. Due to the existence of agglomeration economies, it further affects the exit of enterprises in other industries. Figure 7 shows the results of estimating (3.3) for regional capital adjustment. All coefficient estimates after the closures are positive but not statistically significant for the yearly exit number, indicating that closures of plants can significantly increase the exit of existing firms but the effects are not immediate. Figure 7 demonstrate that the retirement of plants will induce capital reallocate away from these areas.

However, the growing effects on firm exit seem unexpected. Slow capital adjustment can explain this well. Firm owners waiting for installed capital to depreciate before contracting or closing down regional establishments. Figure 7 suggests that the number of exit firms began to increase after 4 periods. The slow capital adjustment is consistent with the growing effects on air quality and economic activities.

In this section, we prove the existence of capital adjustment and find that firm exit increased until 4 periods after the closures of plants. But this does not mean that the areas where coal-fired power plants are closed will continue to deteriorate. The exit of the energy industry and the improvement of air quality may prompt the adjustment of local industrial structure, shifting from energy dependent to energy independent industries. The higher quality of fresh air may also have potential effects on regional human capital, by increasing fertility rates and attracting migration.

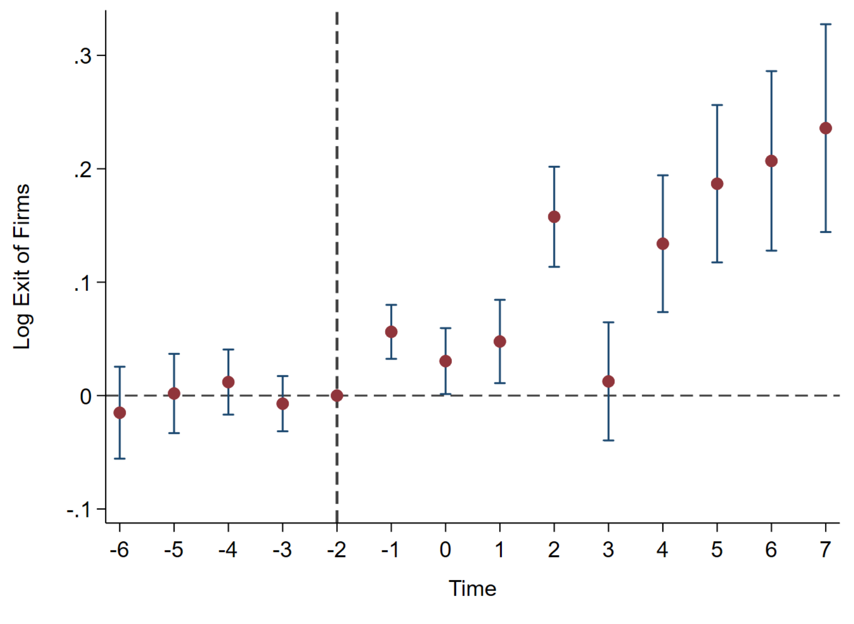


Figure 7: Regional Capital Adjustment

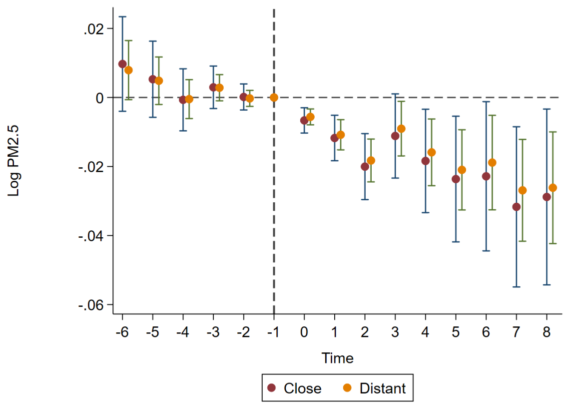
Notes: This figure presents the period coefficients for 6 years before and 8 years after plant closures. Dependent variable is natural log of yearly number of exit firms from 1998 to 2014. A full set of controls, grid, year, and distance-by-year fixed effects are included. Standard errors are clustered at grid level.

4.3 Geographical Heterogeneity

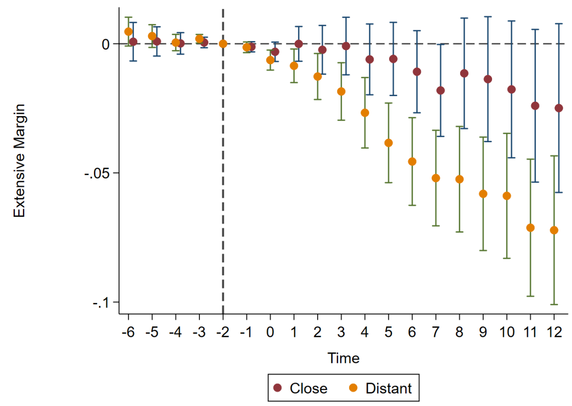
Previous literature has shown that geographical spillover effects on air pollution exist (Fan, Gao and Tang, 2023). In line with this, we examine whether effects on other outcomes are stronger when the treated grid is located closer to the retired plants.

Figure 8 shows the results of estimating equation (3.4) for heterogeneous treatment effects. We define the "close" group as those located within 10 km of the retired plants, while the "distant" group refers to the rest. Figure 8(a) displays the heterogeneous effects on air pollution, suggesting little variation in effects within 30 km. This pattern aligns with previous literature (Fan, Gao and Tang, 2023), although it is somewhat unexpected. Given the spread of wind, PM2.5 can be transported over hundreds of miles (EPA, 2004), and the impact can be substantial (Zhang, 2017). As a result, while effects on air pollution may be similar within 30 km, they are expected to decrease as the distance increases.

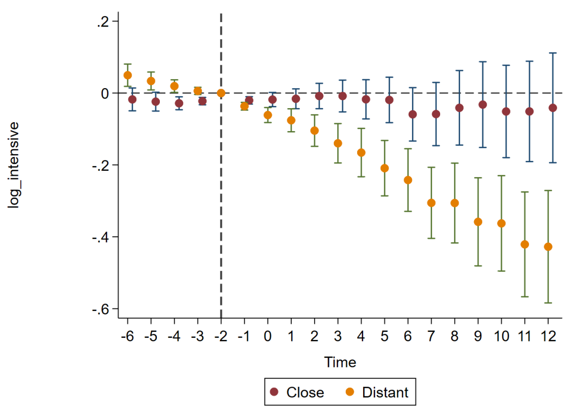
Figure 8(b) and 8(c) show the heterogeneous effects on local economic activities, divided into the extensive margin and intensive margin. The results suggest that the negative impact on local economic activities is larger in the distant areas. In contrast, the negative effects on the close group are relatively short-lived, primarily concentrated within the first two years. This indicates that the close group has greater resilience and can recover faster from the negative shock, while the distant group is more vulnerable. This is not surprising, as coal-fired power



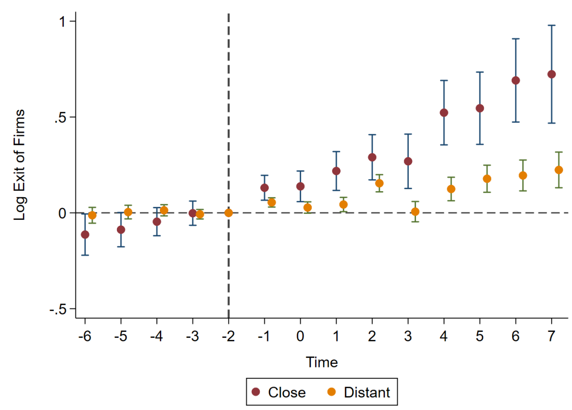
(a) Separate Treatment Effects on Air Quality



(b) Separate Treatment Effects on Extensive Margin



(c) Separate Treatment Effects on Intensive Margin



(d) Separate Treatment Effects on Firm Exit

Figure 8: Heterogeneous Treatment Effects Across Different Distance Groups

Notes: This figure presents the period coefficients for different distance groups. Regression includes all samples within 30km of power plants. We set 10 km as the threshold, therefore the close group includes samples within 10 km. A full set of controls, grid, year, and distance-by-year fixed effects are included. Standard errors are clustered at grid level.

plants are typically located in the center of industrial estates, meaning the close group is more likely to be in more developed areas with a more diverse industrial structure. Figures 8(b) and 8(c) also indicate that our baseline results on the negative economic effects primarily focus on distant areas, due to their more vulnerable economic structure. This has meaningful policy implications, suggesting that when the government forces firms to exit, attention should not only be focused on the industrial estates in the close group, but also on compensating the upstream and downstream industries in the distant group, and assisting them in managing the structural transformation of their industries.

Figure 8(d) shows the heterogeneous effects on capital adjustment. The results are not surprising: the close group experiences larger capital outflows than the distant group, providing evidence of geographical spillover effects. These findings further support the conclusion that the close group has greater resilience than the distant group, as it faces larger capital outflows but experiences smaller negative shocks to local economic activities. Overall, the heterogeneous treatment effects presented here have significant policy implications and can help policymakers design more accurate compensation strategies following the exit of the energy industry.

5 Conclusion

This paper studies the environmental and economic consequences of the closures of coal-fired power plants from 2000 to 2013. Using more than 20 years of satellite data of PM2.5 and nighttime light, we find large and long-run effect on both variables. Contrary to conventional wisdom, which mostly focused on air pollution, this paper studied economic effect of closures of plants and discover some worrying results that the fresh air comes at the cost of economic activities. And this result is not only driven by the plants themselves. We find capital reallocate away from these region with retired plants slowly and continuously. However, this does not mean that the closure of coal-fired power plants is detrimental in every aspect of its economic consequences. This paper finds that the closure eliminates the negative externalities caused by pollution, leading to an increase in nearby land prices. This, in turn, can provide local governments with more revenue to support regional economic development.

Our investigation into heterogeneous treatment effects has meaningful policy implications. We find that areas located closer to retired plants experience larger capital outflows but smaller declines in economic activity, both at the extensive and intensive margins. This suggests that these areas have a more diverse industrial composition, which contributes to greater resilience. Our findings remind policymakers that attention should be given to compensating both upstream and downstream sectors in areas farther from the retired plants. These distant areas, with more monotonous industrial structures, are more vulnerable to negative shocks to economic activity.

However, this does not mean that these regions need to go through the original Kuznets curve, which predicts that environmental pollution will worsened again with economic development. The exit of the energy industry provides an opportunity for the transformation of the local economic structure from energy dependent to less energy dependent. But the insufficient time window of data don't provide the chance to study this transformation.

Our empirical results extend the understanding of the consequence of coal-fired power plants closures. Our results suggest that the exit of energy industry impacts the capital adjustment significantly, which is neglected by the before literature. In the context of the rapid global energy transition, the insights provided by this paper can help governments formulate energy transition policies while ensuring the stable economic development of regions. This paper also provide a new idea to study the consequence of closures of coal-fired plants, including labor productivity and transformation of the local industry structure.

References

Adhvaryu, Achyuta, Teresa Molina, Anant Nyshadham, Jorge Tamayo, and Nicolas Torres. 2023. "The Health Costs of Dirty Energy: Evidence from the Capacity Market in Colombia." *Journal of Development Economics*, 164: 103116.

Bauer, Thomas K., Sebastian T. Braun, and Michael Kvasnicka. 2017. "Nuclear Power Plant Closures and Local Housing Values: Evidence from Fukushima and the German Housing Market." *Journal of Urban Economics*, 99: 94–106.

Callaway, Brantly, and Pedro H.C. Sant'Anna. 2021. "Difference-in-Differences with multiple time periods." 225(2): 200–230.

Cao, Jing, and Rong Ma. 2023. "Mitigating Agricultural Fires with Carrot or Stick? Evidence from China." *Journal of Development Economics*, 165: 103173.

Chen, Cheng, Bing Xue, Guotian Cai, Heiko Thomas, and Stefan Stückrad. 2019. "Comparing the Energy Transitions in Germany and China: Synergies and Recommendations." *Energy Reports*, 5: 1249–1260.

Dix-Carneiro, Rafael, and Brian K Kovak. 2017. "Trade Liberalization and Regional Dynamics." *American Economic Review*.

Duque, Valentina, and Michael Gilraine. 2022. "Coal Use, Air Pollution, and Student Performance." *Journal of Public Economics*, 213: 104712.

EPA. 2004. "The particle pollution report: current understanding of air quality and emissions through 2003."

Fan, Yi, Qiuxia Gao, and Cheng Keat Tang. 2023. "The Unintended Consequences of Coal-fired Power Plant Closures: Evidence from China."

Haller, Melissa, Michael Haines, and Daisaku Yamamoto. 2017. "The End of the Nuclear Era: Nuclear Decommissioning and Its Economic Impacts on U.S. Counties."

Hao, Jiming, Litao Wang, Minjia Shen, Lin Li, and Jingnan Hu. 2007. "Air Quality Impacts of Power Plant Emissions in Beijing." *Environmental Pollution*, 147(2): 401–408.

Kahrl, Frederich. 2016. "Issues in China Power Sector Reform: Generator Dispatch."

Kahrl, Fredrich, James H. Williams, and Junfeng Hu. 2013. "The Political Economy of Electricity Dispatch Reform in China." *Energy Policy*, 53: 361–369.

Komisarow, Sarah, and Emily L. Pakhtigian. 2022. "Are Power Plant Closures a Breath of Fresh Air? Local Air Quality and School Absences." *Journal of Environmental Economics and Management*, 112: 102569.

Li, Zheng, and Bohan Jin. 2024. "A Breath of Fresh Air: Coal Power Plant Closures and Health in China." *Energy Economics*, 129: 107235.

Ma, Qiao, Siyi Cai, Shuxiao Wang, Bin Zhao, Randall V. Martin, Michael Brauer, Aaron Cohen, Jingkun Jiang, Wei Zhou, Jiming Hao, Joseph Frostad, Mohammad H. Forouzanfar, and Richard T. Burnett. 2017. "Impacts of Coal Burning on Ambient $PM_{2.5}$ Pollution in China." *Atmospheric Chemistry and Physics*, 17(7): 4477–4491.

Wang, Weiliang, Zheng Li, Junfu Lyu, Hai Zhang, Guangxi Yue, and Weidou Ni. 2019. "An Overview of the Development History and Technical Progress of China's Coal-Fired Power Industry." *Frontiers in Energy*, 13(3): 417–426.

Wei, Jing. 2021. "Reconstructing 1-km-resolution high-quality PM2.5 data records from 2000 to 2018 in China: spatiotemporal variations and policy implications."

Yamamoto, Daisaku. 2022. "Cursed Forever? Exploring Socio-Economic Effects of Nuclear Power Plant Closures across Nine Communities in the United States." *Social Science*.

Ye, Liang-Cheng, Hai Xiang Lin, and Arnold Tukker. 2019. "Future Scenarios of Variable Renewable Energies and Flexibility Requirements for Thermal Power Plants in China." *Energy*, 167: 708–714.

Zhang, Qiang. 2017. "Transboundary health impacts of transported global air pollution and international trade."