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RESEARCH ARTICLE

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Enforcement of Capacity-Differentiated Regulations in China: Evidence from Coal-Fired Power Plants

Abstract This article investigates the effects of the capacity-differentiated regulations that are popular in China. These regulations usually involve measures that gradually shut down small plants while allowing them to continue to operate until shutdown. We use a panel data set from coal-fired power plants during the period from 2003 to 2010 and employ the input demand equations and the difference-in-differences method to quantify the effects of these regulations. Our findings, which are robust to a variety of specifications, indicate that regulations of this type reduce capital spending and fuel efficiencies in the vulnerable small plants that are subject to shutdown under this regulation. We find no effect on the operating expenses of these small plants.

Keywords environmental regulations in china, distortion effects, difference-in-differences, efficiency, electricity

JEL Classification G18, O38, Q43

1 Introduction

Numerous industrial and environmental regulations imposed on the energy- and pollution-intensive industries in China apply different standards to small and large units or plants.[1] Recently, an increasing number of these regulations have

[1] For example, power projects with a capacity larger than 50 MW need to be approved by the National Development and Reform Committee (NDRC) of China, while projects with a capacity of 50 MW or less only need to be approved by the provincial government (Lam and Shiu, 2004).

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involved phasing out small plants while simultaneously building new plants with larger capacity.[2] The rationales for implementing such extreme capacity-differentiated regulations in China are threefold. First, small plants in China are usually equipped with outdated technology and are less efficient; they cannot meet the environmental standards that are becoming more stringent (Chang and Wang, 2010). Second, the Chinese government tends to address the problem of low capacity utilization in many industries by closing down small plants (Lin, 2004; Zheng et al., 2009; International Monetary Fund, 2012). Third, the capacity-differentiated regulations implemented in China usually specify clear capacity thresholds for the plant shutdowns or other regulation measures; consequently, there are fewer loopholes and they are easily implemented (Zhou et al., 2010).

The capacity-differentiated regulations in China can cause distortions in the short term. First, plants subject to the regulation are usually shut down sequentially rather than all at once. They are allowed to continue operating until the planned closure date. Second, such capacity-differentiated regulations generally provide few details on the shutdown process (Kostka and Hobbs, 2012). Therefore, small plants are usually unclear as to whether or when they will be shut down; they do not know how long they will be able to operate.[3] As a result, there is little incentive for the plants scheduled for closure to continue investing while operating; this lack of investment may lead to reduced efficiency.

In this article, we study these distortion effects by examining how one particular capacity-differentiated regulation in the electricity generation sector has affected the operations of coal-fired power plants in China. Specifically, we study the effects of a nationwide regulation introduced in 2007 that will gradually phase out small coal-fired power plants. We provide the first empirical evidence of the distortion effects of such capacity-differentiated regulations in China.

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[2] For example, in 2006, the NDRC announced a plan that would gradually close cement production units with capacities less than 2000 metric tons per day (Cai et al., 2009). In 2011, the NDRC introduced a plan that gradually closes paper mills using straw pulps with capacities less than 34,000 metric tons per year and closes paper mills using chemical pulps with capacities less than 17,000 metric tons per year (Zhang et al., 2012).

[3] For example, local governments in China often make a concentrated effort at the end of each year to close a large number of small plants in order to meet the target for capacity reduction in that year.

Our empirical strategy makes an inference about the effects of this regulation based on the plant-level data from 59 independently operated coal-fired power plants in China during the period from 2003 to 2010. We estimate the input demand equations for capital, coal, and operating expenses to quantify the effects of this regulation. Taking advantage of the panel nature of our data, we employ the difference-in-differences (DD) method; we define plants with capacities below the phase-out threshold as the treatment group and other plants as the control group. We implement the DD method in a regression form in which we control for plant-invariant and time-invariant heterogeneities in input use by using plant and year fixed effects. The causal interpretation of the results from our DD analysis depends on two assumptions. First, the trends in the use of inputs would be the same between the two groups (i.e., the large and small plants) if the regulation we study had not been implemented. Second, the implementation of the regulation is uncorrelated with the unobserved factors affecting input demands. In Section 4.2, we discuss in detail the implications of these two assumptions and their justification in our analysis.

Three major findings emerge from our study. First, small plants, which are subject to being phased out under the regulation, reduce capital investment by 13.6% relative to the scenario without such regulation. Second, fuel efficiencies in these vulnerable plants are degraded by 7.4% during the operational period, compared to the non-regulated larger plants. Third, we find no evidence that operating expenses increase in the small plants. These results are obtained after controlling for the size and output of the plants, and they are robust to the incorporation of the effects of plant age and to different definitions of vulnerable plants.

Our findings suggest that the capacity-differentiated regulations in China can cause substantial distortion effects on the operating efficiencies in the small plants, even in the short term. Our findings also imply that the overall benefits from the programs and regulations aimed at promoting production efficiencies in many industries could be (partially) offset by the reduced efficiencies in the small plants, particularly when considering the large number of small plants in many industries in China.[4]

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[4] For example, in 2005, the total capacity of small plants that are subject to be closed under such regulations account for 14%, 15%, and 55% of the total capacity in coal-fired electric generation, steel production, and cement production industry, respectively (Zhou et al., 2010; Price et al., 2011).

This article is related to previous studies of the distortions caused by regulations that apply different standards to different subjects. For example, Goldberg (1998) provided evidence that the Corporate Average Fuel Economy standards for new vehicles in the US have led to an increase in the sales of used vehicles. Various studies (e.g., Maloney and Brady, 1988; Nelson et al., 1993; Gray and Shadbegian, 2003; Keohane et al., 2009; Bushnell and Wolfram, 2012) found that the New Source Review (NSR) program in the US, which requires industry to undergo a pre-construction review for environmental controls if they propose any modifications to existing facilities that would create a "significant increase" in a regulated pollutant, actually discouraged investments in grandfathered facilities. Our study adds to the literature by studying the effects of capacity-differentiated regulations, which apply different standards depending on capacity. We examine these effects in the largest developing country, China, which usually adopts an extreme version of these regulations by forcibly phasing out units or plants with small capacity.

Our study is also among the first to examine the distortion effects of China's capacity-differentiated regulations. Although this type of regulation has been adopted to overhaul most energy- and pollution-intensive industries in China, few studies have examined its effects on a firm's productivity and efficiency, particularly the distortion effects.

Finally, this article contributes to the research on the efficiency and productivity of China's coal-fired electricity generation industry. The existing literature has primarily focused on the effects of the unbundling reforms in China's electricity sector unveiled in 2002, which dismantled the former vertically integrated electricity monopoly, the State Power Corporation (SPC) (e.g., Lam and Shiu, 2004; Du et al., 2009; Yang and Pollitt, 2009; Gao and Biesebroeck, 2014; Zhao and Ma, 2013). By contrast, we study the effects of another major environment-oriented regulation on coal-fired power plants in China.

This article is organized as follows. Section 2 introduces the industry background. Section 3 briefly discusses the theoretical framework of our analysis. Section 4 presents our empirical strategy and discusses the issues related to identification. Section 5 describes the data. Section 6 discusses the results. Section 7 presents our conclusions.

2 Industry Background

Coal-fired power plants are the backbone of China's electric power industry. In 2010, coal-fired power plants accounted for 73% of the total installed electricity generation capacity, and 80.8% of the total electricity generation in China. Coal-fired power plants were also responsible for approximately 40% of the CO_2 emissions and 44% of the SO_2 emissions in China.[5]

Small plants are prevalent in China's coal-fired electricity generation sector (Wirtshafter and Shih, 1990; Yang and Yu, 1996; Lam and Shiu, 2004). As a result, the energy efficiency of China's coal-fired power plants has been low, with an average thermal efficiency of 30% in 2005, compared to 38% in Organization for Economic Cooperation and Development (OECD) countries in the late 1990s (*Financial Times Energy*, 1999; Cui et al., 2012). The Chinese government attempted to overhaul the coal-fired power industry in the late 1990s and early 2000s. One significant initiative was the closure of small plants, which were deemed to be less efficient and more polluting (Zhou et al., 2010). However, these efforts were thwarted and abandoned when China faced a serious electricity shortage in the first half of the 2000s (Yuan et al., 2007).[6]

In 2006, China made a commitment in its 11th Five-Year Plan[7] that the per-unit-GDP energy consumption and pollutant emission would be reduced by 20% and 10%, respectively, in 2010 (Zeng et al., 2008). Therefore, coal-fired power plant restructuring was revitalized and enforced in an unprecedented effort. In January 2007, the State Council issued an executive order[8] to close down coal-fired electricity generation units with capacities less than 50 MW. The order specified that a total capacity of 50,000 MW would be phased out by 2010.

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[5] Source: *China Electric Power Yearbook 2010*.

[6] For example, at the end of 2005, there were 3796 50 MW or smaller coal-fired power units in China, with a total installed capacity of 87,000 MW. They accounted for 14% of the total installed coal-powered electricity generation capacity in 2005. All these numbers increased from the values from 2000. (Source: *China Electric Power Yearbook 2005*).

[7] The Five-Year Plan for National Economic and Social Development, or the Five-Year Plan, of China is a series of social and economic development initiatives for a five-year period proposed by the Communist Party of China through the plenary sessions of the Central Committee and national congresses. The first Five-Year Plan was unveiled in 1953 for the period 1953 to 1957, and the latest plan, the 12th (2011–2015), was carried out in 2011.

[8] The State Council Executive Order 2007-02.

Furthermore, the State Council specified the total capacity target for retirement in each province or municipality.

However, this plan provided few details or guidelines on how the small plant closures would be implemented, such as which units or even how many units would be shut down in each year. In addition, the total capacity scheduled for phase-out (50,000 MW) under the plan was less than the total capacity of those targeted small units, which totaled 87,000 MW at the end of 2005. Such ambiguity would inevitably generate considerable uncertainty surrounding the operation of the small power plants unsure of whether and when they would be closed down.

3 Demand for Input Factors

The performance of power plants can degrade over time, and therefore investment is required to recover the lost efficiency. The primary justification for such investment is the comparison of the cost of the investment and the future savings through lower input use (i.e., the investment improves the efficiency) and lower operating expenses (i.e., the investment improves the reliability). The capacity-differentiated regulations we study in this article expose small power plants to the risk of being shut down in the near term, therefore increasing their cost of capital. As a result, small plants reduce their capital spending in the face of this uncertainty, and possibly use more coal and spend more on operations because of the reduced efficiency and reliability resulting from the lack of investment.

To examine the effects of these capacity-differentiated regulations, we adopt the empirical framework of Fabrizio et al. (2007) and Bushnell and Wolfram (2012) to first derive the demand function for each input for the coal-fired power plants and use the DD approach to compare the input use across plants of different capacities. We then examine whether the risk and uncertainty associated with this regulation has caused the vulnerable small plants to change the combination of inputs, i.e., to substitute capital expenses with additional coal or operating expenses.

In this section, we begin our empirical analysis by first deriving the demand equations for the inputs of coal-fired power plants.

Let i denote a coal-fired power plant, and t denote the year. Based on existing literature (e.g., Nerlove, 1963; Christensen and Greene, 1976; Kleit and Terrell, 2001; Knittel, 2002), we assume the following Cobb-Douglas production function for plant i in year t:

$$Q_{it} = C_{it}^{\eta_i^C} K_{it}^{\eta_i^K} M_{it}^{\eta_i^M}, \tag{1}$$

where "C" denotes coal, K denotes capital, M denotes operating expenses, excluding coal purchases and including wages, and the parameters η_i^I measure the output elasticities for input $I \in \{C, K, M\}$.

We follow the approach of Fabrizio et al. (2007) and Bushnell and Wolfram (2012) to derive the demand for each of the inputs. Specifically, the cost-minimizing problem the power plant i faced at year t is as follows:

$$\min_{C_{it}, K_{it}, M_{it}} P_{it} \cdot C_{it} + P_{it} \cdot K_{it} + W_{it} \cdot M_{it}, \tag{2}$$

$$\text{s.t.} \quad Q_{it} \leqslant C_{it}^{\eta_i^C} K_{it}^{\eta_i^K} M_{it}^{\eta_i^M}, \tag{3}$$

where P_{it}, R_{it}, and W_{it} are the costs for coal, capital, and operating expenses, respectively.

Solving the above cost-minimizing problem results in the following input demand equations:

$$K_{it} = \frac{\lambda_{it} \eta_i^K Q_{it}}{R_{it}}, \tag{4}$$

$$C_{it} = \frac{\lambda_{it} \eta_i^C Q_{it}}{P_{it}}, \tag{5}$$

$$M_{it} = \frac{\lambda_{it} \eta_i^M Q_{it}}{W_{it}}, \tag{6}$$

where λ_{it} is the Lagrange multiplier on the constraint (3).

The log transformations of each input $I \in \{C, K, M\}$ in Eqs. (4) to (6), respectively, are as follows:

$$\ln(K_{it}) = \ln(Q_{it}) - \ln(R_{it}) + \ln(\lambda_{it}) + \ln(\eta_i^K), \tag{7}$$

$$\ln(C_{it}) = \ln(Q_{it}) - \ln(P_{it}) + \ln(\lambda_{it}) + \ln(\eta_i^C), \tag{8}$$

$$\ln(M_{it}) = \ln(Q_{it}) - \ln(W_{it}) + \ln(\lambda_{it}) + \ln(\eta_i^M). \tag{9}$$

In our context, the cost of capital R_{it} is a function of plant size (Q_{it}) and closure probability (S_{it}), that is, $R_{it} = R(Q_{it}, S_{it})$. As noted by Bushnell and Wolfram (2012), R_{it} is an increasing function of S_{it}, because, in the small coal-fired power plants, the regulation will increase their cost of capital R_{it}. For example, it will be much more difficult for these small plants to access inexpensive credit from banks, as they are vulnerable for being shut down. Most of these plants will turn to informal lending markets for financing, and usually face much higher interest rates (Ayyagari et al., 2010). This increase in the cost of capital has both direct and indirect effects on the small plants' demand for capital. The direct effect of an increase in R_{it} will be a reduction in the demand for capital for a given level of output. An increase in R_{it} will also increase the λ_{it}, the shadow value of the production constraint (3), because it is more expensive to maintain production at an identical level when capital becomes more expensive. Increases in λ_{it} will then indirectly increase the demand for capital, all other factors remaining unchanged. For any given level of output Q_{it}, the direct effect dominates, leading to the negative total effect of increased capital costs on demand for capital.

For coal C_{it}, the increase in capital costs will only affect their demand through the indirect effect of the increase in λ_{it}, which will cause the increase in the demand for coal.

As another way to see the effects of the regulation on capital (K_{it}) and coal (C_{it}) through R_{it}, we can divide Eq. (4) by Eq. (5) to obtain that $\left(\frac{K_{it}}{C_{it}}\right)=\left(\frac{\eta_i^K}{\eta_i^C}\right)\times\left(\frac{P_{it}}{R_{it}}\right)$. For any given level of output Q_{it}, an increase in R_{it} will lead to a decrease in K_{it} and an increase in C_{it}, as the ratio $\frac{K_{it}}{C_{it}}$ should decrease and the output level is fixed.

However, for $I_{it}=M_{it}$, the sign of δ could be ambiguous, as our measurement of operating expenses is not as accurate as that for capital and coal. In our data, the operating expenses include all expenses the plant incurs other than coal purchase costs. For example, if this truly measures the costs for daily production and maintenance that contribute to production, it will be positively affected by the increase in capital cost. However, if it includes other costs that do not directly contribute to production, such as the costs of installing flue gas desulfurization (FGD) to reduce SO_2 emissions to meet the new emission regulations, the sign of δ will be less clear (Bushnell and Wolfram, 2012).

4 Estimation

In this section, we specify our estimation equations and discuss several identification issues.

4.1 Empirical Specification

Our empirical strategy is to track the use of the inputs of the individual smaller capacity power plants that face the risk of being shut down before and after the regulation was implemented, and then to compare the changes in these input uses with the corresponding changes observed in larger plants not subject to this regulation.

Our empirical specifications are based on the log transformations of factor demand equations (4) to (6). We apply the DD method to assess the effects of the capacity-differentiated regulations on the power plants' input uses. Our primary specification is the following two-way fixed effect linear regression model:

$$\ln(I_{it}) = \beta \ln(Q_{it}) + \delta \cdot (small_i \times post2007) + X'_{it}\,\theta + c_i + \gamma_t + u_{it}, \qquad (10)$$

where i denotes a plant and t denotes the year. We define $I_{it} \in \{K_{it}, C_{it}, M_{it}\}$ as one of the three input factors specified in Eq. (1) for plant i in year t. Q_{it} is the total output level of plant i in year t. $post2007$ is a binary indicator that equals one if the period t occurs in or after the year 2007, when the regulation to shut down the small electricity generating units was unveiled. $small_i$ is a binary indicator that equals one if the plant i is identified as a small plant (the treatment group). We also control for the observed time-varying plant characteristics, X_{it}, a full set of plant fixed effects, c_i, and a full set of time fixed effects γ_i. These two sets of fixed effects help control for time-invariant, plant-level heterogeneity in input demand, and variations in such demand across years.[9] u_{it} is the idiosyncratic error term. In this setup, $\hat{\delta}$, the ordinary least squares (OLS) estimate of δ, can be used to calculate the average treatment effects on the

[9] We do not include input prices in our estimations. However, input prices for coal-fired power plants in China usually do not vary within a year across plants. For example, the coal prices sold to electricity generation sectors are still tightly controlled by the government (Wang, 2007). At the same time, the government in China regulates the interest rates. Therefore, the plant and year fixed effects will pick up the geographic and time trends in these input prices.

treated (ATT).[10]

As discussed in Section 3, we expect $\delta < 0$ for $I_{it} = K_{it}, \delta > 0$, for $I_{it} = C_{it}$, and the sign of δ for $I_{it} = M_{it}$.

4.2 Identification

The first identification issue encountered in estimating Eq. (10) is the simultaneity between output Q_{it} and the input I_{it} (Griliches and Mairesse, 1995). According to Holtz-Eakin (2003), Fabrizio et al. (2007) and Bushnell and Wolfram (2012), we use the instrumental variable approach to control for the endogeneity caused by such simultaneity. We use the electricity demand in year t, at the province where the plant i is located, as the instrument for its output Q_{it}.[11] The validity of this instrument depends on the assumption that the electricity demand at the province level is unrelated to unobserved shocks to the individual plants' productivity.

The second identification issue is the validity of using the OLS estimate of δ as the estimator of ATT. The validity relies on two assumptions. The first is that the trends in the dependent variables over time in Eq. (10) (i.e., the plant-level demand for inputs), which are captured by time fixed effects γ_t, should be identical for both large and small plants. This assumption could be violated if changes in factors that affect both large and small plants (such as macroeconomic conditions, other industry-wide regulations, etc.) have different effects on their demand for inputs. Because the treatment (small plants) and control (large plants) groups are significantly different, the trends in the demand for inputs, in the absence of the studied regulation, are of concern. To alleviate the concern for this parallel-trend assumption, we re-estimate our main equations by including size-specific (i.e., small vs. large plants) time trends as a robustness check of our main results. The test result is presented and discussed in Section 6.4.

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[10] As Eq. (10) takes the semi-logarithmic form and is a binary indicator, the unbiased and consistent estimator for the percentage impact of on the leveled dependent variable is (Kennedy, 1981). Therefore, in the following, we will report the OLS estimate of in the tables but interpret its effect according to this percentage term.

[11] The data on province-level electricity demand in each year are obtained from the *China Electric Power Yearbook*, 2003–2010.

Second, it is assumed that the start of the regulation is mean independent of the error term u_{it} in Eq. (10), after controlling for plant and time fixed effects. This assumption is violated if the regulation was implemented in response to time-varying demand factors for inputs that are specific to small plants. However, this violation is unlikely to occur in our context because the regulation is primarily a measure to curb pollution and to increase capacity utilization in the power generation industry. These factors are also unlikely to be time-variant because the regulation had been implemented for approximately four years prior to 2010.

These two assumptions ensure that Eq. (10) can be consistently estimated by OLS. Conventional OLS standard errors are generally invalid if error terms exhibit serial or spatial correlations in the DD analysis (Bertrand et al., 2004). Therefore, we follow Bertrand et al. (2004) to calculate cluster-robust standard errors by choosing entire provinces as clusters. Bertrand et al. (2004) demonstrated that this correction method is more accurate than other correction methods, such as block bootstrap, when the number of states (i.e., provinces in our study) is small.

Finally, identifying the plants that face the threat of closing under the regulation is the key to our empirical analysis. As described above, the closing criteria are based on the capacity of the *unit*, not the capacity of the plant. Unfortunately, we only have data at the plant level, not at the unit level. Therefore, our key identification assumption is that small plants are more likely to have small units that meet the closing criteria. We define the treatment group as the power plants with a total capacity less than or equal to 100 MW; the control group is defined as the plants with a total capacity greater than 100 MW. Because the capacity-differentiated regulation studied in this article specified a unit shutdown threshold of 50 MW/unit and power plants usually have multiple units, the threshold of 100 MW/plant ensures that all units in the treatment group plants could be subject to shutdown under the regulation. We will check the robustness of our estimation in Section 0 by relaxing our definition of the treatment group.

In our empirical specifications, we use the period between 2007 and 2010 as the regulation enforcement period. This period was chosen because the NDRC issued its executive order to shut down small coal generating units in January 2007; the NDRC plan only encompassed until 2010, which was the last year of

China's 11th Five-Year Plan.

In summary, we define small plants as those with a total capacity less than or equal to 100 MW and define the enforcement period as the years from 2007 to 2010.

5 Data

The data are obtained from one major Chinese energy group that operates coal-fired power plants in all provinces and municipalities in Chinese mainland, except Tibet. The sample consists of operating information for 59 power plants in 11 provinces and municipalities,[12] with 410 observations for the years from 2003 to 2010. Our panel is not balanced because some plants were built after 2003 and some plants were divested before 2010. Although the energy group owns these plants, they are independently operated and responsible for their own profits and losses. For example, Lam and Shiu (2001) document that, since the early 1990s, China has been converting individual state-owned coal-fired power plants into "independent holding firms" to promote efficiency, and these "independent holding firms" usually have much larger autonomy power regarding their operations. Meanwhile, China also allows individual coal-fired power plants to be partially privatized by issuing shares to private and foreign investors.[13]

Table 1 presents a summary of statistics. As in Bushnell and Wolfram (2012), we use monetary amounts (in yuan and inflated to 2010 levels)[14] for capital and operating expenses. As the industry standard in China, we use ton of coal equivalent (TCE) as the unified measure for coal consumption because different plants use coals with different heating values. One TCE is equivalent to 29.3076

[12] These provinces and municipalities are: Chongqing, Fujian, Guangdong, Hebei, Henan, Hunan, Jiangsu, Liaoning, Shanghai, Tianjin, and Zhejiang.

[13] Nevertheless, we acknowledge that, as our data come from one large energy group, there is still some degree of direct control from the parent company over the operations of each individual power plant, such as input prices and output quota. Therefore, we build these features into our model by allowing input prices to be fixed for individual plants, and we study the input demand by controlling the output level. On the other hand, plant-level data used in our analysis have the natural advantage over the typical company-level data used in the previous literatures, as the policies of the focus (i.e., the capacity-differentiated regulations) are usually implemented at the plant level, rather than the company level.

[14] In 2010, 1 yuan ≈ 0.15 USD.

gigajoules (GJ). The annual coal consumption for each plant is calculated in TCE, using the total amount of coal consumption and the heating value of the coal for each plant in each year.[15]

Table 1 Summary Statistics

Variable	Sample Size	Mean	S.D.	Min	Max
Installed capacity (megawatt, MW)	410	172.88	105.76	21	440
Output (gigawatt hours, GWh)	410	6845.34	4826.32	134.61	19912.96
Capital (in 100 million yuan)	410	37.17	27.58	3.74	147.32
Coal use (in 10 thousand tons of coal equivalent, TCE)	410	242.63	145.31	17.50	830.17
Operation expenses (100 million yuan)	410	18.38	10.90	3.19	62.11
If small plant (=1 if capacity⩽100MW, =0 otherwise)	410	0.45	0.26	0	1
Plant age (in years)	145	8.98	6.91	1	26

Note: one ton of coal equivalent (TCE) is equal to 29.307 GJ. Only plants in Zhejiang province included in the data have information on plant age.

Table 2 presents the summary statistics for the treatment (small plants) and the control (large plants) groups separately. It should be noted that the last row of Table 2 indicates that small plants are, on average, older than large plants, and this difference is statistically significant at the 1% level. Aging plants might receive less investment, have lower fuel efficiencies, and require greater operating expenses; it is thus important to control for the effects of plant age when we study the effects of the regulation on input uses. Therefore, in Section 0, we also conduct estimations using a restricted sample of plants from Zhejiang province, including information on plant age, to further test the validity of our results obtained using the full sample.

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[15] In China, coal-fired power plants are required to report their coal consumptions in terms of TCE to the regulatory agency, the State Electricity Regulatory Commission. Therefore, the measurement of coal consumption has already been converted into TCE in our data.

Table 2 Summary Statistics by Treatment and Control Groups

	Treatment Group (Small Plants)					Control Group (Large Plants)					t-statistic for Difference in Means
	Sample Size	Mean	S.D.	Min	Max	Sample Size	Mean	S.D.	Min	Max	
Installed capacity (MW)	183	54.59	21.64	21	100	227	168.41	63.73	107	440	-25.17^{***}
Output (gigawatt hours, GWh)	183	3669.10	2339.21	134.61	9506.20	227	8962.83	3089.79	1134.61	19912.96	-19.73^{***}
Capital (in 100 million yuan)	183	25.94	17.35	3.74	91.11	227	48.21	28.01	13.59	147.32	-11.18^{***}
Coal (in 10 thousand tons of coal equivalent, TCE)	183	141.20	89.03	17.50	610.01	227	310.24	136.08	93.48	830.17	-15.13^{***}
Operation expenses (100 million yuan)	183	10.13	5.40	3.19	35.63	227	23.88	10.16	19.21	62.11	-17.55^{***}
Age (in years)	55	10.64	6.73	1	26	90	6.70	6.56	1	21	3.45^{***}

Note: Only plants in Zhejiang province have information on plant age. *** denotes statistical significance at the 1% level, ** denotes statistical significance at the 5% level, * denotes statistical significance at the 10% level.

6 Empirical Results

6.1 Capital

Table 3 presents the estimation results of Eq. (10) for capital. Column (1) of Table 3 presents the OLS result using the full sample. The coefficient δ on the term $small \times post2007$ is negative and significant at the 10% level, suggesting that small plants at risk of being closed down under the regulation reduced their capital spending compared to the unregulated larger plants.

Table 3 Parameter Estimates of Demand for Capital

	(1) All Observations	(2) All Observations	(3) Plants in Zhejiang Province	(4) Plants in Zhejiang Province
Small×Post 2007	–0.060*	–0.128**	–0.128	–0.171**
	(0.038)	(0.041)	(0.109)	(0.063)
ln(Output)	0.140***	0.283***	0.067**	0.174**
	(0.042)	(0.079)	(0.033)	(0.068)
Age			–0.020*	–0.030
			(0.013)	(0.025)
Plant fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Estimation method	OLS	2SLS	OLS	2SLS
Number of observations	410	410	145	145
R^2	0.873	0.837	0.899	0.857
First-stage F-statistic		22.81		13.01

Note: The dependent variable is ln(*total capital*). Small plants are defined as those with total capacity less than or equal to 100 MW. All specifications include a constant. Standard errors are in parentheses and adjusted for clustering at the province level. *** denotes statistical significance at the 1% level; ** denotes statistical significance at the 5% level; * denotes statistical significance at the 10% level.

In column (2) of Table 3, we use the log of electricity demand at the province level as the instrument to control for the endogeneity of output. After controlling for the endogeneity of output, the coefficient δ on $small \times post2007$ remains negative and increases in absolute value, suggesting the regulation's negative effects on capital investment in small plants were significant. In addition, the standard error of δ in the instrumental variable (IV) estimation decreases, and it is now significant at the 5% level.

One concern for the results in columns (1) and (2) is that we do not account for the age of the plants in our data. Aging plants may receive less investment as they approach the end of their life cycles, and this effect is both plant-specific and time-varying so it cannot be controlled by either plant or year fixed effects. Therefore, we include data on plant age for the plants in Zhejiang province. We then re-estimate the specifications as in columns (1) and (2), with plant age as the additional control, using the data for the plants in Zhejiang province. The results in columns (3) and (4) are consistent with the results in columns (1) and (2). The coefficient δ on term $small \times post2007$ is negative and is significant at the 5% level in the two-stage least squares (2SLS) results, suggesting that small coal-fired power plants tend to reduce their capital spending in the face of uncertainty under the regulation, even after controlling for the effects of plant age.

Quantitatively, these negative effects on capital spending are economically significant. The magnitude of the estimates in column (2), based on the entire sample, suggests that the small power plants subject to the regulation reduce their capital spending by as much as 13.6%[16] compared to the unregulated large plants. In our data, the mean level of capital stock for small plants (with capacity less than or equal to 100 MW) is approximately 2.3 billion yuan. Therefore, a 13.6% reduction in capital stock would be equivalent to 0.31 billion yuan. When considering plant age, the negative effects of the regulation on capital at the small plants increases to 18.4%, which amounts to 0.48 billion yuan.[17]

6.2 Fuel Efficiency

Table 4 presents the estimation results for plant coal consumption. The results in column (2) of Table 4 indicate that, after controlling for the endogeneity of output, small plants use approximately 7.4% more coal than larger plants; this is statistically significant at the 5% level. In columns (3) and (4) of Table 4, we focus our attention on the subsample of plants in Zhejiang province to further control for the effects of plant age on coal consumption. After controlling for the effects of plant age, the results in column (4) continue to demonstrate that the small plants use

[16] We calculate the percentage changes using the formula in footnote 11.

[17] The average capital stock of small plants in Zhejiang province that have information about plant age is 2.6 billion yuan.

more coal after the regulation was implemented, approximately 5.8% more.

Table 4 Parameter Estimates of Demand for Coal

	(1) All Observations	(2) All Observations	(3) Plants in Zhejiang Province	(4) Plants in Zhejiang Province
Small×*Post 2007*	0.006	0.072**	0.013	0.057**
	(0.034)	(0.035)	(0.051)	(0.025)
ln(*Output*)	0.832***	0.815***	0.692***	0.765**
	(0.093)	(0.097)	(0.055)	(0.120)
Age			0.014**	0.013**
			(0.006)	(0.005)
Plant fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Estimation method	OLS	2SLS	OLS	2SLS
Number of observations	410	410	145	145
R^2	0.977	0.967	0.981	0.857
First-stage F-statistic		22.81		13.01

Note: The dependent variable is ln(*Coal*). Small plants are defined as those with total capacity less than or equal to 100 MW. All specifications include a constant. Standard errors are in parentheses and adjusted for clustering at the province level. *** denotes statistical significance at the 1% level; ** denotes statistical significance at the 5% level; * denotes statistical significance at the 10% level.

Economically, these estimates suggest that, on average, the regulation requires a small plant to expend an extra 0.1 million tce a year[18] when compared to the unregulated scenario, which was equivalent to 74.6 million yuan for an average small power plant in 2010.[19]

6.3 Operating Expenses

Table 5 presents the estimation results of Eq. (10) for operating expenses. The

[18] The result is based on the average coal consumption of 1.41 million TCE for small plants in our sample and the 7.4% increase in coal consumptions for small plants estimated in column (2) of Table 5.

[19] The average price per one TCE in the electricity generation industry was 746 yuan in China in 2010 (Data source: *China Electric Power Yearbook 2010*).

estimated coefficients on the interaction term $small \times post2007$ are statistically insignificant in all specifications, whether controlling for endogeneity of output or for the effect of plant age.

Table 5 Parameter Estimates of Demand for Operating Expenses

	(1) All Observations	(2) All Observations	(3) Plants in Zhejiang Province	(4) Plants in Zhejiang Province
Small×Post 2007	–0.022	–0.023	–0.035	–0.020
	(0.195)	(0.197)	(0.302)	(0.266)
ln(*Output*)	1.179***	1.174***	1.215***	1.246***
	(0.236)	(0.320)	(0.261)	(0.248)
Age			–0.008	–0.012
			(0.023)	(0.019)
Plant fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Estimation method	OLS	2SLS	OLS	2SLS
Number of observations	410	410	145	145
R^2	0.899	0.890	0.981	0.857
First-stage *F*-statistic		22.81		13.01

Note: The dependent variable is ln(*operation expenses*)(*Operation Eexpensees*). Small plants are defined as those with total capacity less than or equal to 100 MW. All specifications include a constant. Standard errors are in parentheses and adjusted for clustering at the province level. *** denotes statistical significance at the 1% level; ** denotes statistical significance at the 5% level; * denotes statistical significance at the 10% level.

As discussed above, the insignificant effect on operating expenses may be because the operating expenses in our study are not as accurate a measure as capital or fuel efficiency.

6.4 Robustness Check

First of all, as discussed above, our difference-in-differences method is only valid when trends in input demand prior to the treatment period (i.e., before the year 2007) are identical for the treatment (small plants) and control (large plants) groups. If such trends differ between the small and large plants, our estimation results may interpret the preexisting differences between the plants with different capacities as the effects of the capacity-differentiated regulation. Therefore, we further include size-specific (i.e., small vs. large plants) time trends in Eq. (10) as a robustness check for this concern.

Table 6 Robustness Check I: Parallel Trend between Small and Large Plants

	(1) Capital	(2) Coal	(3) Operation Expenses
Small×Post 2007	–0.116**	0.085**	–0.042
	(0.041)	(0.042)	(0.262)
ln(*Output*)	0.295***	0.783***	1.193***
	(0.093)	(0.102)	(0.335)
Size-specific time trend	Yes	Yes	Yes
Plant fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Estimation method	2SLS	2SLS	2SLS
Number of observations	198	198	198
R^2	0.937	0.979	0.915

Note: The data are from 2003 to 2006. Small plants are defined as those with total capacity less than or equal to 100 MW. All specifications include a constant. The standard errors are in parentheses and are clustered at the province level. *** denotes statistical significance at the 1% level, ** denotes statistical significance at the 5% level, * denotes statistical significance at the 10% level.

Table 6 shows the regressions results for capital, coal, and operation expenses from Eq. (10) using all observations but with size-specific time trends. The results are very similar to our main results in Tables 3–5, and they suggest that different trends in input demand between small and large plants is not a concern in our context.

Second, our empirical analysis relies on the assumption that it is unknown which plant in the sample would be closed, so that the affected plants could not adequately adjust their input uses beforehand. To empirically examine the validity of this assumption, we estimate the following modified version of Eq. (10):

$$\ln(I_{it}) = \beta \ln(Q_{it}) + \delta \cdot (small_i \times post2007) + \varphi \cdot (small_i \times I_i \times post2007) + X'_{it}\theta + c_i + \gamma_t + u_{it}, \quad (11)$$

where I_i is a binary indicator that equals one if a small plant is closed after 2007, and zero otherwise. If our assumption of ignorability of treatment (Rosenbaum and Rubin, 1983) holds, the estimate of φ should be close to zero and statistically insignificant.

Table 7 presents the regression results of Eq. (11) for capital, coal, and operation expenses, respectively. In all specifications in Table 7, the estimates of φ are close to zero and statistically insignificant at any conventional level. These testing results suggest that our assumption of small plants' ignorability of closure decisions is valid.

Table 7 Robustness Check II: Ignorability of Treatment

	Capital		Coal		Operation Expenses	
	(1)	(2)	(3)	(4)	(5)	(6)
Small×I×Post 2007	–0.062	0.075	0.091	0.046	–0.145	–0.111
	(0.541)	(0.238)	(0.490)	(0.107)	(0.115)	(0.186)
Small×Post 2007	–0.159**	–0.139**	0.057**	0.061**	–0.022	0.031
	(0.064)	(0.061)	(0.029)	(0.031)	(0.056)	(0.101)
ln(*Output*)	0.191***	0.298***	0.823***	0.741***	1.297***	1.380***
	(0.063)	(0.073)	(0.072)	(0.109)	(0.275)	(0.298)
Age		–0.052		0.010**		–0.019
		(0.086)		(0.004)		(0.033)
Plant fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Estimation method	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS
Number of observations	410	145	410	145	410	145
R^2	0.980	0.861	0.968	0.859	0.893	0.862
First-stage *F*-statistic	13.63	12.50	13.63	12.50	13.63	12.50

Note: The dependent variable is ln(*capital*) in columns (1) and (2), ln(*coal*) in columns (3) and (4), and ln(*operation expenses*) in columns (5) and (6). Columns (2), (4), and (6) use data from Zhejiang province only. Small plants are defined as those with total capacity less than or equal to 100 MW. All specifications include a constant. Standard errors are in parentheses and adjusted for clustering at the province level. *** denotes statistical significance at the 1% level; ** denotes statistical significance at the 5% level; * denotes statistical significance at the 10% level.

Finally, another caveat regarding our results in Tables 4–6 is that we only have plant level capacity data, whereas the threshold for plant shutdown is at the unit level. Therefore, in our previous estimations, we base our threshold for vulnerable units as plants with a capacity less than or equal to 100 MW. Power plants usually have multiple units; the threshold of 100 MW at the plant level ensures that the capacities of each unit within the plants with capacities less than or equal to 100 MW would be below 50 MW, and therefore are subject to shutdown under the regulation. However, our estimated effects of regulation would be biased if units in larger plants also fall under the 50 MW-threshold and face the risk of being shut down.

In this subsection, we conduct a robustness check to verify that our results presented in Tables 4–6 are robust to different definitions of small and large plants. Specifically, in Table 8 we define small plants as those with a total capacity less than or equal to 150 MW. We assume that the units in these plants face the risk of being shut down under the regulation.

Table 8 Robustness Check III: Alternative Definition of Vulnerable Plants

	Capital		Coal		Operation Expenses	
	(1)	(2)	(3)	(4)	(5)	(6)
Small×*Post 2007*	–0.168**	–0.121**	0.044**	0.052**	–0.013	0.019
	(0.076)	(0.045)	(0.019)	(0.023)	(0.076)	(0.055)
ln(*Output*)	0.183***	0.277***	0.817***	0.726***	1.160***	1.250***
	(0.043)	(0.064)	(0.094)	(0.121)	(0.304)	(0.245)
Age		–0.024		0.008*		–0.006
		(0.025)		(0.005)		(0.018)
Plant fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Estimation method	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS
Number of observations	410	145	410	145	410	145
R^2	0.837	0.899	0.977	0.980	0.899	0.916
First-stage *F*-statistic	15.32	10.89	15.32	10.89	15.32	10.89

Note: The dependent variable is ln(*capital*) in columns (1) and (2), ln(*coal*) in columns (3) and (4), and ln(*operation expenses*) in columns (5) and (6). Columns (2), (4), and (6) use data from Zhejiang province only. Small plants are defined as those with total capacity less than or equal to 150 MW. All specifications include a constant. Standard errors are in parentheses and adjusted for clustering at the province level. *** denotes statistical significance at the 1% level; ** denotes statistical significance at the 5% level; * denotes statistical significance at the 10% level.

Table 8 presents the results of our robustness checks. For each of the inputs, we run 2 SLS estimations using all observations in the sample and observations from Zhejiang province, which include information on plant age. The results in Table 8 are consistent with the results in Tables 4–6: small plants that are more likely to house vulnerable units reduced their capital spending relative to the larger plants, which tend to have larger units that are safe under the regulation; and their coal consumption increased when the regulation was unveiled. However, there is no significant difference in operating expenses between the small and large plants.

7 Conclusion

This article quantifies the distortion effects of a major capacity-differentiated regulation in the electricity sector in China that involved closing small coal-fired power plants. We find that the vulnerable small plants reduced their capital spending as a response to this regulation, and their fuel efficiencies decrease.

The distortion effects we discuss in this article are quantitatively larger than those produced under other similar regulations. For example, Bushnell and Wolfram (2012) found that the New Source Review (NSR) program in the US reduced capital spending in vulnerable grandfathered coal-fired power plants by approximately 7%, but it had no significant effects on fuel efficiencies in the short term. The primary reason we find larger negative effects on capital and fuel efficiencies is that China's capacity-differentiated regulations have imposed much greater risks on the affected plants (i.e., the risk of being closed down) than other similar regulations (e.g., the requirement to install pollution control equipment under NSR). Therefore, this regulation caused much greater short-term negative effects on the affected plants' operations.

Our analysis suggests that the distortive effects found in this study can have significant economic effects when we consider the large numbers of small plants across many industries in China and the long implementation periods for these capacity-differentiated regulations (e.g., such regulations may take five to ten years to be implemented). Therefore, our analysis calls for more sophisticated regulations to promote industry efficiency and utilization without causing significant loss in the efficiencies of plants that fall out of the favor of the policies.

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