Pollution Regulations, Local Labor Markets, and Skill Heterogeneity

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Abstract

This paper examines the impact of environmental regulations on the local labor markets by exploiting China's first air pollution regulation as a natural experiment. The identification strategy uses a new instrumental variable proposed based on engineering considerations related to polluting activities. The results, based on aggregated firm and census data, show that the pollution regulation led to a decline in employment in the targeted prefectures and sectors by causing net firm exits. Analyses at the worker level, using census data with rich individual characteristics, further reveal the distributional consequences of this adverse effect by skill level, such that less educated workers are more likely to have lost their jobs. Moreover, less educated workers are less likely to have spatially adjusted to other labor markets due to the high and skill-biased migration costs imposed by the *hukou* system.

Keywords: Environmental regulations; Local labor market shocks; Skill heterogeneity; Migration cost
JEL codes: Q52, J21, R11, R23

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1 Introduction

Air pollution regulations have important health and environmental benefits in both developed and developing countries. However, the findings regarding the associated costs imposed on targeted firms and workers vary between the two contexts. Studies based on the experiences in developed countries generally show that pollution abatements lead to job losses, firm exits, and costly labor transitions (e.g., Becker and Henderson, 2000; Greenstone, 2002; Walker, 2013). In contrast, the studies on similar policies in emerging economies offer conflicting findings.

The literature on the potential regulatory costs in this "environment versus economic growth" debate in emerging economies has provided important information for policy makers. For example, studies on China's Two Control Zone (TCZ) policy show that it has driven away foreign direct investment and reduced exports (Dean et al., 2009; Cai et al., 2016; Hering and Poncet, 2014). However, no adverse effects have been found for domestic firms. In contrast, recent studies are in support of the Porter hypothesis that this regulation brings about cost-reducing innovation and boosts local employment (e.g., Jefferson et al., 2013; Khanna et al., 2019).[1] With respect to regulatory policies, this ambiguity can lead to a misalignment between short-term growth and incentives to abate harmful polluting activities.

Given the uncertainty regarding the net effects of China's environmental regulations, it is crucial to understand how targeted firms and the workforce adjust to such regulations to determine welfare considerations and design supportive policies. The effects of environmental regulations tend to be strongly spatially distributed as the regulatory intensity is stronger in more polluted locations. Although the "pollution haven" effect, in which polluting firms relocate to less regulated locations to avoid environmental abatements, has been well documented in the literature, there is little evidence on the spatial transitional costs faced by workers as a result of reduced local labor demand. This factor may be more salient in the context of emerging economies in which the barriers to migrating from adverse local labor market shocks can be far greater for reasons such as remoteness, social stigma, and institutional restrictions. Consequently, the labor transitional costs resulting from environmental regulations may be further exacerbated by high migration costs.

The goal of this paper is to study the potential regulatory costs and induced labor market adjustments stemming from the aforementioned TCZ policy, which was China's first national air pollution regulation. In 1998, the revision of China's Air Pollution Prevention and Control Law (APPCL) marked the country's first formal step toward combating polluting activities. In the literature, "TCZ policy" refers to the provision relevant to sulfur dioxide (SO_2) pollution (the most severe air pollutant at the time). The term "TCZ prefectures" refers to the list of prefectures that have been directly monitored by the State Council because of their severe SO_2 pollution and acid rain phenomena since 1998.

In exploring the regulatory effects of the TCZ policy, this paper departs from the literature in three important ways. First, this paper identifies a large adverse TCZ effect on local employment in the targeted prefectures. In this case, part of the difference in the estimated effects is due to the different methodology used in this paper. Studies commonly use

[1] These findings are not only different from the developed-country experience, but also inconsistent with studies that identified China's water regulation outcomes and the corresponding firm productivity-reducing effects (He et al., 2020; Chen et al., 2018).

various difference-in-differences (DID) approaches to identify the effects of the TCZ policy. However, due to data limitations, the parallel trend assumption remains untested and the identification largely rests on controlling for a rich set of industry, regional, and time fixed effects. Using newly constructed population census and firm-level data from the pretreatment years, I find that prior to the implementation of the TCZ policy, the TCZ prefectures and their local firms exhibited slower growth trends in terms of city size, industrial base, and skill distribution compared with the non-regulated prefectures. Therefore, this pre-existing difference in growth trends may leave the DID setup susceptible to bias.

To mitigate this downward bias, I propose a novel instrumental variable of power plant suitability that is widely used for site selection in civil engineering [2] (e.g., Barda et al., 1990; Pohekar and Ramachandran, 2004; Choudhary and Shankar, 2012). This suitability index is a nonlinear transformation of a set of locational characteristics for measuring the cost, accessibility, and safety considerations in building power plants. I construct the index using granular remote sensing data. The identification stems from the set of nonlinear scaling functions and weights used in computing the index, rather than the constituting geospatial characteristics. As thermal power plants consistently contribute about 50% of China's SO_2 emissions (Lu et al., 2010), the suitability index uses the orthogonal determinants at the pollutant source to capture the likelihood of having higher ambient SO_2 levels as a result of hosting thermal power plants.[3] Through this linkage, the suitability index determines a location's probability of being a TCZ regulation target. Applying this instrumental variable alongside a first-difference setup substantially improves the balance between the TCZ and non-TCZ prefectures in terms of their pretreatment growth trends.

This paper also departs from the literature by investigating the potential local employment adjustments in response to the TCZ policy. To do so, I use the rich details in the censuses of the above-scale industrial firms. Consistent with the policy details, the identified adverse employment effect is driven by heavy coal-using firms in the secondary industries. This TCZ-induced adverse employment shock occurs in the first half of the sample period, before China joined the World Trade Organization (WTO). Although there is some evidence of employment being reallocated from the regulated heavy coal-using to the light coal-using industries locally, it is not enough to negate the adverse regulatory impact. Last, patterns in the growth of other local economic measures suggest that the TCZ policy largely works through the channel of net firm exits, rather than reductions in worker productivity.

The third contribution of this paper is to lend insight to the distributional consequences of the TCZ-induced adverse shock by examining skill heterogeneity among workers. Making use of the unique labor mobility (*hukou*) reform that was implemented in the late 1990s and an exclusive random sample of over half a million labor force participants from the 2000 and 2010 population censuses, I observe a number of temporal and geographic patterns. First, college-educated workers are less likely to be made redundant and more likely to remain employed throughout the TCZ period. Second, TCZ-induced internal migrants are less attracted to the regulated prefectures. Third, college education and working in heavy coal-using industries characterize the labor force participants who are more likely to spatially

[2] The Public Service Commission of the state of Wisconsin, for example, has its own *Common Power Plant Siting Criteria*.

[3] This index reflects the *potential*, rather than the *actual*, power plant locations, which may still be endogenous for reasons such as political nepotism.

adjust across labor markets in response to the negative employment shock.

The findings in this paper provide new evidence on the local employment and labor reallocative effects of China's TCZ policy. The regulation of SO_2 polluting activities leads to declines in net firm growth in the targeted locations and industries, which directly lead to local employment reductions with limited reallocation to the non-targeted industries. The distribution of this adverse employment effect varies substantially by skill. Workers with a college education and above are less likely to be affected by the TCZ policy, and they are more likely to respond to this adverse labor market shock by migrating away from the targeted prefectures. In contrast, less-skilled workers asymmetrically bear the regulatory costs of the environmental protection policies.

In addition to providing new findings that complement the literature, this paper uses a novel instrumental variable to ensure exogenous variation in the spatial distribution of the SO_2 emissions. Two widely applied instrumental variables in the literature are the phenomenon of thermal inversion (Arceo et al., 2016; Sager, 2019; Chen et al., 2017a; Fu et al., 2017) and the distribution of pollution from its sources by wind direction and speed (Schlenker and Walker, 2016; Freeman et al., 2019; Lin, 2018). The suitability index serves as a new instrumental variable for air pollution as it exploits the spatial variation in the pollutant sources rather than the distribution of the pollutant across space. The suitability index can also serve as a complementary instrumental variable in pollution-related research as an independent cross-sectional empirical tool, or a time-varying instrument when interacted with wind features or changes in the utility network of electricity production and transmission. As evidenced by the robustness and sensitivity checks, the baseline results are consistent across a wide range of different specifications, restrictive samples, alternative computations of the instrumental variable, and the use of thermal inversion as an alternative instrumental variable.

The rest of this paper is organized as follows. The next section introduces the institutional context and policies underpinning the research question and data sources. Section 3 presents the empirical strategy. Section 4 discusses the estimation results and investigates the potential mechanisms. Section 5 concludes this paper.

2 Background and Data

2.1 SO_2 pollution and the TCZ policy

This paper focuses on the regulation of SO_2 emissions, which have presented the most severe environmental challenge in China since the 1990s. Since the 1990s, China has emitted 20 million tons of SO_2 annually, which represents a quarter of the global emissions and more than 90% of East Asian emissions (Lu et al., 2010). SO_2 is a major by-product of burning fossil fuels such as coal in power plants and related industrial facilities. It is also a primary precursor of acid rain, which can damage agricultural land, buildings, and the overall ecosystem. High levels of airborne SO_2 are harmful to the human respiratory system. When interacting with other compounds in the atmosphere, SO_2 also contributes to the formation of haze and particulate matter (US Environmental Protection Agency, 2017b,a).

China's Ninth Five-Year Plan (1996-2000) revised the Air Pollution Prevention and Control Law (APPCL) by adding the TCZ policy as a new means of addressing the country's environmental deterioration, particularly the declining air quality due to severe SO_2 pollution. The objective was to improve the air quality ratings for all prefectures to the level of "merit," thus marking China's first serious attempt to implement environmental regulations. Based on this goal of the TCZ policy, it is reasonable to assume that the existing prefecture-level SO_2 pollution levels serve as reasonable proxies for the intensities of local regulation (Shi and Xu, 2018).

The TCZ policy was named after the strategy of targeting the high SO_2 and acid rain pollution zones, which cover 160 prefectures in mainland China (excluding the autonomous regions). Enforcement of the State Council approved practices included 1) limiting the use of high-sulfur coal, 2) installing desulfurization facilities, upgrading boilers and kilns, and treating effluent gas in high coal-usage plants, 3) shutting down low-efficiency coal users and restricting the construction of new thermal power plants, and 4) levying emission charges on extremely heavy polluters (Gao et al., 2009; Goulder, 2005).

In an empirical study, World Bank (2003) documents that low-sulfur coal is twice as expensive as high-sulfur coal. Research based on the U.S. Clean Air Act also estimates that upgrading equipment and treating pollutants increase the average firm costs by 17% (Becker and Henderson, 2000). Based on the above policy instruments and evidence, I conceptualize the implementation of the TCZ policy in 1998 as an adverse productivity shock that imposed additional costs on the regulated firms and prefectures.

2.2 SO_2 pollution trends

The Chinese context differs from the well-studied experiences of developed countries in terms of the extent of SO_2 pollution and the implementation of environmental protection policies. Similar to other emerging economies undergoing rapid industrialization, the pollution levels in China are magnitudes higher than those in developed economies (Greenstone and Hanna, 2014). Moreover, the levels of SO_2 pollution in China have remained consistently high even after the implementation of the environmental protection policy. To visualize this striking difference, Figure 1 compares the SO_2 time trends for China (consistently high), the United States (steady decline), and the European Union (steady and the fastest decline) since 1990.[4]

In addition to the contrasting time trends across countries, China's SO_2 levels during the sample period used in this paper can be divided into two sub-periods corresponding to two important policy years. The first turning point is around 1998, the year the TCZ was implemented. Between then and 2002, China's overall SO_2 pollution levels show no upward movement. However, starting in 2003, the levels increase substantially after China's entry to the WTO and the end of the SOE reform spur further industrialization. This sharp change in trend is closely related to China's overall economic cycle and structural changes. Therefore, the potential heterogeneity of the two sub-periods is examined closely in the discussion of Table 8.

Figure 2 further shows the important role that China's structural changes play in the

[4]Data sources: China Ministry of Environmental Protection, U.S. Environmental Protection Agency, European Environment Agency. Accessed on August 9, 2017.

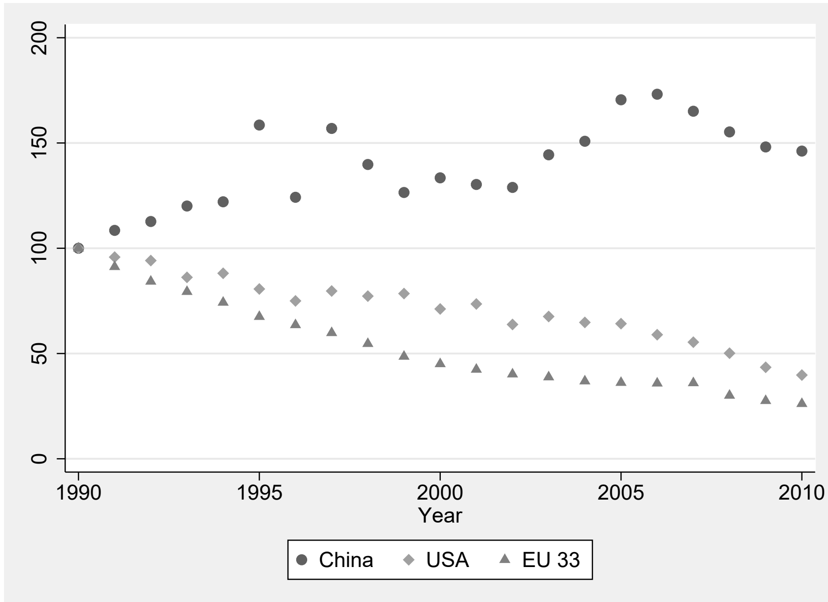


Figure 1. The relative severity of SO_2 emission in China, 1990-2010

Notes: Data are converted to relative terms with respect to 1990 (=100).

TCZ policy implementation and SO_2 time trend. Sub-figures (a) and (b) show the SO_2 levels and SO_2 per GDP levels for 1998-2010 in relation to the 1998 levels, respectively. Without scaling by GDP, part (a) shows no convergence relative to the initial levels. After scaling by GDP, the underlying correlation in part (b) suggests that the SO_2 per GDP levels in the initially more polluted and hence more stringently regulated prefectures grow more slowly. This pattern suggests the TCZ policy effectively suppressed SO_2 pollution growth.

2.3 The *hukou* reform and skill heterogeneity

The nature of the *hukou* reform and its associated skill heterogeneity are important factors in understanding the distributional effects of the TCZ-induced labor market shock. The *hukou* system is similar to an internal passport system in that it ties all Chinese citizens to their place of residence (specifically, to a census tract) through inheritance. By designating the *hukou* location as an individual's only legal place to access social benefits, the system has served as an effective tool for limiting internal migration in China since the 1960s (Naughton, 2017).

Prior to the implementation of the reform in the late 1990s, it was extremely difficult to change one's *hukou* status or move to a different location in China. The rare channels for migration were through job assignments after college education, job relocations within the state sector, or marriage.[5] This inflexibility was a strong disincentive to relocation, and the labor supply was therefore largely spatially inelastic.

[5]People could otherwise move illegally as "unregistered" migrants or legally but temporarily. In either case, they were not entitled to local public provisions at the destination (Au and Henderson, 2006).

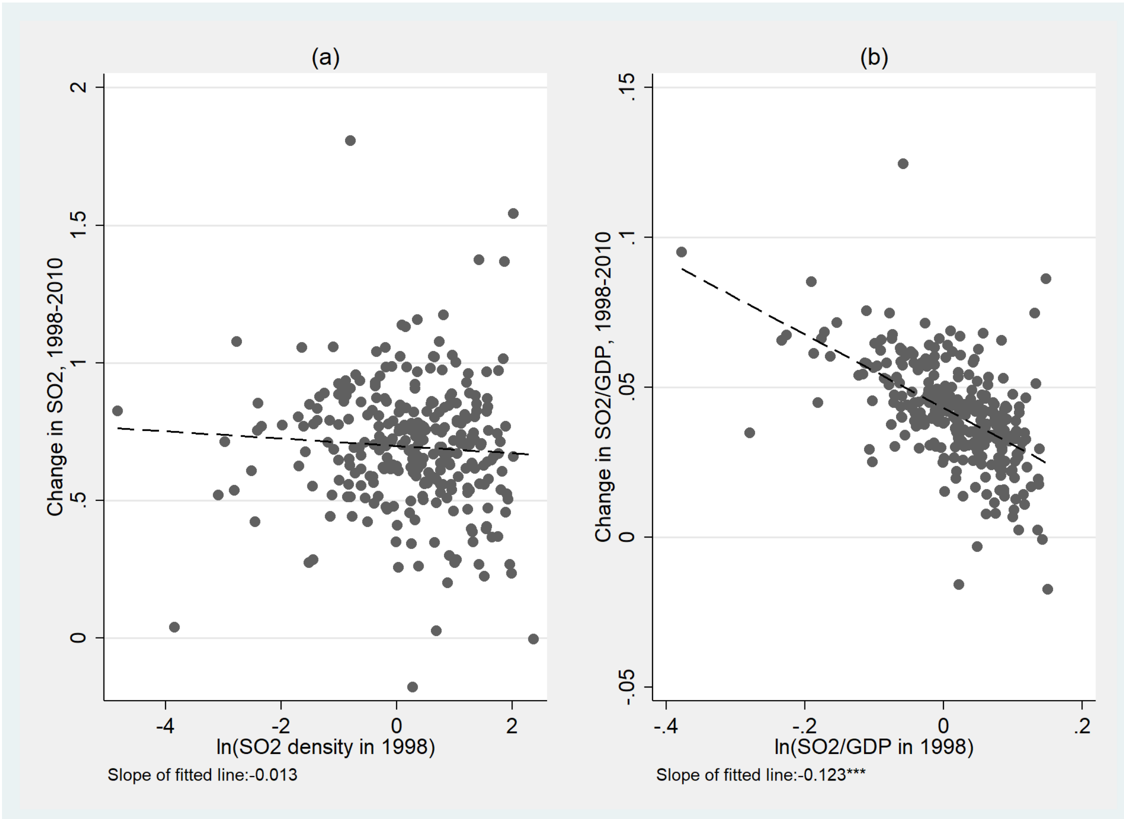


Figure 2. Convergence in SO_2 levels after TCZ implementation

Notes: These two figures show the potential "convergence" since the TCZ implementation by plotting the prefecture-level changes between 1998 and 2010 as a function of the initial 1998 levels. Part (a) uses the SO_2 pollution levels and part (b) scales the SO_2 levels by GDP.

The *hukou* reforms in the 1990s substantially relaxed (but did not eliminate) the barriers to migration. The reforms allowed people to voluntarily and legally relocate for employment and gain access to local housing. As a result, China's internal migration began to grow in scale and the motivations for moving shifted. Figure 3 plots the post-reform time trend of different motivations for internal migration between 1995 and 2000.[6] Voluntary internal migration for work clearly shows the greatest increase, followed by those who move for further education and training. The two main reasons for migrating prior to the reform, namely work assignment and moving with/for family, both show declining trends.

However, the extent to which the *hukou* reform lowers migration cost varies by skill. Migrants with college degrees and above can relocate their *hukou* to a destination, where they are granted full access to local social benefits such as health care and schooling for their children. Although less educated migrants can legally seek employment at their destination, the possible means of relocating their *hukou* are far more limited[7] (Chan, 2013). In this

[6]Unfortunately, the precise year of migration only dates back to 1995 when the *hukou* reform had already begun.

[7]Examples of the means of relocating one's *hukou* without meeting the education requirement are en-

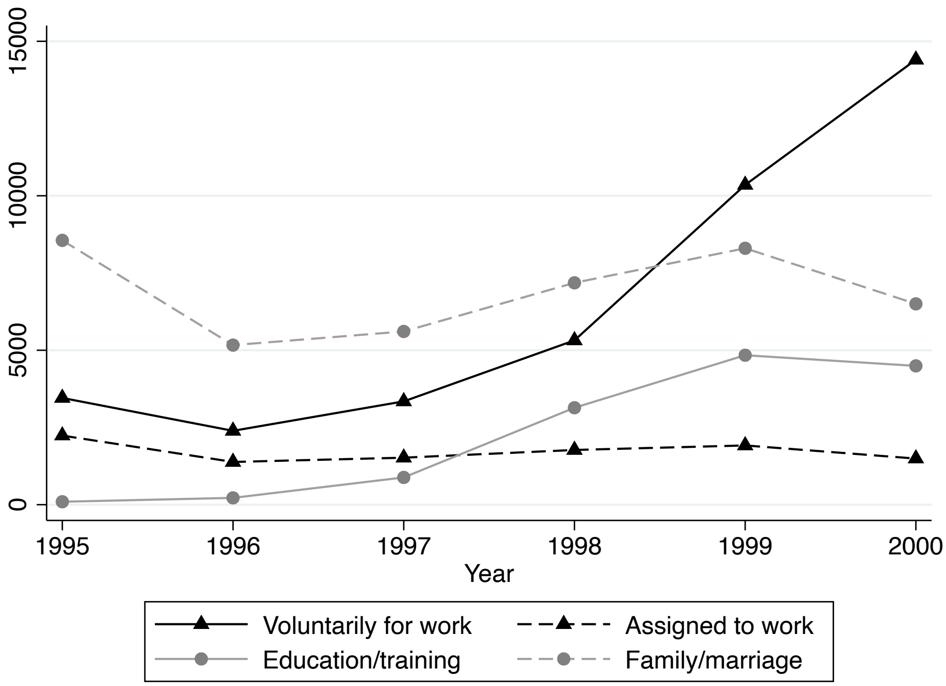


Figure 3. Number of migrants by migrating motivation

Notes: The 1995 figure is estimated because all migrants prior to October 1995 are grouped into the "migrated more than five years ago" category (not shown).
Data source: The National Population Census (conducted in October 2000), 1% random sample.

respect, the *hukou* reform has been interpreted in the literature as a skill-biased reduction in migration costs (Tombe and Zhu, 2019; Au and Henderson, 2006). Thus, given any TCZ-induced adverse local labor market shocks, less educated workers face higher transitional costs in spatially adjusting to other local labor markets, which stem from higher migration costs.

2.4 Data

The data used in this paper comprise three main data sets merged to the unified prefecture level, namely, the Chinese Population Censuses (1982, 1990, 2000, 2010), the Medium and Large Industrial Enterprise Surveys from 1998 to 2007, and spatial and geographic data based on satellite-derived images, remote sensing data, and geological surveys. The State Council's documentation of the TCZ prefectures and Bureau of Statistics reports provide additional institutional information to complement the main data.

The Chinese Population Census is the most representative and comprehensive source of data on the local prefectures. The census data allow for the computation of the following prefecture-level variables in the four census years: population, populations of high- and low-skilled workers (i.e., college education and above versus below), total employment, and

trepreneurship and housing investments, both of which require large sums of capital.

employment by sector (primary, secondary,[8] and tertiary). This source of the census data is published at the unit of districts and counties, which are then aggregated to consistent prefecture boundaries based on Baum-Snow et al. (2017).[9]

The firm survey data are widely used in the literature as the sample covers over 90% of China's total industrial output (Brandt et al., 2012) from 1998 to 2007. Although the sample omits small non-state-owned firms whose annual sales are less than RMB5 million (Brandt et al., 2014), its rich details allow for the aggregation of information such as employment, capital, value-added, and wage variables by firm ownership and sector at the prefecture level. In this paper, I focus on the heterogeneity between heavy and light SO_2-emitting firms by their coal use intensity[10] and ownership types. I also use the 1996 and 1997 firm surveys to check the pretreatment balance.[11]

This paper also makes use of a large amount of spatial data. I collect and compute the prefecture-level annual average SO_2 density, temperature, wind speed, and precipitation using satellite-derived spatial data from various NASA projects. These satellite-derived measures provide more granular and consistent coverage than the ground measures, and are the only source of climate variables for this sample period. For more recent years in which both satellite and ground measures of climatic data are available, Chen et al. (2017a) show that the two sources share consistent time trends. To compute the instrumental variable, I process remote sensing and geo-survey records from the United States Geological Survey and the Harvard WorldMap library. Table A3 in the Appendix documents the types of data, their corresponding sources, the timespan and spatial resolution. Another key component of the research design is the location of coal-fired power plants, which I collect from the non-profit coal monitoring website SourceWatch Coal Issues.[12] The power plant coordinates are geo-located based on their official addresses and confirmed using Google Map Satellite imagery. Lastly, this paper benefits from the generosity of Baum-Snow et al. (2017), who kindly shared their road and rail maps of China and unified prefecture boundaries that account for the frequent boundary changes that occur during the sample period.

To further examine the TCZ-induced migration response in Section 4.3, I also use an exclusive sample of over 1 million individuals randomly selected from the 2000 and 2010 Population Censuses database. In addition to providing rich individual characteristics such as eduation level and occupation, the data record the immigration status and year of out-migration (up to five years prior to the census date) of each individual.[13] The sample used

[8]The secondary sector is industry plus raw material extraction.

[9]Districts and counties are smaller administrative units than prefectures. Another common source of prefecture-level data comes from China's regional year books. Although this source provides many more variables, the prefecture boundary changes over time have not been accounted or adjusted for. Therefore, using prefecture-level panel data constructed from the regional year books is prone to measurement error.

[10]Combining the three-digit industrial codes and data from the 1997 Bureau of Statistics Input-Output Table of China, I categorize the top 12 industries (out of 106 industries in the input-output matrix) in terms of coal use (in monetary value) as heavy coal users. Each of the defined heavy coal-using industries accounts for 2% or more of the national coal consumption, and they jointly consume more than 70% of the coal used in China.

[11]The sample sizes of the 1996-97 firm surveys are substantially smaller than those in later years as they were run as trials.

[12]Accessed in June 2017.

[13]The destination of migration is the current location of the respondent at the time of the census. However,

in this paper is restricted to labor force participants aged between 15 and 64 who are either working or seeking employment.

Table 1 presents the summary statistics of the key variables by TCZ status. The TCZ and non-TCZ prefectures clearly differ across many of the presented characteristics. Although the literature largely relies on the DID approach, in the next section I discuss its potential limitations and introduce a new identification strategy.

	Non-TCZ (N=126)		TCZ (N=160)	
Variable description:	Mean	SD	Mean	SD
Sulfur dioxide density, 1998 (ln)	-0.056	(1.307)	0.494	(0.874)
Dummy of hosting thermal power plants, 1998	0.286	(0.454)	0.406	(0.493)
Thermal power plant suitability index (mean)	4.320	(0.663)	4.663	(0.524)
Thermal power plant suitability index (top quartile)	4.947	(0.722)	5.359	(0.571)
Dummy of eastern China	0.278	(0.450)	0.487	(0.501)
Dummy of western China	0.278	(0.450)	0.194	(0.396)
Dummy of provincial capital and provincial-level city	0.024	(0.153)	0.138	(0.345)
Number of road and rail rays, 1990	3.968	(2.043)	4.588	(2.084)
Distance to the nearest coast (ln)	5.549	(1.963)	5.193	(1.724)
Distance to the nearest major river (ln)	4.496	(1.473)	3.896	(1.768)
Annual average temperature, 2000	284.774	(5.914)	287.581	(4.765)
Annual average wind speed, 2000	3.044	(0.749)	3.063	(0.736)
Annual average precipitation, 2005	2.870	(1.256)	3.288	(1.229)
Thermal power plant capacity, 1998 (ln)	1.721	(2.780)	2.656	(3.268)
Mean average elevation (ln)	5.557	(1.595)	5.397	(1.404)
Distance to the nearest coal mine (ln)	0.702	(0.925)	0.685	(0.761)
Dummy of areas prone to natural disasters	0.627	(0.486)	0.681	(0.467)
Coverage of natural gas access	0.608	(0.337)	0.801	(0.236)
Share of pop with college edu and above, 2000	0.026	(0.015)	0.037	(0.027)
Share of migrants, 2000	0.039	(0.077)	0.070	(0.096)
Share of primary employment, 2000	0.710	(0.168)	0.592	(0.200)
Share of secondary employment, 2000	0.119	(0.093)	0.201	(0.137)

Table 1. Mean and standard deviation of the key variables by TCZ status

3 Research design

To identify the local labor market effects of the TCZ policy, I begin with a specification following the general form of a growth equation:

$$\ln(y_{i,2010}) - \ln(y_{i,2000}) = \xi + \eta \text{TCZ}_{i,1998} + \phi Z_i^{'} + \epsilon_i \quad (1)$$

where i denotes the prefectures, which constitute the level of analysis. The change in y between 2000 and 2010 represents the set of outcomes of interest, capturing the growth in,

the place of origin is not provided.

for example, local employment and share of high-skilled workers. The treatment of interest, environmental regulation, is measured as the TCZ status at the baseline. As a measure of regulation intensity, I use the interaction between the TCZ dummy and the concurrent ambient SO_2 density in log form to utilize the fact that more polluted prefectures are under more pressure to improve their local air quality.[14]

To control for observable differences across prefectures that may be associated with both the outcome and treatment variables, I include a vector of pre-existing prefecture political, economic, and climatic characteristics, Z_i. The set of political characteristics includes regional dummies and provincial-level city and provincial capital dummies to address the concerns that higher administrative status might be correlated with higher pollution levels, industrial productivity, and more stringent regulations. Concerning the pre-existing economic conditions, I control for the completeness of the transportation network (log number of rail and road rays), log distance to the coast line, and the share of employment in heavy coal-using industries in 1996. These covariates aim to address the concerns that prefectures with more stringent regulations differ fundamentally in their transportation infrastructure, connectivity, and/or industrial composition. The vector Z also includes climatic characteristics that may affect local SO_2 pollution formation, namely, the average temperature, wind speed, and precipitation. The error, ϵ_i, represents unobserved prefecture shocks to the growth in local outcomes.

3.1 Power plant suitability as the instrumental variable

The setup of equation 1 ensures that prefectures of varying regulatory status are as comparable as possible in terms of observed differences, but unobserved characteristics potentially correlated with group-specific growth trends could pose a challenge with respect to identification. To address the above endogeneity concern, my research design uses power plant suitability to instrument for variations in prefecture TCZ regulatory status.

3.1.1 Coal-fired power plants in China

Several attributes of the coal-fired power plants in China make this a valid identification strategy. The first is the paramount role that coal-fired power plants play in energy generation and coal consumption in China. According to the International Energy Agency, over 70% of China's electricity is still generated from coal sources.[15] Second, coal-fired power plants consistently account for around 50% of China's coal consumption throughout the 2000s.[16] As the main contributor of SO_2 emissions, coal-fired power plants have hence been the key target of China's SO_2 regulatory policies since the late 1990s. Based on these two attributes, prefectures hosting coal-fired power plants are likely to face more stringent environmental regulations after the implementation of the TCZ policy.

[14] Shi and Xu (2018) show that the existing SO_2 pollution levels serve as reasonable proxies for the local regulation intensities in the TCZ policy context.

[15] Data sources: IEA statistics: China, People's Republic of: Electricity and Heat. Data accessed on August 16, 2017. The percentage of electricity generated by coal in 1990, 2000, 2010, and 2014 is 71%, 78%, 77%, and 73% respectively.

[16] Industrial production accounts for another 40% and the rest is for domestic use and transportation (Lu et al., 2010).

The power generation and supply networks in China are also individually managed during the sample period. Electricity is produced locally, but distributed centrally by regional offices and supervised by the State Council (China State Council, 1993). Therefore, firms do not have an incentive to locate near thermal power plants to access cheap electricity within a given region (hence the importance of controlling for regional fixed effects). It is still possible that firms may locate near thermal power plants for indirect reasons such as access to coal or transportation networks. I return to this particular concern in Section 3.2.

Despite these nice contextual features of thermal power plants, there may still be unobservable factors correlated with actual plant locations and the economic prospects of their hosting cities. It is possible that a coal-fired power plant is strategically placed to create new jobs or due to the nepotistic motivations of the local politicians. To tackle this challenge, I exploit the exogeneity in the selection processes of the power plant hosting sites by drawing on the power plant suitability index used in the engineering literature.

3.1.2 The power plant suitability index

The power plant suitability index measures the probability of a given location hosting coal-fired thermal power plants subject to construction cost, safety, and feasibility considerations from a civil engineering perspective. The engineering literature (Barda et al., 1990; Pohekar and Ramachandran, 2004; Choudhary and Shankar, 2012) and practical guidelines (e.g., the *Common Power Plant Siting Criteria* set by the State of Wisconsin Public Service Commission) generally agree on the factors to be considered, such as topography, land use, water bodies, and fuel supply. The transformation of factors to compute the suitability index follows the general form:

$$s_j = \sum w_k f_k(k_j) \tag{2}$$

where the suitability for hosting a thermal power plant at location j is calculated as the weighted sum of the rescaled value of factor k. The nonlinear scaling function f and weights w are both factor-specific.

The exact formula I use is based on Zoej et al. (2005), an Iranian government commissioned site selection project led by a civil engineering team and the Iran Energy Efficiency Organization.[17] Although this approach is commonly used in many countries (Barda et al., 1990; Pohekar and Ramachandran, 2004; Choudhary and Shankar, 2012), Zoej et al. (2005) provides a rare instance of having made public the exact formulations of f and w. Table 2 lists the detailed weights for each factor and the nonlinear rescaling functions used in this paper. For example, the exact value of the distance to the nearest small river of location j is transformed into four scores by four ranges of distance. Being near a water source is cost efficient for the cooling process in electricity generation, but being too close to water banks increases the risk of soil instability. Therefore, the mapping from the ranges of the factor values to the exact scores is nonlinear.

Figure 4a maps the spatial distribution of the suitability index across China's prefectures in greyscale, with the darker colors indicating greater suitability for hosting coal-fired power plants. In practice, the spatial resolution of each location j is that of the coarsest layer

[17] The modification process is discussed in the Appendix Section A3.

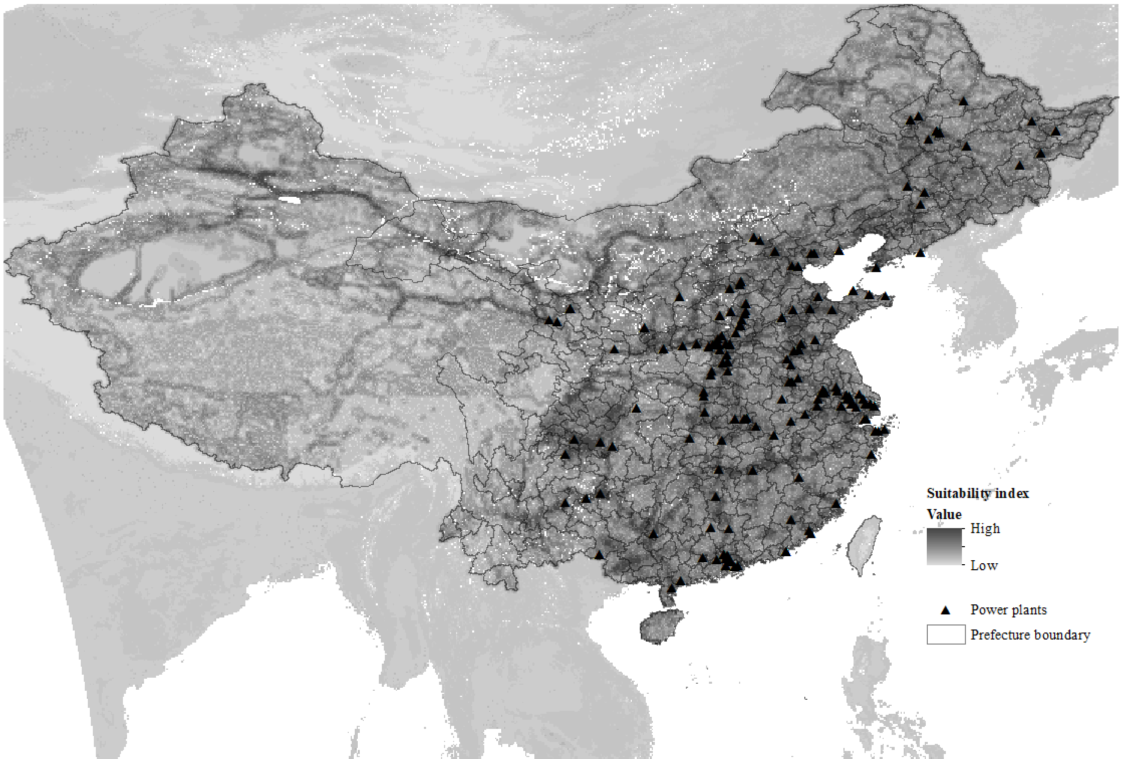
of remote sensing data, which is approximately 81 km^2.[18] Figure 4b maps the distribution of ambient SO_2 density across China, with darker pixels indicating higher SO_2 pollution. Both parts of Figure 4 also show the locations of coal-fired power plants in 1998. Visually, there are clear spatial overlapping patterns between power plant suitability and the actual locations, and SO_2 pollution and the power plant locations.

[18]To be precise, the spatial resolution is $0.08° \times 0.08°$ in this case.

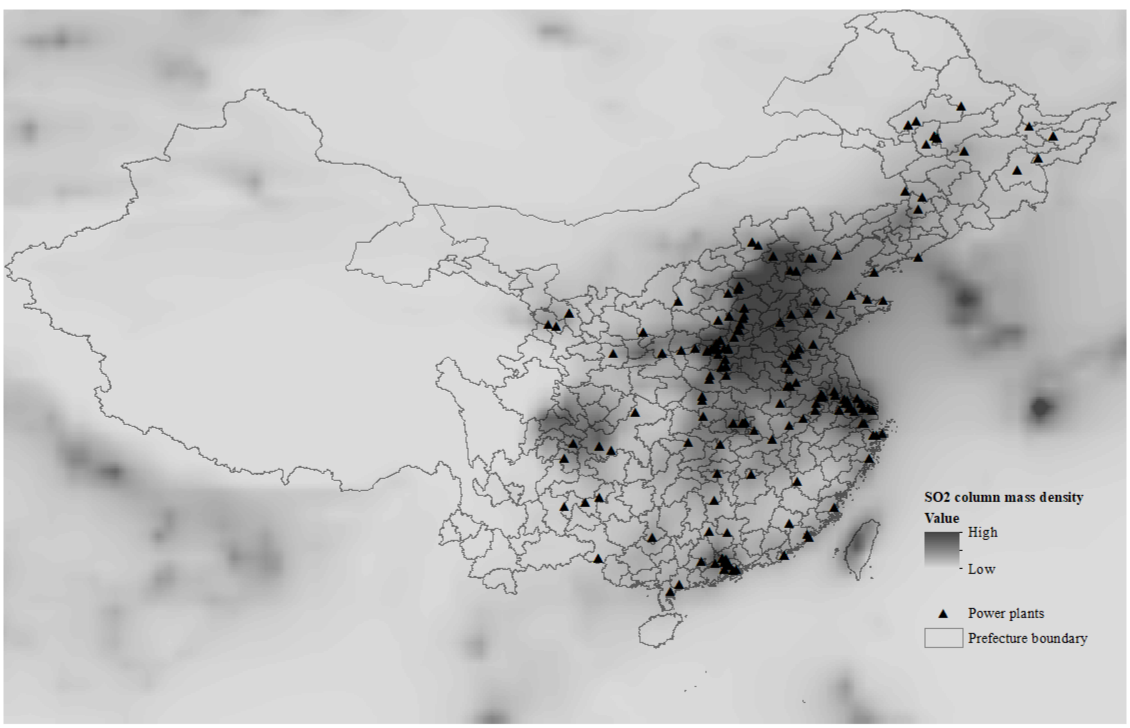
Factor, k (Weights, w)	Mapping from value ranges to scores, f_k (Reclassified scores)					
Location characteristics:						
Elevation	0-1000m	1000-1400m	1400-1800m	>1800m		
(0.06)	(10)	(8)	(4)	(0)		
Ruggedness	0-6%	6-10%	>10%			
(0.05)	(10)	(7)	(0)			
Suitable for agriculture	Yes	No				
(0.04)	(5)	(10)				
Distance to the nearest:						
Rail	0-500m	0.5-10km	10-20km	20-40km	>40km	
(0.14)	(0)	(10)	(7)	(3)	(0)	
Coal mines	0-5km	5-50km	>50km			
(0.1)	(10)	(5)	(0)			
Road	0-500m	0.5-10km	10-20km	20-40km	>40km	
(0.08)	(0)	(10)	(7)	(3)	(0)	
Natural gas pipe line	0-500m	0.5-5km	5-10km	10-20km	20-40km	>40km
(0.08)	(0)	(10)	(8)	(6)	(3)	(0)
Oil and natural gas fields	0-5km	5-50km	>50km			
(0.08)	(10)	(5)	(0)			
Large river	0-500m	0.5-10km	10-20km	>20km		
(0.08)	(0)	(10)	(5)	(0)		
Small river	0-500m	0.5-10km	10-20km	>20km		
(0.07)	(0)	(10)	(5)	(0)		
Untapped coal sources	0-5km	5-50km	>50km			
(0.05)	(10)	(5)	(0)			
Urban area	0-10km	10-20km	20-50km	50-100km	>100km	
(0.05)	(0)	(10)	(7)	(4)	(0)	
Earthquake spots	0-1km	>1km				
(0.05)	(0)	(10)				
Airfields	0-5km	>5km				
(0.05)	(0)	(10)				
Volcanoes	0-1km	>1km				
(0.02)	(0)	(10)				

Table 2. Constructing the thermal power plant suitability index

Notes: This table presents the factors (k) that constitute the thermal power plant suitability index, the factor-specific nonlinear transformation (f_k), and the associated weights (w). For each factor k listed on the left column, the mapping from the ranges of its value to the corresponding scores (in parenthesis) is presented across the right columns.



(a) Coal-fired power plant suitability and actual locations in 1998



(b) Ambient SO_2 density and coal-fired power plant locations in 1998

Figure 4. Spatial distributions of thermal power plants, suitability index, and SO_2 density

3.2 Validity of the instrumental variable and supporting evidence

The predictive power of the suitability measure is established based on its ability to predict the locations of thermal power plants, which are the main SO_2 emitters in China during the sample period. Table 3 presents quantitative evidence supporting the links between suitability, power plant hosting, ambient local SO_2, and prefecture regulatory status. Because the analysis is carried out at the prefecture level, the prefecture-level mean of the suitability index is used as the instrument in the main specifications.[19]

	Without covariates	With economic covariates
	(1)	(2)
Panel A: Likelihood of hosting a thermal power plant (probit)		
Prefecture suitability: mean	0.660***	0.522***
	(0.146)	(0.173)
Panel B: Predicting local SO_2 levels (linear)		
Hosting power plants by 1998	0.603***	0.292**
	(0.127)	(0.119)
R^2	0.07	0.26
Panel C: Likelihood of being in Two Control Zones (probit)		
ln(SO2 density in 1998)	0.292***	0.278***
	(0.068)	(0.079)
N	286	286

Table 3. The relationships between suitability, power plant hosting, SO_2 pollution levels, and regulation intensity

Notes: Panel A shows the predictability of thermal power plant suitability (prefecture mean) in relation to the prefecture power plant hosting status. Panel B presents the positive association between power plant hosting and the local SO_2 pollution levels. Panel C suggests that the more polluted prefectures in 1998 are more likely to be listed as Two-Control Zones by the State Council. Robust standard errors in parentheses.

* p<0.1, ** p<0.05, *** p<0.01.

Panel A shows that prefectures with higher average thermal power plant suitability values are more likely to host power plants in 1998, both with and without controlling for the prefecture economic characteristics. Panel B then establishes the positive correlation between thermal power plant hosting status and the local ambient SO_2 pollution level. Lastly, panel C shows that the 1998 ambient SO_2 levels are predictive of a prefecture's regulatory status under the TCZ policy. Panel C also provides support for using the interaction between the TCZ dummy and the 1998 ambient SO_2 levels as a valid measure of regulation intensity.

[19]The rationale is that although the suitability of an individual pixel may have been difficult to detect for engineers and planners in the 1990s, prefecture-level comparisons in terms of their respective average suitability would potentially have been available through other means. The baseline findings are robust to other prefecture-level suitability measures as shown in the later robustness checks.

To formalize the instrumental variable specification, the first-stage regression is as follows:

$$\text{TCZ}_{i,1998} = \alpha + \beta S_i + \gamma Z_i^{'} + \theta K_i^{'} + \varepsilon_i, \tag{3}$$

where the prefecture-level (i) average of the pixel-level (j) suitability, $S_i = \mathbb{E}(s_j)_i$, is used to predict the TCZ regulatory status of the prefecture or the regulation intensity measure $\{\text{TCZ} \times \ln(\text{SO}_2)\}_{i,1998}$.

In addition to the covariates mentioned in equation 1, Z_i, I further include the vector of the prefecture averages of the constituting components of the suitability index in log-linear or linear form, $K_i = \mathbb{E}(k_j)_i$. The components comprise the log average elevation, log number of raw energy fields (gas, oil, and coal), dummy if near a volcano, air field, or earthquake spot, and urban area gas supply coverage.[20] Adding K to the covariates addresses the concern that the growth potential of some industrial firms may be correlated with their decisions to locate near power plant sites to gain access to transportation links or raw materials. In other words, the inclusion of the suitability index comprising factors in linear form allows the set of factor-specific non-linear transformations (f_k) and weights (w_k) to work as the instrumental variable.

The baseline specification is hence the two stage least square (2SLS) version of equation 1, with predicted TCZ status and the inclusion of vector K. Table 4 presents the first-stage results based on equation 3. The prefecture average suitability index is strongly predictive of both the treatment status and intensity. Experimenting with the prefecture-level top quartile of the suitability measure leads to very similar results.

Dependent variables:	TCZ status		Regulation intensity	
	(1)	(2)	(3)	(4)
Prefecture suitability: mean	0.223***		0.432***	
	(0.060)		(0.080)	
Prefecture suitability: top quartile		0.204***		0.342***
		(0.051)		(0.067)
N	286	286	286	286
R^2	0.28	0.28	0.38	0.37

Table 4. IV first stage: predicting regulation status and intensity

Notes: The regressions follow the specification of equation 3. The first two columns show the instrumental variable predictability of the TCZ status, and the second two columns show the results for the regulation intensity. Standard errors (in parentheses) are clustered at the prefecture level.

* p<0.1, ** p<0.05, *** p<0.01.

The suitability index captures a location's likelihood of hosting coal-fired power plants rather than the actual presence of plants, which further mitigates potential confounding

[20] The geographic covariates and prefecture characteristics are computed using the same remote sensing data used for the suitability computation. The only exception is the measure of urban area gas supply coverage, which is obtained from the 1999 China Urban Yearbook as it provides better accuracy at the prefecture level.

factors such as the local leader's motivation to create more local jobs by hosting a power plant. The channel through which the suitability index works as an instrumental variable is effectively the set of weights and rescaling functions from the geo-engineering formula (i.e., w_k and f_k, rather than k). The assumption that this nonlinear transformation in the computation of the suitability index is orthogonal to treatment underpins the validity of the instrumental variable. By using the weights and scaling functions from the vastly different Iranian context and computing the suitability index at the most granular level allowed by the available data, I have made every effort to ensure that this assumption holds.

Table 5 compares the balance of the pretreatment growth by prefecture TCZ status and mean suitability. The estimation results in panel A show, perhaps surprisingly, that the manufacturing employment and high-skilled populations in the regulated prefectures grew slower relative to their non-regulated counterparts prior to the policy implementation. These pretreatment diverging trends indicate that this specification will bias the estimate of interest downward. In comparison, the prefecture level average power plant suitability is not correlated with the pretreatment growth trends in city size, high-skilled worker population, total employment, and manufacturing employment. These results further substantiate that this instrumental variable can help reduce the bias.

Dependent var:	Δ Industrial employment				Δ Population		
Sub-category:	Manu.	Heavy coal	Excl. elec.	Total	High school	College	Total
Sample period:	82-90	82-90	96-97	96-97	82-90	82-00	90-00
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: by regulatory status							
TCZ	-0.092**	-0.164*	-0.132**	-0.056*	-0.002	-0.101***	-0.040
	(0.044)	(0.084)	(0.066)	(0.031)	(0.058)	(0.027)	(0.025)
R^2	0.59	0.10	0.08	0.09	0.27	0.33	0.15
Panel B: by instrumental variable							
Suitability	-0.008	-0.020	0.045	0.014	-0.005	-0.005	0.004
	(0.048)	(0.069)	(0.057)	(0.017)	(0.048)	(0.032)	(0.013)
R^2	0.58	0.10	0.07	0.06	0.27	0.30	0.13
N	286	286	286	286	286	286	286

Table 5. (Im)balance in pretreatment outcomes: TCZ status versus suitability

Notes: This table presents the balance of the pretreatment growth trends by regulatory status (Two Control Zone) in panel A versus the instrumental variable (power plant suitability) in panel B. Prefectures along the distribution of suitability measures are more comparable than they are in terms of regulatory status, where the TCZ prefectures show pre-existing declining trends in employment (manufacturing, high coal-using manufacturing, all industrial firms excluding electricity producers, and all industrial firms) and high-skilled populations. The regressions control for the same set of covariates as the baseline regression. The pretreatment years are inconsistent across columns due to data limitations. Standard errors (in parentheses) are clustered at the prefecture level.

* $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Despite the above evidence, another threat to the validity of the instrumental variable is that firms in other heavy industries (e.g., smelting) may be attracted to certain locational characteristics that are highly suitable for hosting thermal power plants prior to the TCZ policy. An example would be the close proximity to existing coal sources. Acknowledging this challenge, I include the pretreatment (1996) share of heavy industry employment in the baseline specification to control for this variation across prefectures. In fact, excluding this covariate has little impact on the estimated results (table A2 panel D). This indirect evidence and the non-statistically significant point estimate in column 2 of Table 5 panel B jointly suggest that the bias potentially brought about by the pretreatment heavy industrial composition may be minor.

The later robustness checks of the identification validity include the usage of thermal inversion as an alternative instrumental variable, which gives similar estimates to the baseline findings. Consistent patterns from two different instrumental variables stemming from varying sources of variation give support to the robustness of the findings in this paper. However, the thermal inversion measure is weaker than the suitability index in its statistical power as the IV for the context of this paper. A more in-depth discussion is provided in the Appendix Section A1.

4 The local labor market outcomes and adjustments

4.1 Aggregate effects on the local labor market

4.1.1 Baseline results

The first set of results examined in this paper is the TCZ-induced local labor market outcomes between 2000 and 2010 based on the population census data. Although the aggregated population census dataset has limited variables, it provides by far the most representative and highest quality data for China. Table 6 first presents both the OLS (panel A) and 2SLS estimates (panel B for the treatment dummy and C for the treatment intensity) of the effect of the regulation on the prefecture employment growth trends. The results in columns 2 and 6 show that the level of employment growth and the growth in the share of employment in the secondary sector are relatively slower in the regulated prefectures relative to the non-regulated prefectures.

Between 2000 and 2010, China's industrial sector grew rapidly with the level of employment in an average prefecture increasing by 45%. The baseline estimate in column 2 suggests that the TCZ status implies the employment growth in this sector is 50% slower at the prefecture level during this decade. The treatment intensity measure implies that the local SO_2 levels are 10% higher in 1998, and hence the more stringent regulation intensity leads to a 2.5% relative decline in employment growth. The baseline estimates have the same sign but a much smaller magnitude than the findings based on the U.S. Clean Air Act (e.g., Greenstone, 2002; Walker, 2011).

The employment reduction effect is only present in the secondary sector (resource extraction, manufacturing, and utilities), and not in the primary (agriculture and fishery) or tertiary (service) sectors. This indicates that the negative effect on the regulated sectors is a direct result of the TCZ policy. Although China was one of the fastest growing manufacturing countries during the sample period, the secondary industries accounted for, on average, 22% of the national employment in 2010 (16% in 2000), while the primary and tertiary sectors accounted for 51% and 26%, respectively. Partly due to this employment composition, the TCZ policy shows no impact on the prefecture total employment (column 4).

Dependent variable:	Δ ln(employment)				Δ share of employment		
Sector:	Primary (1)	Secondary (2)	Tertiary (3)	Total (4)	Primary (5)	Secondary (6)	Tertiary (7)
Panel A: Treatment dummy OLS							
TCZ	-0.045	-0.121***	0.013	0.021	-0.043***	-0.250***	-0.014
	(0.028)	(0.040)	(0.020)	(0.015)	(0.016)	(0.082)	(0.027)
R^2	0.43	0.50	0.23	0.27	0.54	0.46	0.32
Panel B: Treatment dummy 2SLS							
TCZ	-0.069	-0.492***	0.072	0.037	-0.071	-1.031***	-0.005
	(0.101)	(0.162)	(0.085)	(0.066)	(0.064)	(0.353)	(0.117)
First-stage F stat	13.62	13.62	13.62	13.62	13.62	13.62	13.62
Panel C: Treatment intensity 2SLS							
Regulation intensity	-0.036	-0.254***	0.037	0.019	-0.037	-0.531***	-0.003
	(0.052)	(0.084)	(0.042)	(0.033)	(0.032)	(0.169)	(0.060)
First-stage F stat	29.51	29.51	29.51	29.51	29.51	29.51	29.51
N	286	286	286	286	286	286	286
Dependent variable mean	-0.25	0.46	0.40	0.05	-0.24	0.64	0.44

Table 6. Effects on employment growth, 2000-2010

Notes: Panels A through C present the OLS and 2SLS estimates of the effect of the TCZ policy on local employment growth, where both the treatment dummy and intensity 2SLS estimates are presented. Standard errors (in parentheses) are clustered at the prefecture level.

* $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Next, Table 7 explores whether the adverse TCZ impact translates into any changes in city size as the *hukou* reform made voluntary internal migration possible during this period. Columns 1 and 2 split the population into workers with below college education and workers with a college degree and above, as the *hukou* reform lowered the migration cost more substantially for highly educated workers (Au and Henderson, 2006; Tombe and Zhu, 2019). The estimation results show that the TCZ prefectures experienced a faster decline in the increase in highly educated workers relative to the non-regulated prefectures. Although the increase in less educated workers shares the same negative sign, the statistical power is limited in comparison. The diverging pattern of skill heterogeneity has potential inequality implications. A more in-depth analysis of this issue is provided in Section 4.3 using worker-level data. Overall, as the share of highly educated workers is low in China (approximately 3% and 8% in the 2000 and 2010 censuses, respectively), the growth in total city size remains similar between the TCZ and non-TCZ prefectures (column 3).

4.1.2 Robustness

As shown in panel A of Tables 6 and 7, the OLS estimates are biased downward. Consistent with the pattern observed in the balance tests in Table 5, the group of prefectures designated as TCZ was already on a downward trending growth path prior to the implementation of the TCZ policy. Panel C follows the 2SLS specification of panel B but uses

Dependent variable:	Δ ln(population)			Δ share of population	
Education level:	Below college (1)	College & above (2)	Total (3)	Below college (4)	College & above (5)
Panel A: Treatment dummy OLS					
TCZ	-0.004	-0.041*	-0.004	0.001	-0.099*
	(0.012)	(0.024)	(0.011)	(0.006)	(0.059)
R^2	0.27	0.31	0.44	0.26	0.37
Panel B: Treatment dummy 2SLS					
TCZ	-0.067	-0.447***	-0.023	-0.043*	-1.196***
	(0.060)	(0.147)	(0.054)	(0.022)	(0.355)
First-stage F stat	13.62	13.62	13.62	13.62	13.62
Panel C: Treatment intensity 2SLS					
Regulation intensity	-0.034	-0.230***	-0.012	-0.022**	-0.616***
	(0.031)	(0.070)	(0.028)	(0.010)	(0.161)
First-stage F stat	29.51	29.51	29.51	29.51	29.51
N	286	286	286	286	286
Dependent variable mean	0.01	0.99	0.05	-0.04	1.61

Table 7. Effects on city growth, 2000-2010

Notes: Panels A through C present the OLS and 2SLS estimates of the effect of the TCZ policy on local population growth, in which both the treatment dummy and intensity 2SLS estimates are presented. Standard errors (in parentheses) are clustered at the prefecture level.
* p<0.1, ** p<0.05, *** p<0.01.

the interaction between the TCZ dummy and (log of) annual SO_2 density as a proxy for regulation intensity, following Shi and Xu (2018). The regulation intensity estimates follow the same pattern with the magnitudes being about half of the baseline.

To further demonstrate the validity of the instrumental variable and the baseline estimates, Section A1 in the Appendix includes a series of robustness and sensitivity tests. Table A1 presents supporting evidence on the validity of the instrumental variable with several variations: (i) excluding the linear measure of the individual suitability factors in the specification, (ii) replacing the current instrumental variable with a variable computed using a limited and less economic set of factors (highlighted in Table 1), (iii) replacing the current instrumental variable with the prefecture top quartile of suitability, and (iv) using thermal inversion as an alternative instrumental variable.

These tests give support to the robustness of the suitability index as a valid instrumental variable for determining the spatial distribution of SO_2 pollution. The point estimates from the thermal inversion results in panel E are of the same signs as the baseline but with weak statistical significance. First, this consistency in the signs gives further support to the baseline findings because the two instrumental variables make use of unrelated variations. Second, the thermal inversion measure does not work as well in this research setup as in its previous applications, as suggested by the small first-stage F-stat. The TCZ treatment variation is also spatial, and thermal inversion tends to work better with temporal variations in air pollution.

Table A2 in the Appendix also provides a comprehensive set of sensitivity tests. The main results are robust to: (i) excluding prefectures in the bottom 10% of the 1998 SO_2

distribution, (ii) controlling for the initial level of the outcome variable as an additional covariate, (iii) excluding the pretreatment share of employment in heavy coal-using industries as a covariate, (iv) controlling for prefectures that provide coal-fired winter heating, i.e., the Huai River policy dummy as in Ebenstein et al. (2017), (v) using the TCZ dummy as the treatment variable, (vi) replacing the treatment intensity variable with 1998 SO_2 per capita, and (vii) using the 1998 $PM_{2.5}$ level as the treatment intensity variable. In summary, the baseline results are robust in their signs, magnitude, and statistical significance.

4.2 Local adjustments by sector and time

This section investigates the potential heterogeneity and sectoral adjustments of the TCZ-induced adverse employment effects by coal-usage intensity, ownership, and time period. The analysis in this section aggregates rich prefecture-level variables from the above-scale firm-level survey data, which cover all state-owned industrial firms and all non-state-owned industrial firms with more than RMB5 million in sales. Table 8 presents the estimation results following the baseline 2SLS specification using this dataset.[21]

The point estimate in column 1 is based on the full survey sample of all industrial firms. The results show the expected signs but are not statistically significant, and they are smaller in magnitude compared with the estimates in column 2 of Table 6 using the population census data. This discrepancy highlights the importance of using a representative sample that includes small firms. The following discussion interprets this set of results with this in mind.

Column 2 uses all firms that are light coal users, and column 3 keeps only the state-owned light coal users. Columns 4 through 6 use heavy coal-using firms as the sample.[22] The point estimate of light coal users is positive but only slightly statistically significant, again supporting that the identified adverse impact is driven by the TCZ policy. The point estimates in columns 4 through 6 of the various heavy coal-using firm samples show that they drive the baseline adverse effect. The estimated TCZ effect is large in magnitude and statistically significant for all heavy coal-using industrial firms, all heavy coal users excluding electricity production firms, and all state-owned heavy coal users.

Panels B and C divide the analysis into two sub-periods. The results show that the TCZ effect is concentrated in the first five years of its implementation. The year 2003 is used as the cutoff year for the following considerations. First, China undertook another round of policy revisions in 2003 to broaden the set of polluting activities under regulation. Second, the large-scale privatization of the state sector stabilized in 2003.[23] Lastly, 2003 marks the point when China's export share substantially increased after joining the WTO.[24] As Figure 1 shows, China's national SO_2 emissions rise sharply again in 2003 after stabilizing in 1998.

[21] It is worth noting that when only manufacturing firms are used as the estimation sample instead of all industrial firms, the patterns remain the same.

[22] Please refer to the definition of heavy coal users in 2.4.

[23] The identified TCZ effects are not driven by the SOE reform because the adverse employment impact is only present for state-owned heavy coal users and not the light coal users (column 6 vs 3). A more detailed discussion is provided in Appendix Section A2.

[24] Using 2001, the year that China officially joined the WTO, gives similar results. The relevant policies officially began in the end of 2001.

Dependent variable:	Δ ln(employment):					
Coal-usage intensity	All	Light		Heavy		
Sub-category:	-	-	state	-	excl. elec.	state
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: 1999-2007						
TCZ	-0.145	0.399*	0.661	-0.723***	-1.307***	-1.283**
	(0.191)	(0.241)	(0.437)	(0.251)	(0.402)	(0.613)
Dependent variable mean	0.19	0.22	-1.51	-0.05	-0.06	-1.12
Panel B: 1999-2003						
TCZ	-0.197*	0.265	0.120	-0.857***	-1.094***	-1.161***
	(0.116)	(0.182)	(0.307)	(0.237)	(0.321)	(0.394)
Dependent variable mean	-0.05	-0.03	-0.76	-0.16	-0.21	-0.61
Panel C: 2003-2007						
TCZ	0.052	0.134	0.541	0.134	-0.212	-0.122
	(0.113)	(0.121)	(0.370)	(0.145)	(0.198)	(0.464)
Dependent variable mean	0.24	0.25	-0.74	0.11	0.16	-0.51
N	286	286	286	286	286	286
First-stage F stat	30.45	30.45	30.45	30.45	30.45	30.45

Table 8. Heterogeneity by coal-usage intensity and time period: 2SLS estimates

Notes: This table presents the effect of TCZ on local employment growth by coal-usage intensity and ownership type (across columns), and by sub-periods (panels A-C). *State* refers to state-owned firms and *excl. elec.* is short for excluding electricity producers. The regressions follow the baseline specification. Standard errors (in parentheses) are clustered at the prefecture level.

* $p<0.1$, ** $p<0.05$, *** $p<0.01$.

This emission trend corresponds to the observed estimation patterns.

State-owned firms by two periods:	1999-2003		2003-2007	
Coal-usage intensity:	heavy	light	heavy	light
	(1)	(2)	(3)	(4)
Panel A: Δ ln(output)				
TCZ	-1.679*	0.650	0.783	1.094*
	(0.884)	(0.672)	(1.532)	(0.598)
Dependent variable mean	-0.02	-0.07	0.52	0.09
Panel B: Δ ln(capital)				
TCZ	-2.143**	0.478	1.162	0.856
	(0.987)	(0.577)	(1.704)	(0.535)
Dependent variable mean	-0.12	-0.30	-0.06	-0.29
Panel C: Δ ln(wage bill)				
TCZ	-2.102**	0.437	0.285	0.955*
	(0.856)	(0.555)	(1.107)	(0.510)
Dependent variable mean	-0.08	-0.24	0.15	-0.13
Panel D: Δ ln(number of firms)				
TCZ	-0.582**	0.211	0.044	0.685**
	(0.256)	(0.205)	(0.274)	(0.274)
Dependent variable mean	-0.51	-0.74	-0.48	-0.83
Panel E: Δ ln(wage per worker)				
TCZ	-0.285	0.144	0.620	0.177
	(0.192)	(0.138)	(0.470)	(0.217)
Dependent variable mean	0.45	0.40	0.70	0.68
N	286	286	286	286
First-stage F stat	13.62	13.62	13.62	13.62

Table 9. Regulatory mechanisms of the TCZ policy

Notes: This table explores the regulatory mechanism by examining the growth in prefecture output, capital, total wages, number of firms, and the average wage in state-owned firms. The regressions follow the baseline instrumental variable specification. Standard errors (in parentheses) are clustered at the prefecture level.

* p<0.1, ** p<0.05, *** p<0.01.

Next, Table 9 explores other local economic outcomes to further investigate the channel through which the TCZ policy imposes its impact. As only state-owned firms are fully covered by the industrial survey, this analysis uses the survey as the sample. Panels A through D examine the dimensions of total local output, capital, wage bills, and number of firms aggregated to the prefecture level. The results present a consistent pattern of adverse regulatory impacts on the targeted sector (heavy coal users) before 2003, and a relatively smaller degree of reallocation to the non-targeted sector (light coal users) after 2003. Panel E shows the results for prefecture growth in the average wage across sectors to shed light on the changes in worker productivity, under the assumption of a competitive market in which workers are paid for their marginal productivity. In terms of the signs, a similar pattern to the outcomes of the prefecture aggregates in the previous panels emerges, but the point estimates are not statistically significant.

The patterns shown in Table 9 suggest that the adverse regulatory impact and the sectoral adjustments are mainly driven by the extensive instead of intensive margin. Specifically, the TCZ regulation led to a faster decline in the growth of firms in the regulated sector in the first five years. The growth in local employment, output, capital, and total wage bills declines as a result. There is a lack of evidence for a TCZ-induced decline in local worker productivity as measured by per-worker wages. However, this pattern does not suggest that the TCZ policy has no impact on local firm productivity. Over time and particularly following China's admission to the WTO, reallocation of firm growth appears in the light coal-using industries in the TCZ prefectures, which suggests local production inputs were adjusted from the regulated to non-regulated sectors.

4.3 Skill heterogeneity and spatial adjustments

In this section, I use unique random samples of individual labor force participants from the 2000 and 2010 population censuses[25] to explore the role of skill heterogeneity in the context of TCZ regulation and the *hukou* reform. The data are highly representative as they comprise a 1% random sample from the 2000 and 2010 population censuses of more than one billion individuals, respectively.

4.3.1 Skill-biased TCZ effect

First, I explore the adverse TCZ effect on local employment adjustments by skill levels. Aggregating individual data to the prefecture level, I construct a panel of the number of employed workers[26] by industry and by skill-level in 2000 and 2010. The baseline specification is then applied to test the TCZ impact on the growth of local employment by the two skill levels (college educated versus without a college degree) in heavy versus light coal-using industries.

Table 10 presents the 2SLS estimation results using the TCZ dummy in panel A and TCZ regulation intensity in panel B. The first four columns use the changes in log of employed workers, and the last four columns examines changes in each of the skill-industry categories as a share of total employment. All the estimated coefficients have signs consistent with the patterns found in Tables 6 and 7. The TCZ policy has imposed adverse shocks to the employment growth in heavy coal-using (regulated) industries, and some of the employment reduction has been adjusted to the light coal-using (non-regulated) industries. However, most of the coefficients are not statistically significant. This may be the limitation of using random subsets of the census data. As a result, the sample of prefectures is also smaller than that in Table 6, when the prefecture-level data aggregated from the full sample of census counties[27] was used.

[25] Details in Section 2.4.

[26] Employed workers are defined as meeting either one of the following conditions: 1) their hours of work in the previous week is greater than zero, or 2) their hours of work in the previous week is zero for reasons such as being on sick leave, holiday, or job-related training.

[27] The advantage of using random sub-samples here is to obtain the skill-industry breakdown.

Dependent variable:	Δ ln(employment)				Δ share of employment			
Coal-usage intensity:	Heavy		Light		Heavy		Light	
Skill levels:	College	Non-col	College	Non-col	College	Non-col	College	Non-col
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Treatment dummy 2SLS								
TCZ	-0.261	-0.406	0.308	0.301*	-0.045	-0.799*	0.031	0.033
	(0.380)	(0.398)	(0.203)	(0.176)	(0.371)	(0.427)	(0.118)	(0.027)
First-stage F stat	14.27	14.27	14.27	14.27	14.27	14.27	14.27	14.27
Panel B: Treatment intensity 2SLS								
TCZ regulation intensity	-0.137	-0.213	0.162	0.158*	-0.024	-0.419**	0.016	0.018
	(0.191)	(0.196)	(0.106)	(0.089)	(0.193)	(0.204)	(0.063)	(0.014)
Dependent variable mean	0.50	0.63	0.72	0.65	0.09	0.17	0.10	-0.00
N	280	280	280	280	280	280	280	280
First-stage F stat	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.65

Table 10. Local employment adjustments by industry and skill

Notes: This table explores potential skill heterogeneity in employment adjustments across industry by examining the changes in the employed workers by skill and coal-usage intensity. The regressions follow the baseline instrumental variable specification. "College" refers to employed workers with a college degree or above, and "Non-college" refers to employed workers with less than college education. Standard errors (in parentheses) are clustered at the prefecture level.

* p<0.1, ** p<0.05, *** p<0.01.

Nonetheless, the difference in the coefficient magnitudes between college educated and less than college educated workers is striking. Particularly in columns 5 and 6, the adverse TCZ effect is estimated to be substantially larger for workers without a college degree than those with a college education. In comparison, this striking difference in the magnitudes of coefficients is not present for the light coal-using (non-regulated) industries. The findings of Table 10 suggest that the adverse TCZ shock is biased against low-skilled workers.

4.3.2 Skill-biased spatial adjustments

In this section, I make use of the individual level data from the 2000 census to double check the skill heterogeneity found in the previous section, and examine to what extent are workers able to relocate across space in response to the negative TCZ shock. The analysis is based on a probit model in which an individual's binary outcome is predicted by the prefecture-level TCZ regulatory intensity conditional on a rich set of individual characteristics[28] and the baseline prefecture covariates discussed in 3.2. The probit and probit instrumental variable estimates following the baseline methodology are presented in Table 11.

Panel A of Table 11 first investigates the employment status of the labor force participants (columns 1 and 2) and the probability that an unemployed job seeker had been made redundant(columns 3 and 4). Probit and probit instrumental variable give similar statistically insignificant estimation results for the TCZ regulation intensity. However, the signing of the probit IV estimates suggests that the employment prospects for workers in the TCZ prefectures are worse than those in the non-regulated prefectures. In comparison, the het-

[28] The individual characteristics include age, age squared, dummy variables of sex, urban *hukou*, minority, college education, and categorical variables for the relationship to the household head and *hukou* location.

Estimators:	Probit	Probit IV	Probit	Probit IV
	(1)	(2)	(3)	(4)
Panel A: job prospects of the labor force participants				
Dependent variables:	employment status		made redundant	
Sample:	all		job seekers	
TCZ regulation intensity	-0.023	-0.024	-0.009	0.085
	(0.021)	(0.050)	(0.033)	(0.100)
College educated and above	0.615***	0.615***	0.009	0.007
	(0.018)	(0.018)	(0.028)	(0.028)
N	637329	637329	36366	36366
Panel B: likelihood of labor force participants migrating				
Dependent variables:	post-1995 migration		post-TCZ migration	
Sample:	migrants prior to TCZ		migrants post 1995	
TCZ regulation intensity	0.015	0.047	-0.009	-0.086*
	(0.021)	(0.052)	(0.021)	(0.045)
College educated and above	0.080***	0.079***	0.089***	0.090***
	(0.017)	(0.017)	(0.017)	(0.017)
Heavy coal-using industries	-0.127***	-0.128***	0.142***	0.140***
	(0.039)	(0.039)	(0.041)	(0.041)
College educated in heavy coal	0.054	0.054	-0.321***	-0.317***
	(0.072)	(0.072)	(0.071)	(0.071)
N	157089	157089	75627	75627

Table 11. Migration mechanisms of the *Hukou* reform

Notes: The regressions take the form of the probit model in which an individual's binary outcome is predicted by the prefecture-level TCZ regulatory intensity conditional on a rich set of individual characteristics and the baseline covariates. The individual characteristics include age, age squared, sex, urban *hukou* status, minority, college education, migration status, relationship to the household head, and the *hukou* associated location. The regressions in panel B also control for the service, agricultural, and heavy coal-using industries dummies, and the interaction between college education and heavy coal. The categories of migration motivations are included in panel B. Standard errors (in parentheses) are clustered at the prefecture level.

* p<0.1, ** p<0.05, *** p<0.01.

erogeneity by education level is large and strongly statistically significant.[29] Throughout the TCZ implementation period, workers with a college education or above are much more likely to remain employed and their reason for being unemployed is less likely to be having been made redundant.

Here, the estimated coefficients also need to be interpreted with caution because China's unemployment rate during this time was largely under-reported, as shown in the literature[30] (e.g., Giles et al., 2005; Knight and Xue, 2006). Lastly, the industry in which the workers were employed was only recorded for workers currently in employment, which makes it impossible to explore the heterogeneity by coal-usage intensity. Despite the data limitations, this panel and the findings in Table 10 jointly suggest that skill heterogeneity played an important role in determining employment as a consequence of the adverse local labor market shock brought about by the TCZ policy.

Next, in panel B, I explore the skill heterogeneity along the channel of internal migration. The option for workers to freely move between local labor markets in response to an adverse shock in their home location would imply they face a smaller welfare loss than workers facing high migration costs. The slight difference in timing between the *hukou* reform (in 1995) and the TCZ policy (in 1998) together with the availability of data on the migration years make the following analysis possible.

In columns 1 and 2 of panel B, the outcome variable of migration after 1995 (*hukou* reform) is regressed on the sample of all migrants prior to the 1998 TCZ regulation (the *hukou*-induced migration). Columns 3 and 4 then use the sample of all post *hukou* reform migrants to test the probability of moving after the TCZ regulation (the TCZ-induced migration). The analysis rests on the assumptions that between 1995 and 1998 migration was mostly driven by the migration cost reduction brought about by the *hukou* reform (i.e., *hukou*-induced) and that post-TCZ migrants were more motivated by the TCZ regulation (TCZ-induced). Comparing these two specifications would shed light on the underlying mechanism of the greater outflow of human capital in the TCZ prefectures estimated in Table 7.

Comparing the column estimates, four intriguing patterns emerge. First, the TCZ-driven migrants (column 4) are less attracted to the more regulated prefectures,[31] whereas the *hukou*-driven migrants (column 2) are indifferent to the difference between the TCZ and non-TCZ prefectures prior to the TCZ regulation. This suggests the TCZ policy made the regulated prefectures less attractive local labor markets.

Second, workers with a college education are generally more likely to become migrants relative to those without a college education (the omitted group). For one, this is consistent with the lower migration costs faced by college-educated workers, as the reform allowed them to legally relocate their *hukou* to the migrating destination. However, the results in panel A suggest that educated workers are generally more competitive on the job market, which implies that adjustments across space may be less risky for them.

[29]The heterogeneity of coal-usage intensity cannot be explored here because a worker's occupation industry is only available if he or she is employed.

[30]For example, workers made redundant from state-owned firms were unofficially categorized as "left the post", and not officially registered as "unemployment" in the population census.

[31]Note that here the location is the migrating destination, not the origin. The origin of migration is only recorded at the province level.

The third finding is that workers in the heavy coal-using industries are less likely to be *hukou*-induced migrants but more likely to be TCZ-driven migrants. This is consistent with the findings in Table 8 showing that the heavy coal-using industries are more affected by the TCZ policy. This finding is inferred from the coefficients of the heavy coal-using industries switching from negative to positive across the two specifications, in which the omitted group is light coal-using industries.

The fourth intriguing observation comes from the coefficients of the college-educated workers in heavy coal-using industries. The estimates turn from no effect to strongly negative from the *hukou*-induced to the TCZ-induced specification. Combined with the estimates on college education and heavy coal-using industries, these results suggest that college-educated workers in heavy coal-using industries are less likely to be migrants. Considering this finding alongside the pattern in Table 10, the employment prospects of highly educated workers in the more regulated sectors were not as adversely affected as their less educated counterparts.

The findings in this section stress the importance of examining the TCZ-induced effects along the distribution of skills. Highly educated workers are more likely to be employed, face lower costs in out-migration, and are overall less likely to be adversely affected by the TCZ-induced employment shock. As the TCZ-induced out-migration is consistent with the previous prefecture-level findings, the results suggest that the less educated workers face a larger welfare loss, exacerbated by the fact that they are also less able to adjust to different local labor markets.

5 Conclusion

In the recent decades, China has experienced rapid economic growth while its air quality issues have remained significant. As per capita income rises, more people may demand cleaner air (Zheng and Kahn, 2013). As such, the government may be under greater pressure to tighten environmental regulations, which is a common pattern in many emerging economies. Therefore, it is paramount for policy makers to accurately assess the costs of environmental protection policies and the economic inequalities they may create.

The findings of this paper show that China's TCZ environmental regulation caused local manufacturing employment in heavily polluted prefectures to decline, with the impact concentrated in firms in polluting industries. Over time, some unemployment reallocated within the local labor market from regulated industries to non-polluting industries. However, the overall net effect is largely negative over a 10-year period.

"Produce and pollute first, clean up later" is a frequent choice made by policy makers, as low-efficiency fuels appear to provide cheaper energy and to immediately boost economic output. However, the subsequent cost of cleaning up and the loss of human capital can be substantial. Notably, these costs are in addition to the well-documented health costs of heavy pollution.

The findings of this paper also shed light on the unequal impacts of environmental regulations by skill level. The limited ability of less educated workers to spatially shift to other local labor markets may have further exacerbated the effects of the TCZ-induced adverse employment shock. The asymmetric effects in relation to skill are an important welfare consideration, particularly in emerging economies in which the migration costs differ substantially for different cohorts of workers.

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Appendix A1 Robustness and sensitivity checks

In Tables A1 and A2, I present two sets of tests to comprehensively check the robustness of the identification strategy and results.

Table A1 checks the validity of the instrumental variable. With the key outcome variables listed across the columns, panel A re-prints the IV baseline estimates for comparison. Panel B removes the set of covariates that are themselves factors in the suitability construction. Results only deviate slightly in the magnitude of point estimates. Their similarity suggests that this instrumental variable works through the non-linear transformation of the geo-spatial characteristics assigned by engineers, rather than the values of these factors themselves.

Panel C uses an alternative instrumental variable where the suitability measure is constructed with a limited subset of factors, printed in bold in Table 2. This alternative IV is hence based on factors that are relatively less likely to have economic impacts themselves. For example, distance to small rivers is kept while that to large rivers is dropped. Arriving at close estimates in this panel shows that the most effective parts of the baseline IV are contributed by non-economic factors.

Panel D addresses the concern over whether the prefecture level mean of suitability measure is a sensible choice. Results presented here use the top quartile of suitability measure at the prefecture level as IV. Using the top quartile rather than the mean shows a slightly better first-stage F-stat, while the point estimates are very similar.

Lastly in Panel E, I check the results using a thermal inversion measure, which is the most popular IV for air pollution in the literature (e.g., Arceo et al., 2016; Jans et al., 2014; Sager, 2019; Fu et al., 2017). A warmer air layer at higher altitude traps pollutants close to the ground during thermal inversion episodes, while under normal temperature-altitude conditions pollutants disburse. The exact thermal inversion measure in use is the natural log of the number of days in 1998 that a prefecture experiences this phenomena. The estimated results follow the same signs as the baseline, but are not statistically significant and the first-stage F-statistic is very small. This panel suggest that the thermal inversion measure is not as powerful as an instrumental variable for the spatial variation of air pollution in the context of this paper. Findings in the existing literature have shown that it works well when both the spatial and temporal variations are present.

Another concern with computing thermal inversion in the case of China is with regards to potential inconsistency in altitude levels from which the thermal inversion episodes are counted. Due to its vast land area and variation in geographic characteristics, altitude of Chinese prefectures diverge greatly from east to west. In the current practice of deriving thermal inversion for China based on NASA satellite data, researchers have used temperature measures at the 110 and 320-meter levels for the main computation. As half of Chinese prefectures are located at more than 320 meters above sea level, these locations have missing values in temperature for these two key layers. Their thermal inversion episodes are then filled in by the next available two layers with non-missing temperature, which are at relatively arbitrary levels. A more precise method of inferring thermal inversion in China is needed, but beyond the scope of this paper.

The following table, Table A2, explore the sensitivity of estimates across various alternative specifications and treatment variables, with baseline results printed in panel A for comparison. Panel B excludes 25% of the sample that are in the bottom quartile of 1998

	college edu 00-10 (1)	secondary emp 00-10 (2)	coal emp 99-07 (3)	coal emp state 99-07 (4)
Panel A: IV baseline				
TCZ	-0.447***	-0.492***	-0.639*	-2.248**
	(0.147)	(0.162)	(0.387)	(1.004)
N	286	286	286	286
First-stage F stat	13.62	13.62	13.62	13.62
Panel B: excluding IV components as covariates				
TCZ	-0.523***	-0.392***	-0.723***	-1.283**
	(0.125)	(0.152)	(0.251)	(0.613)
N	286	286	286	286
First-stage F stat	30.45	30.45	30.45	30.45
Panel C: IV constructed with limited geographic factors				
TCZ	-0.443***	-0.485***	-0.608	-2.237**
	(0.142)	(0.159)	(0.370)	(0.993)
N	286	286	286	286
First-stage F stat	14.51	14.51	14.51	14.51
Panel D: using top quartile suitability as IV				
TCZ	-0.479***	-0.521***	-0.545	-1.803**
	(0.146)	(0.161)	(0.336)	(0.858)
N	286	286	286	286
First-stage F stat	16.01	16.01	16.01	16.01
Panel E: using thermal inversion as IV				
TCZ	-0.300	-0.140	-0.528	-0.048
	(0.258)	(0.303)	(0.558)	(1.620)
N	286	286	286	286
First-stage F stat	3.86	3.86	3.86	3.86

Table A1. IV validity checks

* p<0.1, ** p<0.05, *** p<0.01. Standard errors (in parentheses) are clustered at the prefecture level.

SO_2 pollution level. This address the concern that under-developed prefectures with good air quality may not be valid control group. Using only the top 75% of the distribution of SO_2 density, the sample arrives at similar point estimates.

Panel C includes the pre-TCZ level of the outcome variable as covariate. While including the initial level deals with concern over regression toward the mean, it does not change the conclusion. Panel D answers the question of whether or not initial industrial composition affect baseline results. Having excluded the 1996 share of employment in heavy coal-usage industries, results are consistent while point estimates vary slightly. Panel E includes a heating dummy following the research design of Huai River Policy used in Chen et al. (2013). As Panel E shows similar results to the baseline, there is little concern over potential bias from systematic sources of energy use such as heating.

In Panel F, the per capita SO_2 density levels in 1998 is used as an alternative treatment variable to address the concern that local air pollution and population might be positively correlated. As discussed in the main text, the change in local population has been very limited throughout this period even with relaxation of the *hukou* system. Therefore, the results remain unaffected by scaling the pollution levels by population. The difference in magnitudes of the point estimates are mainly driven by using SO_2 density instead of the TCZ dummy. Lastly, using (the log of) 1998 $PM_{2.5}$ levels in panel G also gives similar estimates to the baseline. The 1998 $PM_{2.5}$ measure is derived from satellite data with finer spatial resolution than the SO_2 density measure, and the patterns remain consistent.

	college edu 00-10 (1)	secondary emp 00-10 (2)	coal emp 99-07 (3)	coal emp state 99-07 (4)
Panel A: IV baseline				
TCZ	-0.447***	-0.492***	-0.639*	-2.248**
	(0.147)	(0.162)	(0.387)	(1.004)
N	286	286	286	286
First-stage F stat	13.62	13.62	13.62	13.62
Panel B: excluding bottom 10% in 1998 SO_2				
TCZ	-0.634***	-0.372**	-0.853*	-1.856**
	(0.236)	(0.168)	(0.469)	(0.865)
N	257	257	257	257
First-stage F stat	8.61	8.61	8.61	8.61
Panel C: conditional on initial level				
TCZ	-0.406*	-0.469***	-1.200*	-2.225**
	(0.209)	(0.163)	(0.637)	(0.983)
N	286	286	286	286
First-stage F stat	6.82	13.49	7.90	13.31
Panel D: exclude share of emp in heavy coal-users in 1996				
TCZ	-0.447***	-0.447***	-0.447***	-0.447***
	(0.141)	(0.141)	(0.141)	(0.141)
N	286	286	286	286
First-stage F stat	15.42	15.42	15.42	15.42
Panel E: controlling for Huai River policy dummy				
TCZ	-0.416***	-0.454***	-0.603*	-2.032**
	(0.134)	(0.143)	(0.352)	(0.879)
N	286	286	286	286
First-stage F stat	16.11	16.11	16.11	16.11
Panel F: treatment variable is per capita SO_2 levels				
ln(SO_2 density/person in 1998)	-0.118***	-0.130***	-0.168*	-0.592**
	(0.028)	(0.042)	(0.091)	(0.245)
N	286	286	286	286
First-stage F stat	112.01	112.01	112.01	112.01
Panel G: treatment variable is 1998 $PM_{2.5}$				
ln($PM_{2.5}$ in 1998)	-0.379***	-0.418***	-0.542*	-1.907**
	(0.105)	(0.142)	(0.286)	(0.820)
N	286	286	286	286
First-stage F stat	60.90	60.90	60.90	60.90

Table A2. Sensitivity tests

Appendix A2 Heterogeneity by firm ownership

This section further discusses further the pattern of stronger regulatory effects found for heavy coal-using SOE's in table 8.

A2.1 Reform of the state owned enterprises

As China begins its market reform in the late 1970s, reform over SOE's also has began. The timing of the SOE reform briefly overlaps with the TCZ policy. Background information on the state-owned sector is hence important for understanding potential heterogeneous effects of by ownership types.

The reform of SOE's began soon after China's market reform, but it was not until the mid-1990's that serious reinforcement actions had taken place. Measures such as financial support, layoffs, buy-out and action against corporate insolvency were implemented to help SOE's become profitable (OECD, 2009). Existing work documents large scale of privatization of SOE's across all firm sizes and industries between 1997 and 2001 (Fang, 2002; Jefferson and Su, 2006). Rawski (2002) estimates 6 out of 44 million state industrial workers loses their jobs during this time.

During my sample period, data shows that the privatization of state owned firms continued throughout 1998 to 2007. State's share of firm count reduced from 35% to 4% while private's grew from 29% to 77% between 1998 and 2007. Meanwhile, state's share of value-added shrank from 47% to 20% and private's increased from 28% to 59%. The reversing trends of their economic importance are crucial for interpreting estimation results.

A2.2 The heavy coal-using SOE's

Table 8 column 6 suggest that the adverse employment effect of the TCZ policy may be stronger for state-owned firms than firms of other ownership types. As briefly discussed in the main text, this does not mean that the identified effects are caused by the SOE reforms. In fact, the lack of a similar pattern in column 3 of light coal-using state owned firms is indicative of a heterogeneous TCZ effect by firm ownership.

Given vast existing evidence on the governmental favoritism toward state owned firms that allowed them to be less efficient in the usage of capital and labor inputs (e.g., Hsieh and Klenow, 2009; Chen et al., 2017b), one may expect an opposite pattern. In fact, existing research on environmental regulations shows no convincing evidence for any ownership advantages by SOE. For example, Wang and Jin (2007) show that state- and privately owned polluting firms behave similarly under regulation.

Beyond differences in firm behaviors by ownership, three plausible explanations arise from the research and institutional contexts. The first straightforward explanation would be the previously highlighted data limitation of the industrial survey data. The non-state owned firms with annual sales less than five million RMB excluded from this data could potentially be the group of firms most affected by the TCZ policy. In particular, the implementation of the TCZ policy directly imposes cost on production, which may have a disproportionately greater average cost impact on small firms.

The second reason relates to resource limitation in the enforcement of environmental regulations. Becker and Henderson (2000) document a non-uniform enforcement of regulation across firm size in the US under the Clean Air Act. As a result of limited regulatory resources, heavy polluters that are usually larger in size turn out to be the targets of regulation, whereas the enforcement agencies do not have enough resources to monitor smaller polluters as closely. This offers one good basis for the pattern observed here. Figures A1 and A2 show kernel density of firm size for state versus privately owned firms in heavy and light SO_2 polluting industries respectively. The state owned firms in heavy coal-using and hence SO_2-polluting industries are much larger in size compared to privately owned firms, and this pattern is consistent over time in both 1999 and 2007. For non-polluting industries, however, firm size distributions are very similar across ownership types. Therefore, it is likely that state owned firms in heavy polluting industries attract greater regulatory attention simply because they are large and conspicuous in polluting activities.

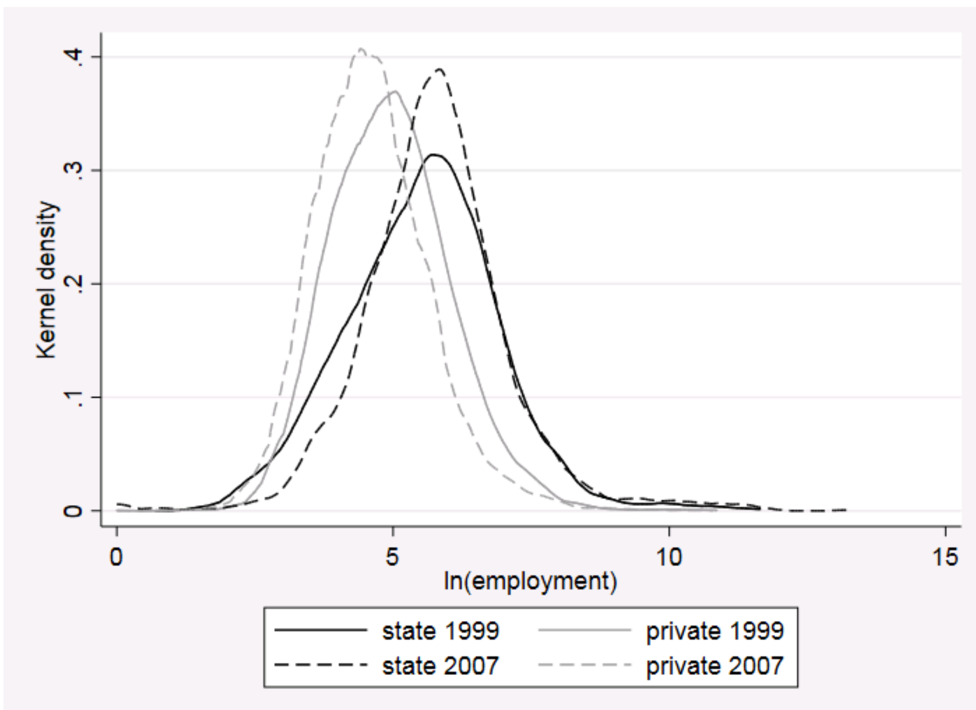

Figure A1. Firm size by ownership types, **heavy** coal-using firms & SO_2 polluters

The third explanation is embedded in the Chinese contexts. There is evidence that the state owned enterprises (SOE's) have been the main targets of the TCZ policy during this time as China undergoes a large scale privatization of the SOE's between 1997 and 2001 (Fang, 2002; Jefferson and Su, 2006). Heavy polluting SOE's are deemed unproductive by the State and need to be eliminated. For example, a State Council 1999 announcement declares, "SOE's that waste resources, pollute heavily, employ outdated technologies need to be forced into bankruptcy and shut down" (China State Council, 1999). Therefore, it is likely that environmental regulations accelerated the downward employment shock on polluting SOE's during the national privatization.

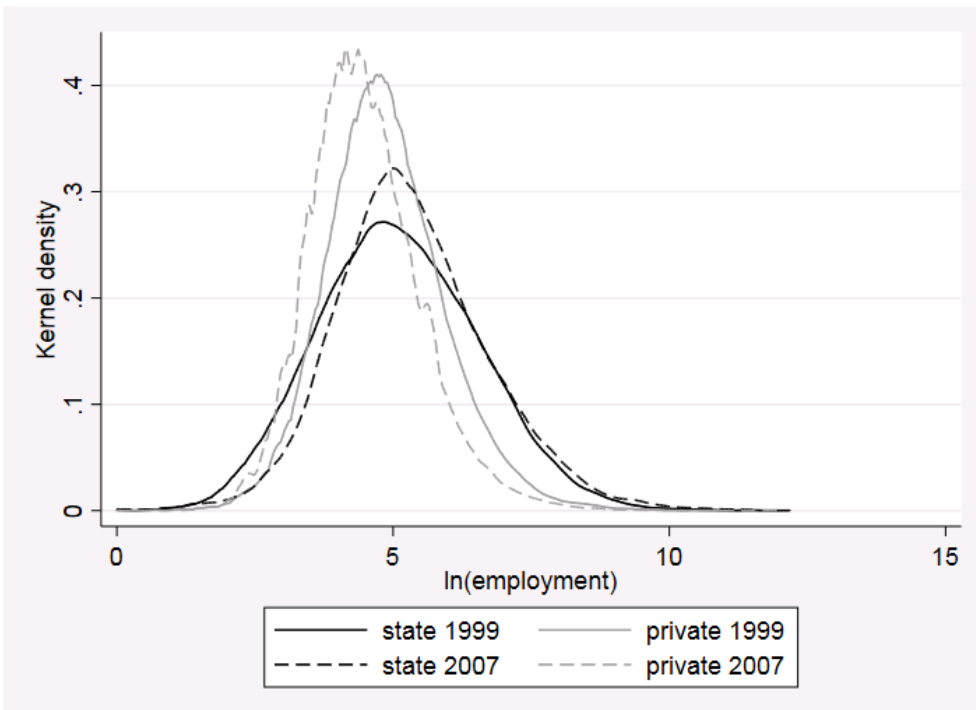

Figure A2. Firm size by ownership types, **light** coal-using firms & SO_2 polluters

Appendix A3 Sources of geo-spatial data

The following table lists the links to and details of the geo-spatial data used in this paper.

Name:	Source:	Details:
SO_2 column density	NASA Global Modeling and Assimilation Office	Time span: 1998-2010, annual means Scale: $0.5° \times 0.625°$; unit: kg/m^2
Infrastructure & land use	United States Geological Survey: Coal Geology, Land Use, and Human Health in China Compiled by Alex W. Karlsen et al.	List of shapefiles compiled by 2001 Key variables: airfields, small/large rivers, earthquake spots, volcanoes, coal bearing fields
Coal mines, oil & gas fields	USGS Compilation of GIS Data Representing Coal Mines and Coal-Bearing Areas in China	Surveyed by 2001, published in Jan 2015 Key info: coal mines, oil and gas fields
Gas pipelines	China Natural Gas Pipelines Data set, Harvard ChinaMap	Natural gas pipelines and nodes (polylines and points)
Elevation	Harvard China Historical GIS V5 DEM	1km pixel resolution based on GTOPO-30 data from USGS
Land cover	Global Land Cover Facility, MODIS Land Cover	$5' \times 5' \approx 0.083°$ resolution, yearly 2001-2012

Table A3. Sources of geo-spatial data

The suitability index used in this paper is based on Zoej et al. (2005) with two major modifications. First, the factor of soil quality from Zoej et al. (2005) is not used. This is because I was unable to find data of soil quality that matches exactly the categorical breakdowns in the original paper. Second and as a result of omitting soil quality, the weights for each factor (w_k) have been adjusted to add up to 1 by uniformly re-distributing the assigned weight for soil quality to the other factors. This second modification arguably has little impact on the variation of the instrumental variable, as the baseline results remain unchanged when the same weights are used for all factors.