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ABSTRACT

Since 2005, the Chinese government has engaged in an ambitious effort to move China's energy system away from coal and towards more environmentally friendly sources of energy. However, China's investment in coal power has accelerated sharply in recent years, raising concerns of massive overcapacity and undermining the central policy goal of promoting cleaner energy. In this paper, we ask why China engaged in such a pronounced investment boom in coal power in the mid-2010s. We find the protective rules under which China's coal power industry has historically operated have made excessive investment extremely likely unless the central government serves as a "gatekeeper," slowing and limiting investment in the face of incentives for socially excessive entry. When coal-power project approval authority was decentralized from the central government to local governments at the end of 2014, the gate was lifted and approval time considerably shortened, allowing investment to flood into the market. We construct a simple economic model that elucidates the effects of key policies on coal power investment, and examine the model's predictions using coal-power project approval records from 2013 to 2016. We find the approval rate of coal power is about 3 times higher when the approval authority is decentralized, and provinces with larger coal industries tend to approve more coal power. We estimate that local coal production accounts for an additional 54GW of approved coal power in 2015 (other things equal), which is about 1/4 of total approved capacity in that year.

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1. Introduction

Since 2005, the Chinese government has engaged in an ambitious effort to move China's energy system away from coal and towards more environmentally friendly sources of energy. The government has sponsored a historically unprecedented expansion of renewable energy, with its wind and solar photovoltaic (PV) capacity growing rapidly to double those of the U.S. by 2017 and 2016 respectively. This growth was greatly enabled by the renewable energy policy framework created by the landmark *Renewable Energy Law*, passed in 2005 and amended in 2009. Paradoxically, however, China has – at the very same time – been investing heavily in a massive expansion of coal-fired thermal energy capacity. From 2010 to 2015, China's coal power capacity increased from 660 to 884 GW, and China approved nearly 200 GW of new coal power capacity in 2015 alone.[1]

The rapid expansion of coal power investment raised serious concerns of overcapacity in coal power and increased rates of renewable energy curtailment, in which wind and solar power generation are refused by the grid operator even though power is available. In 2016, it was estimated that China would face 200 GW of overcapacity in coal power if all the coal power projects submitted for Environmental Impact Assessment (EIA) approval were put into operation in 2020 (Yuan et al., 2016). In 2018, Feng et al. (2018) estimated the excess scale to be around 210 GW under their basic scenario and 240 to 260 GW under a high scenario. At the same time, the curtailment rates for renewable energy in China rose to astonishingly high levels – 17.1%[2] of wind energy and 19.81%[3] of solar energy were curtailed in 2016 (compared to less than 2.5%[4]

[1] Authors' calculations based on coal power project approval dataset described in Section 4.1.
[2] From http://www.nea.gov.cn/2018-02/01/c_136942234.htm
[3] From http://www.nea.gov.cn/2017-01/19/c_135996630.htm
[4] (Bird, Cochran, & Wang, 2014)

annual aggregate wind and solar curtailment in the United States since 2013). Starting from March 2016, the central government issued a series of policies designed to halt investment in coal power generation across the country, cancelling and suspending coal power projects up to 90 GW of capacity in 2016 and 2017.[5] Apparently, the government realized the risk of enormous excessive supply in coal power and took immediate actions to mitigate the associated social cost.

If the Chinese government has been aggressively promoting renewable energy to restructure its energy mix, why did it also keep investing in coal power to the point where the government had to conduct emergency measures to limit this investment? What is holding China back from using more renewable power and less coal power? In this paper, we argue that longstanding market rules created a persistent incentive for power companies to invest, as they effectively guaranteed positive profits for new investments. We demonstrate the implications of these incentives in a simple model and empirically confirm its predictions using a newly collected dataset of coal-fired power project approval records. The decentralization of coal power approval authority in 2014 removed an important historical "brake" on a longstanding

[5] 2016/3/17 "Notice on Promoting the Orderly Development of Coal Power in China"《关于促进我国煤电有序发展的通知》
2016/4/20 "Notice on Establishing Risk Early Warning Mechanism for Coal Power Planning and Construction"《关于建立煤电规划建设风险预警机制暨发布 2019 年煤电规划建设风险预警的通知》
2016/8/5 "Notice on further standardizing the order of construction of power projects"《关于进一步规范电力项目开工建设秩序的通知》
2016/9/15 "Notice on canceling a batch of coal-fired power projects that do not have the approved construction conditions"《关于取消一批不具备核准建设条件煤电项目的通知》
2016/10/10 "Notice on further regulation of coal power planning and construction"《关于进一步调控煤电规划建设的通知》
2017/7/26 "Opinions on promoting the structural reform of the supply side and preventing the overcapacity of coal-fired power generation"《关于推进供给侧结构性改革，防范化解煤电产能过剩风险的意见》
2017/9/26 "Notice on Printing and Distributing the List of Cancelled and Suspended Coal Power Projects in 2017"《关于印发 2017 年分省煤电停建和缓建项目名单的通知》

tendency to overinvest in thermal power; coal power approval rates tripled after approval authority was decentralized. This occurred because local governments tended to place greater value on the short-run economic stimulative effect of new power plant construction, and less value on the longer-run problems created by excessive thermal power capacity. This misalignment of incentives should be greatest in provinces that have large coal industries, and we find strong empirical evidence supporting this hypothesis.

Prior researchers have studied China's unusually high level of curtailment of renewable power by reviewing the distinctive policies and institutional structure in China's power sector. These prior studies recognized the deep-rooted political and institutional obstacles to the effective utilization of renewable energy capacity in China (García, 2011; Kahrl & Wang, 2014, 2015; Lam, Branstetter, & Azevedo, 2016, 2017; Zhao, Wang, & Wang, 2012). One key problem relates to the rules under which renewable energy and coal-fired power plants compete for utilization – these rules have traditionally privileged coal power in a number of ways, including assigned generation hours and administered on-grid electricity price (Davidson, 2014; Kahrl et al., 2013; Ma, 2011; Zhao et al., 2012). Prior research has also identified the incentives faced by local governments to prioritize economic growth over environmental policy objectives in ways that undermined central government policies to promote cleaner energy (Zhao et al., 2013). In this paper, we investigate key industry policies that have tilted the playing field of power generation towards coal power and against renewables. In particular, we show that a recent policy that decentralized coal power project approval authority from the central government to provincial governments significantly increased firms' investment in coal power. This paper explains China's overinvestment in coal power from an economic perspective, and provides a plausible explanation for provincial differences in coal power investment.

The paper is organized as follows. Section 2 provides an overview of China's power industry, key policies, and institutional background. Section 3 constructs an economic investment model to illustrate the economic incentives driving coal power investment in China. Section 4 examines the effects of industry policies on the 2015 investment boom using a unique dataset of coal-power project approval records from 2013 to 2016. Section 5 provides a discussion, and Section 6 concludes.

2. China's Power Industry

2.1. Energy Structure, Supply and Demand

The development of renewable and coal power have proceeded almost in parallel in China. Figure 1 shows China's coal, wind, and solar PV production capacity from 2005 to 2015. The expansion of coal power in recent years has been quite large relative to the growth in renewable energy capacity. The utilization rate of power generation facilities, measured by average annual operation hours, has declined by almost 30 percent from 2005 to 2015. In addition to declining operation hours, wind and solar curtailments have been rampant across Chinese provinces, as Table 1 shows. Since wind and solar energy are clean, have no fuel cost, and have been developed rapidly with extensive government support, these high curtailment rates represent a substantial social loss.[6]

[Figure 1 about here.]

[Table 1 about here.]

[6] Curtailment rates in China have been 7-10 times higher than the United States in recent years.

From 2010 to 2015, as Table 2 shows, total electricity demand increased by 38% while installed generation capacity increased by 55%, which explains the declining operation hours of generation facilities.

[Table 2 about here.]

In the face of declining operation hours and rampant renewable curtailments, the local governments, surprisingly, approved nearly 200 GW of new coal power capacity in 2015, which was almost 1/4 of total existing coal power capacity. Figure 2 shows the quarterly approval of coal power capacity from January 2012 to March 2016. An unanticipated slowdown in industrial demand for electricity occurred in the mid-2010s. However, the explosion in new capacity was so great that overcapacity would have resulted even if demand growth had been stable.

[Figure 2 about here.]

2.2. China's Protective Policies for Coal Power

To understand why China engaged in the massive expansion of coal power, one needs to understand the policies that have incentivized investment in coal power, in particular, the power dispatch and wholesale electricity pricing mechanisms. Dating back to the 1980s, China experienced surging electricity demand, as market-oriented reforms caused economic growth to accelerate. Inadequate electricity generating capacity quickly emerged as a factor limiting industrial expansion. To encourage power investment, the government set relatively equal annual operating hours for all coal-fired power generators, and dispatched them based on an annual contract designed to maintain operation hour targets (Kahrl et al., 2013). This rule is known as "equal share dispatch" or "average dispatch" (平均调度 | Ping Jun Diao Du), and is formally named the "generation quota system" (发电配额制度 | Fa Dian Pei E Zhi Du). In economic terms, this allocation rule ensured that demand was equally distributed across producers. This, in turn, raised the possibility of a business-stealing effect inducing excessive entry (Mankiw & Whinston, 1986).

In addition to equal operation hours, to meet surging electricity demand in 1980s, China implemented the so-called "cost-repayment tariff scheme" (还本付息电价 | Huan Ben Fu Xi Dian Jia) to encourage power investment. This policy directed electricity sale prices to be set so as to ensure repayment of principle and interest on all borrowing plus a reasonable profit margin for each coal-fired power plant. However, China soon realized that such a "rate-of-return" policy induced little incentive for generation companies to invest in cost control. The government then introduced the "benchmark on-grid electricity tariff" mechanism in 2003 to set a uniform electricity price within a province for all coal power plants. These benchmark tariffs aimed to reflect average social costs of power generation in each province and to provide incentives for power producers to reduce costs (Ma, 2011). While coal power plants could earn profits under the administratively set electricity price in each province, they could further enlarge their profit margins by reducing operation costs. With the generation quota system and regulated electricity price policy in place, the coal power generation business in China has been almost risk-free.

2.3. China's Project Approval System and Coal Power Investment in China

Since the early 2000s, a unique project approval system has been used in determining the level and composition of investment in power generation and transmission in China. The approval process consists of government review (审批制 | Shen Pi Zhi), project approval (核准制 | He Zhun Zhi), and project registration (备案制 | Bei An Zhi), each applying to different kinds of energy investment projects and carried out by different levels of government. Without coordinating with China's industrial planning process in a way that could carefully balance the energy demand arising from future growth and the energy supply needed to fuel it, government agencies have often approved new projects without any transparent, objective criteria for determining how much and what kind of generation and transmission capacity to build, and where to build it (Kahrl & Wang, 2015).

Coal power projects have been subject to the second type of approval process, project approval (核准制 | He Zhun Zhi). In particular, there was a decentralization of project approval authority from central government to provincial governments for coal power projects in 2014. Prior to November 2014, the central government retained sole authority to approve coal-fired power projects. The approval procedure was often lengthy and costly, sometimes taking years for a project to obtain all the licenses and permits required before construction. To facilitate an easier approval process for business, the government decentralized approval authority of coal-fired power plants from central to provincial governments in November, 2014. Thereafter, the approval procedure was considerably simplified and approval time greatly shortened. Figure 3 shows the time spent from the Ministry of Environmental Protection (MEP)'s pre-approval to National Development and Reform Commission (NDRC)'s final approval for 47 projects approved by the central government and 124 projects approved by provincial governments. Provincial approvals shortened the average approval process by more than half. Figure 4 shows the process time from MEP Pre-approval to NDRC Final Approval using a random sample of projects from the five largest generation companies in China, known as the "Big Five." The plants in the random sample approved under the old, centralized system are plotted as squares. The plants approved under the decentralized system are plotted as circles. The decentralized approval regime decreased approval times, and these reductions were bigger for larger projects. Based on our dataset, the "Big Five" together owned 49.9% of operating coal power capacity in

2017, so a sample based on the Big Five is informative about the underlying population of power plants.

It should also be noted that the Chinese government stipulates that 300MW coal power units be constructed within 24 months, and 600MW units within 26 months, after which the plants will be tested for safety and put through a 168-hour trial commercial operation before transitioning to full operation. Therefore, the average approval time of a project before decentralization was comparable to the maximum construction time of the project.

[Figure 3 about here.]

[Figure 4 about here.]

2.4. Institutional Background

Implementation of a policy at the local level strongly depends on its interest alignment with local stakeholders. Prior to 2017, local economic growth had been put at the top of the policy agenda of local governments, while other social issues such as environmental protection have had a lower priority. Under China's cadre evaluation system, provincial leaders have been pressured to meet GDP growth rate targets and compete with the economic performance of other provinces for future promotion and resource acquisition from superiors (Guo, 2009; Li & Zhou, 2005; Shih, Adolph, & Liu, 2012; Zhang & Zhao, 2014). As a result, provincial leaders are highly incentivized to promote local investments that directly increase local GDP growth. More importantly, they are capable of intervening in power generation investments – state-owned enterprises (SOE) accounted for 91.6% of total revenues in China's power sector in 2010 (Szamosszegi & Kyle, 2011). This means local government leaders can easily intervene in local

SOEs' investment plans through their role as leading shareholders.[7] For centrally owned enterprises, local governments are also able to intervene using coercive administrative force.[8] This institutional background gives rise to a hypothesis concerning the relative impact of approval decentralization across provinces: investment in coal power generation under the decentralized approval regime should be especially strong in provinces with a large local coal mining industry. This positive correlation should exist because the construction of new power plants would not only increase provincial GDP in the very short run – it would also lead to greater demand for (and therefore greater supply of) locally mined coal, providing a secondary boost to GDP and shoring up a local pillar industry.

3. Economic Model

We model the behavior of a representative generation company, which selects a level of generating capacity in which to invest and then produces output in accordance with the government's regulatory structure. In particular, the Chinese government sets the wholesale electricity price and assigns production levels approximately proportionally based on plant capacity. Therefore, each producer in province i will have approximately the same capacity factor, defined as power actually generated divided by rated peak power. The value of this capacity factor will be determined by the total provincial coal power generation (D_i) divided by total provincial rated peak power (Y_i).

[7] The government agency "State-owned Assets Supervision and Administration Agency (SASAC)" represents and performs duties of the shareholder of these nationally owned SOEs on behalf of the Chinese state. SASAC has the right to share asset income, involve itself in important decision-making processes, and appoint the top management teams of these firms. It also makes vets important decisions by these SOEs, including large investments, profit distributions, senior executive dismissals, and bankruptcy, according to China's State-owned Assets Law.

[8] Local governments hold the approval authority for new investments by firms, which they can use as a credible threat to intervene in the current investment of firms operating within their jurisdiction. Also, as firms usually encounter upfront cost (preliminary research, land transfer, and etc.), they are vulnerable to local governments' repeal of previously granted permits and land use rights if they do not conform to the wishes of the local authorities.

$$CF_i = \frac{D_i}{Y_i}, \quad (1)$$

where i indicates province, CF_i indicates the capacity factor of coal power generators in province i, defined by average power generated divided by rated peak power, D_i is the load demand to be served by coal power in province i at time of investment, and Y_i is existing coal power supply in province i at time of investment.[9]

Historically, operation hours of generation facilities have been highly correlated with economic performance (i.e. GDP growth). While operation hours may fluctuate due to economic cycles and shocks, China successfully maintained an average of more than 5000 hours per plant per year from 1978 to 2013,[10] and few people in the power industry were seriously concerned about the momentum of China's economic growth and associated growth in energy demand.[11] Because of this history, we assume that investors in coal power plants presume the capacity factor of a province (average annual operation hours) to be relatively stable in the long run. In addition, they ignore the marginal effect of their own investment on the province's overall capacity factor – we verified this by talking to industry experts in China, including a coal power plant CEO, who acknowledged the fact that they would plan new projects as long as the region's existing operation hours meet their threshold. This CEO also claimed that if his firm did not invest in new coal power capacity under current incentives, other firms would.

From an economic perspective, equal allocation of inelastic electricity demand across producers creates a strong "business-stealing" effect, and when the effect combines with an administratively set price that guarantees a marginal profit for most producers and low

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[9] CF_i can also be calculated by coal power's annual average operation hours divided by 8760h per year

[10] (Wu, 2009) and authors' calculations with more recent data.

[11] Interview and conversation with coal power plant CEO in Jilin province.

administrative barriers for new capacity ("free entry") under the decentralized approval regime, private investments tend to be excessive relative to the social optimum (Mankiw & Whinston, 1986). We ignore the integer constraint on power plants so that investment (capacity) can be treated as continuous. A firm therefore selects capacity s to maximize profit:

$$\pi(s) = P_i q_i^e(s) - c_i(q_i^e(s)) - F(s) - A_{i,d}(s) \tag{2}$$

where P_i is the administered wholesale electricity price in province i, q_i^e is expected lifetime generation output given capacity s, $c_i(q)$ is variable cost to produce output of q, $F(s)$ is the fixed cost to invest capacity s, and $A_{i,d}(s)$ is the administrative cost of government approval. Consistent with Figure 4, this administrative cost varies with capacity s and depends on the relevant approval regime, as indicated by d, which equals 0 before the decentralization and 1 after.

The firm's first-order condition is:

$$\pi'(s) = q_i^{e\prime}(s)\big(P_i - c_i'(q_i^e(s))\big) - F'(s) - A_{i,d}{}'(s) = 0 \tag{3}$$

Having invested in capacity according to (3), firms then produce electricity output q, as assigned by government regulators. Since regulators set each firm's output to achieve the common provincial capacity factor in (1), the firm's expected output given its chosen capacity s is

$$q_i^e = CF_i^e \cdot s \tag{4}$$

Substituting this into the first-order condition yields

$$CF_i^e \left(P_i - c_i'(q_i^e(s))\right) = F'(s) + A_{i,d}'(s). \tag{5}$$

Equation (5) shows that firms will invest up to the point where their marginal cost of investment is equal to the expected marginal profit of investment. Because the cost of capital generally rises with the scale of investment, we assume $F'(s) > 0$ and $F''(s) > 0$. Based on Figure 4, we can also assume the total administrative cost to be approximately linear in the size of capacity investment, which means the slope of $A(s)$ is a positive constant: $A'(s) = a > 0$. Figure 4 also shows that decentralization of approval from the central to provincial governments significantly lowers marginal approval cost, as seen in the flatter slope of the approval time profile after decentralization. Therefore, we have $A'_{i,d=0}(s) > A'_{i,d=1}(s)$, or $a_{d=0} > a_{d=1}$.

We illustrate the equilibrium in Equation (5) in Figure 5. The left-hand-side of (5) is the expected marginal benefit of investment. One unique feature of the coal power industry is that fuel costs constitute the majority of variable cost (60% – 70% in China).[12] Therefore, the marginal cost of generation $c_i'(q_i^e)$ will be principally driven by the fuel cost (coal price) in province i. Also, since the electricity price P_i is administered, the marginal profit $\left(P_i - c_i'(q_i^e)\right)$ for coal power generation will be highly correlated across plants within a province. For expositional purposes, Figure 5 assumes a constant marginal cost of generation, implying a constant marginal profit of investment. Our qualitative conclusions are identical with convex generation costs. The right-hand-side of Equation (5) is the marginal cost of investment, consisting of the marginal fixed cost $F'(s)$ and marginal administrative cost a.[13] Firms therefore maximize profits by investing in capacity s_1 of coal power, at which the marginal benefit meets the marginal cost of investment.

[Figure 5 about here.]

By the end of 2014, however, approval authority was decentralized to provincial level. This decentralization policy effectively lowers the marginal administrative cost of project

[12] (Lin, 2017) http://paper.people.com.cn/zgnyb/html/2017-09/04/content_1803137.htm
[13] Prior to November 2014, approval authority is solely retained by the central government, and thus the marginal administrative cost a_0 does not vary by province.

approval as discussed above, which shifts the marginal cost of investment curve down, while leaving everything else constant. Notice that the optimal investment level (s_{2i}) will now vary by i because provinces may have different marginal administrative costs following the decentralization policy.

In addition to decentralization of approval authority, coal prices had been falling since 2012, and adjustment of electricity prices had lagged behind. Figure 6 shows the changes in national average electricity wholesale price and the coal price from 2014 to 2015. The growing gap implies an increasing marginal profit of generation.[14] This increases the marginal benefit of investment and moves the horizontal line in Figure 5 upward, raising private optimal investment levels to s_{3i}. An increase in the coal price shrinks the marginal profit of generation and has the opposite effect.

[Figure 6 about here.]

Therefore, the model predicts an increase in the level of private investment in coal power after decentralization of approval authority. Also, higher marginal profit should lead to increased capacity investment. We will examine the effects of these two factors in the empirical analysis below. In addition, we test the hypothesis of provincial heterogeneity in exploitation of the decentralization policy based on political incentives embedded in China's cadre evaluation system.

[14] Appendix figures A1-A3 show changes in provincial electricity wholesale prices, coal prices, and marginal profits from March 2012 to March 2016.

4. Empirical Analysis

4.1 Data

In this section, we empirically assess the effect of the approval decentralization policy on coal power investment in China, and also seek to explain the provincial heterogeneity in that effect. We manually collected a dataset of China's coal-fired power project "approval records" from June 2013 to March 2016 across 30 provinces and province-level subnational administrative units, excluding Tibet. A total of 313 approved projects were collected from government websites, power companies' websites, and online news sources.[15] We confirmed the completeness of our data coverage by cross checking with Green Peace's dataset of coal-fired power projects registered with the Ministry of Environmental Protection. The study period ends in March 2016 because, starting from that month, the Chinese central government issued a series of policies to halt the approval and construction of new coal power plants after realizing the vast extent of overcapacity.[16]

On October 31st, 2014, the State Council released the revised *National Investment Project Catalogues*, decentralizing the approval authority of thermal power stations to provincial governments, so the decentralization policy went into effect starting in November 2014.[17]

Table 3 summarizes the implementation of the policy. It shows that the policy is fully implemented within months after its issuance at the end of October in 2014: there is a significant reduction in central-government approvals. Table 4 summarizes the number of projects and the amount of generating capacity approved before and after the decentralization policy was issued. Each period spans 17 months.

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[15] Most records are collected from provincial NDRC websites and news published by http://www.bjx.com.cn
[16] See footnote 5.
[17] Government Investment Project Approval Catalogue (2014) http://www.gov.cn/zhengce/content/2014-11/18/content_9219.htm

[Table 3 about here.]

[Table 4 about here.]

The approval records are incorporated into a panel dataset, with the dependent variable being coal power capacity approved. These data vary by province and month from 2013 June to 2016 March. However, because not every province approved coal power projects every month and there are often months that approved multiple projects, the data are sparse and highly variable: 80% of the dependent-variable entries are zero. The choice of independent variables depends on the hypothesis and the selected model. Table 5 lists the main variables used in this study, their units, and summary statistics. We use the number of full-load operation hours to indicate generators' capacity factor, as capacity factor is calculated by dividing the number of full-load operation hours by the total number of hours in a year.

[Table 5 about here.]

4.2 Empirical Approach

The economic model predicts that decentralization of approval power leads to higher investment in coal power because of lower administrative costs. We assess the effect of the decentralization policy on coal power investment in each province using the following baseline specification.

$$Capacity_{it} = \alpha_i + \gamma_s + \beta_1 P_t + \beta_2 MP_{it} + \beta_2 OH_{iy} + \varepsilon_{it}, \quad (6)$$

where $Capacity_{it}$ is the capacity approved for province i during month t, γ_s is a season dummy (winter, spring, etc.), $P_t = 1$ indicates months after the decentralization policy went into effect, MP_{it} is the lagged 12-month moving average of marginal profit for a representative coal-power generation company in province i during month period t, and OH_{iy} is the 1-year lagged number of operation hours of coal power units in province i. We expect to find that the policy led to increased coal capacity, i.e. $\hat{\beta}_1 > 0$.

The impact of the central government's handover of entry regulation authority to the provinces may also vary across provinces. Figure 7 shows monthly average coal production and coal power approvals by province in our dataset, and we can see that provincial heterogeneity in the approval rate is much greater after decentralization than before. We hypothesize that provinces that already have a relatively large coal mining industry may be more likely to permit the construction of new plants, because this will raise demand for another important local industry, and hence boost local officials' economic performance, a key criterion in China's cadre evaluation system (see Section 2). Also, large coal-mining industries may have more political power to lobby the government for permission to build more coal power plants. We therefore estimate the following interaction model.

$$Capacity_{it} = \alpha_i + \gamma_s + \beta_1 P_t + \beta_2 C_{it} + \beta_3 P_t * C_{it} + \beta_4 MP_{it} + \beta_5 OH_{iy} + \beta_6 GDP_{iy} + \varepsilon_{it} \quad (7)$$

where C_{it} is the lagged 12-month moving average of coal production in province i and GDP_{iy} is the lagged 1-year GDP growth rate (in percentage terms) of province i. All other terms follow specification in equation (6). Because we hypothesize that more coal intensive regions will respond more strongly to the policy, we expect that $\hat{\beta}_3 > 0$.

[Figure 7 about here.]

4.3. Results

Table 6 shows the results of estimating the baseline specification in equation (6). As expected, we find that the decentralization policy has a significant positive effect on coal-power project approval and dominates the effect of the other factors. Table 6 column (3) shows that governments approved about 360MW more coal power capacity per month after decentralization of approval authority. This is a very large effect, since the average monthly approval was only 120MW before decentralization. Note that the standard errors in Table 6 are clustered by province.

[Table 6 about here.]

Because the dependent variables are nonnegative count data with overdispersion, we apply a fixed-effect negative binomial model to control for conditional means and variances.[18] Using a fixed-effect negative binomial model, Table 7 also shows that the approved capacity of coal power is about 3 times higher when the approval authority is decentralized.[19] We also find that the implementation of the decentralization policy mediates the effect of marginal profit, such that the significance of marginal profit declines when the policy dummy variable is included. This means that the policy effect dominates the increase in approval records in the decentralized regime. Because most variation in operational hours is cross provincial rather than over time, the effect of operation hours is not significant when provincial fixed effects are included.

[Table 7 about here.]

[18] We include an indicator variable for each province to control for conditional means of the negative binomial model, suggested by https://statisticalhorizons.com/fe-nbreg#comments

[19] Observations of two municipalities (Beijing and Shanghai) are omitted in the fixed-effect binomial model because of no approvals throughout the study period.

By interacting our decentralization policy dummy with lagged measures of provincial coal production in Table 8, we find that provinces with a larger local coal industry are more likely to approve new coal power investment following decentralization. This effect is statistically significant and economically large, with the coefficient on this interaction term implying that each additional million tons of local coal production is associated with 15 MW of additional coal power capacity approved on a monthly basis after decentralization, other things being equal.[20] Since an average province produced about 10 million tons of coal per month in 2015, this implies that an additional 54GW of coal power was approved due to local coal production in 2015 (other things equal), which is roughly 1/4 of total approved capacity in that year. Using the coefficients from Table 8, we can also get a sense of the effect of GDP growth on coal power approval. Our estimated coefficients imply that a 1% increase in provincial GDP is associated with 28MW of additional coal power approval per month for a province, other things equal. Note that provincial characteristics are lagged by one year. Specifically, since coal production and marginal profit have monthly variation, we use lagged moving averages of past 12 months to capture investors' expectations for these two factors.

[Table 8 about here.]

5. Discussion

Historically, China has struggled to meet its electricity demand in a reliable and efficient manner. Dating back to the 1980s, China experienced chronic power shortages and relied on "demand planning" to allocate limited power resources to municipalities and counties via a quarterly "electricity use quota" (Kahrl & Wang, 2014; Wang & Chen, 2012). After three

[20] The direct impact of local coal production is insignificant, indicating that under centralized approval regime, coal power project approval was not affected by local coal production level.

decades of "reform and opening" in the power industry, China's power shortage has been largely relieved, but instead of achieving a stable balance between energy demand and supply, the Chinese government put in place policies leading to a significant coal power investment bubble.[21] As the government became aware of the overcapacity emerging in coal power generation, it took actions to suspend ongoing projects and prevent further investment, and initiated a new round of reforms to experiment with liberalization of the wholesale electricity market.

However, achieving long-term efficiency in energy investment may be particularly challenging for China. When it comes to development of renewable energy and reform of the electricity sector, China is viewed as having very diverse development goals that can come into conflict with one another – including energy security, socio-economic development (developing local industry, providing employment, lessening rural-urban inequalities and consequent migration, etc.), and environmental protection (García, 2011). The empirical findings of this paper support this theory by showing that coal-abundant provinces tend to approve more coal power projects when approval authority was decentralized, reflecting the various conflicts in the incentives facing local government leaders. Effective reconciliation of these conflicting goals will be a necessary but difficult step on the way toward a more socially efficient energy system.

6. Conclusion

Even as China was aggressively promoting renewable energy in the 2000s, investment in coal-fired power surged, raising concerns of overcapacity and exacerbating renewable power

[21] In 1985, Chinese government allowed the domestic private enterprises and foreign investors to invest in generators sector, and by 1997, the nationwide chronic power shortage had been by and large relieved (Wang & Chen, 2012). In 2002, *the Scheme for the Reform of Power Industry*, was enacted to dismantle the vertically integrated public utility into multiple generation companies to foster competition and power investments.

curtailment. The overall capacity factor of China's power generation facilities has declined by almost 30% from 2005 to 2015, and wind and solar curtailments have been rampant across Chinese provinces. In face of declining operation hours and high renewable curtailments, China further approved nearly 200 GW of new coal power capacity in 2015, which was almost 1/4 of total incumbent coal power capacity. At a time when China is trying to limit carbon emissions, contend with severe air pollution, and adjust to a smaller role of heavy industry, such investment in coal power could come at a high social cost.

In this paper, we ask why China engaged in such a pronounced investment boom in coal power in the mid-2010s. The paper contributes to the growing literature on the importance of incentives in the ongoing reform of China's energy system. We find the protective rules under which China's coal power have historically operated have made excessive investment extremely likely unless the central government serves as a "gatekeeper" slowing and limiting investment in the face of incentives for socially excessive entry. When coal-power project approval authority was decentralized from the central government to local governments at the end of 2014, the gate was lifted and approval time considerably shortened, reducing the cost of entry for generation companies. We also show that decentralized approval authority was most likely to be abused by local governments, given the importance of short-term economic growth in the career advancement of local officials. Empirically, we find an economically and statistically significant positive effect of decentralization of approval authority on coal power project approval. The approval rate of coal power was about 3 times higher when the approval authority was decentralized. Also, provinces with a larger coal industry were more likely to approve new coal power investment. We estimate that local coal production accounted for an additional 54GW of approved coal power in 2015 (other things equal), which is about 1/4 of total approved capacity in that year. These empirical findings are consistent with our economic model and with current scholarship on China's political economy.

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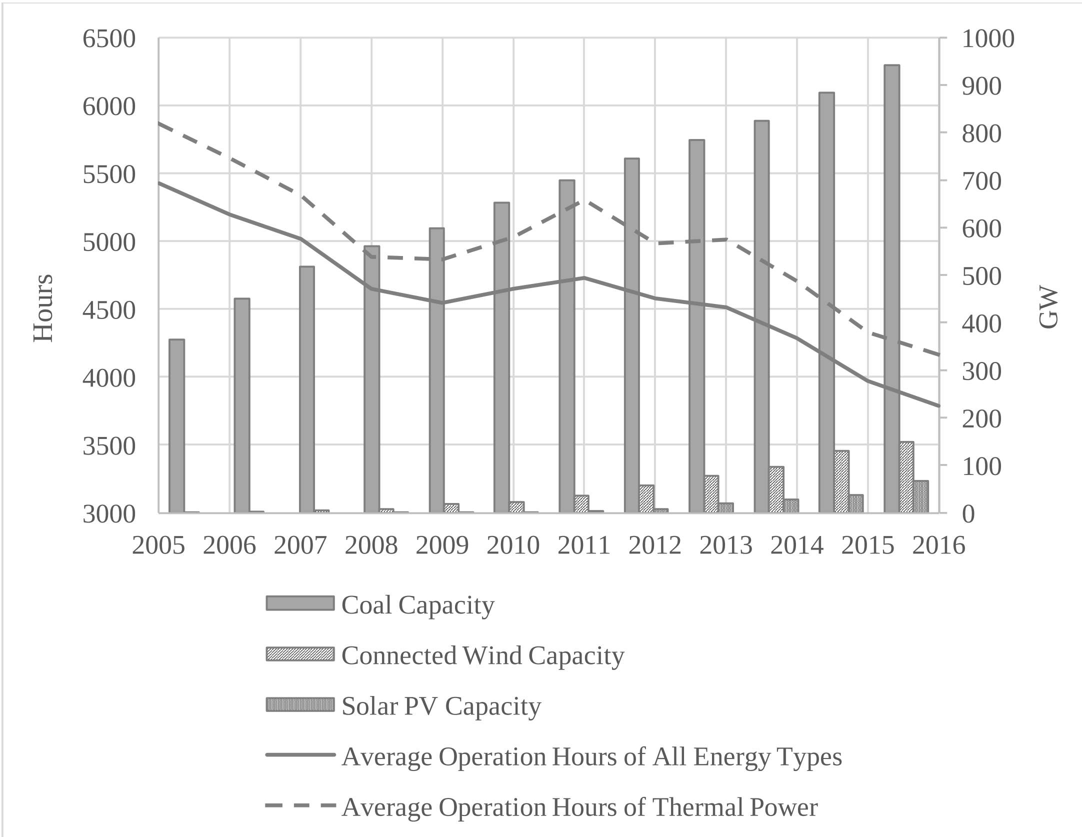
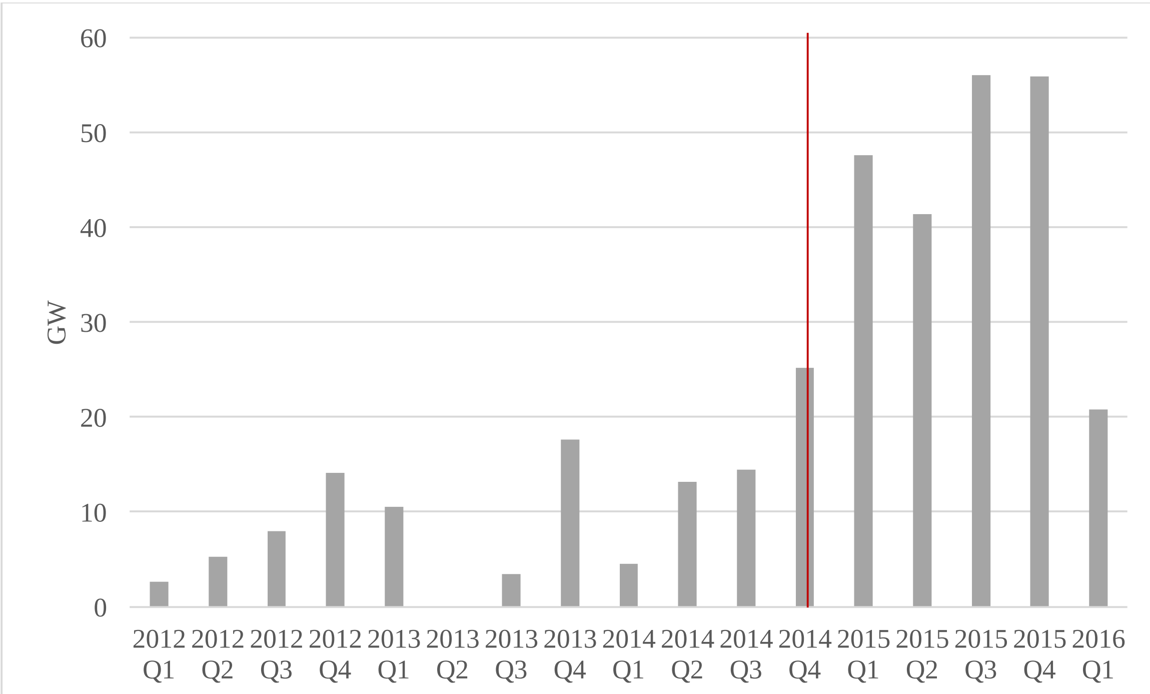
Figure 1. Power Generation Capacity and Annual Operation Hours in China



Sources: National Energy Adminiatration (NEA) of China

Figure 2. Coal Power Capacity Approved in China



Sources: authors' compilation from government websites, power companies' websites, and online news sources.[22]

[22] Most records are collected from provincial NDRC websites and news published by http://www.bjx.com.cn

Figure 3. Time from MEP Pre-approval to NDRC Final Approval

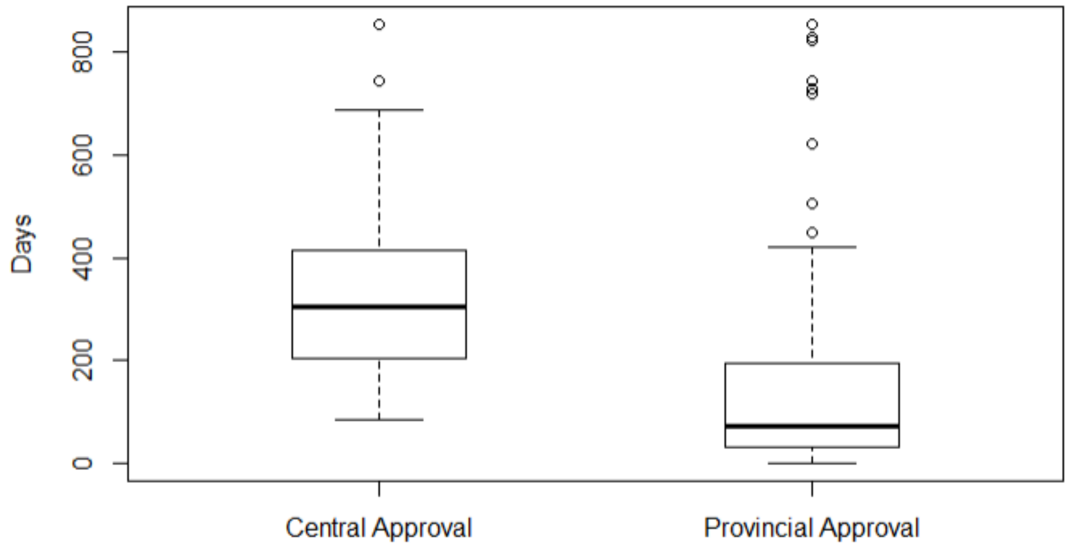
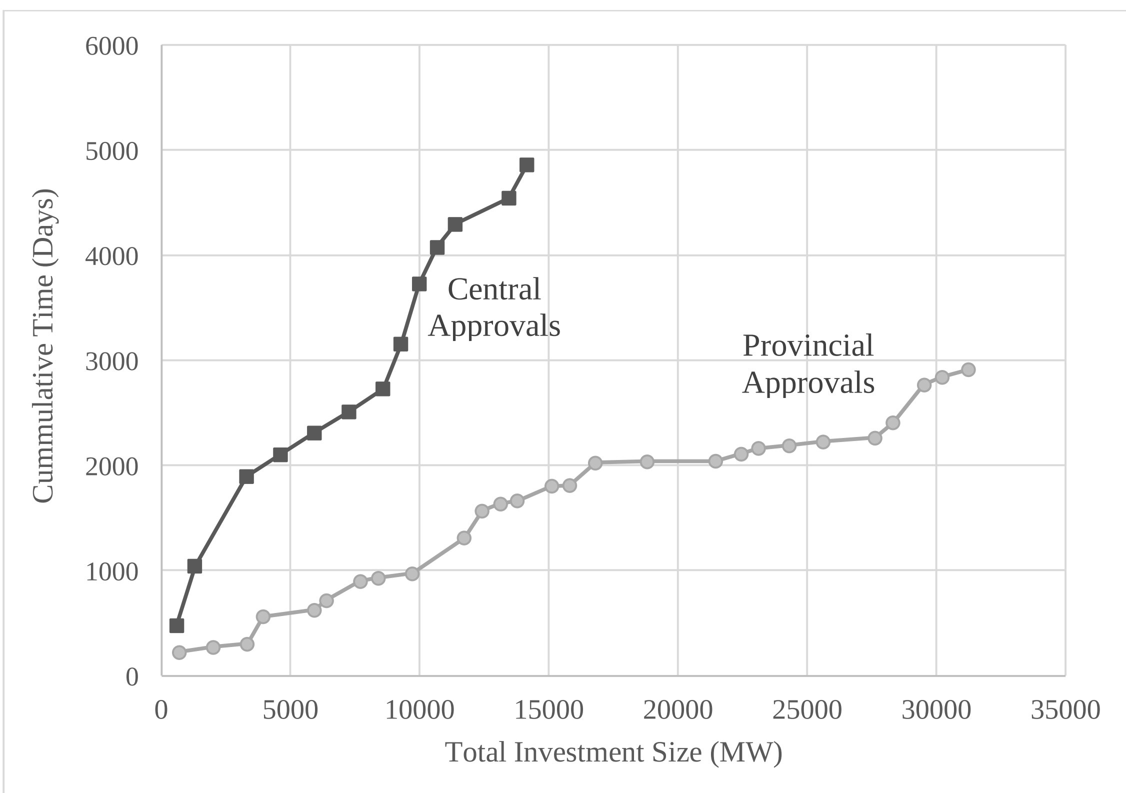


Figure 4. Proxy for Administrative Cost of Coal Power Investment

Time from MEP Pre-approval to NDRC Final Approval



Sources: Greenpeace China, authors' compilation, data sample of Big Five's projects

Figure 5. Firms' Optimal Investment Level with Higher Profit Margin

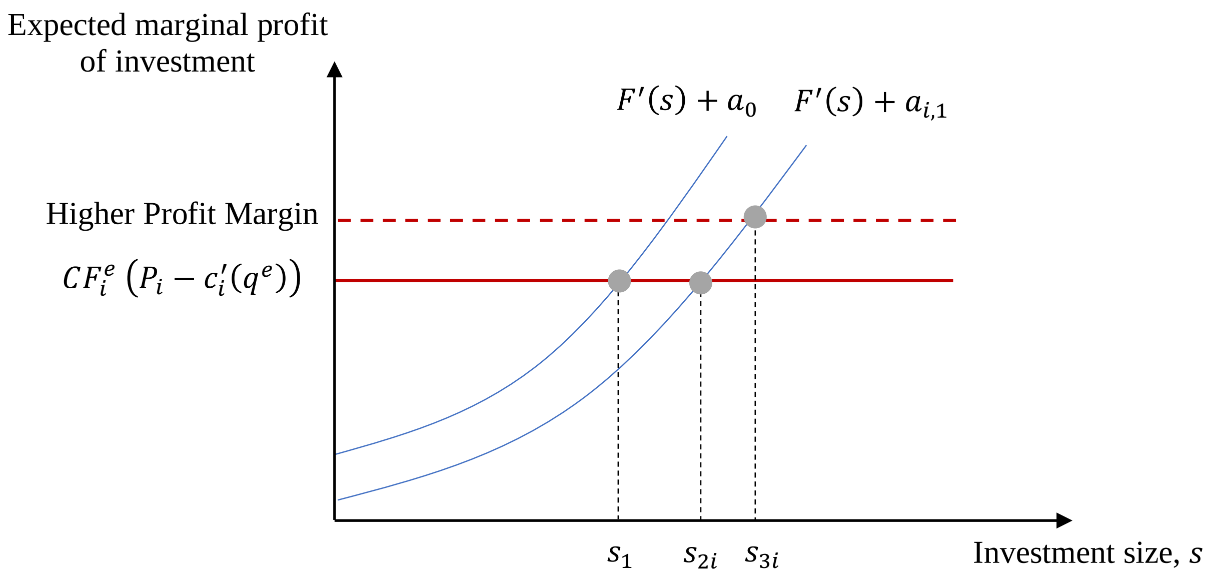
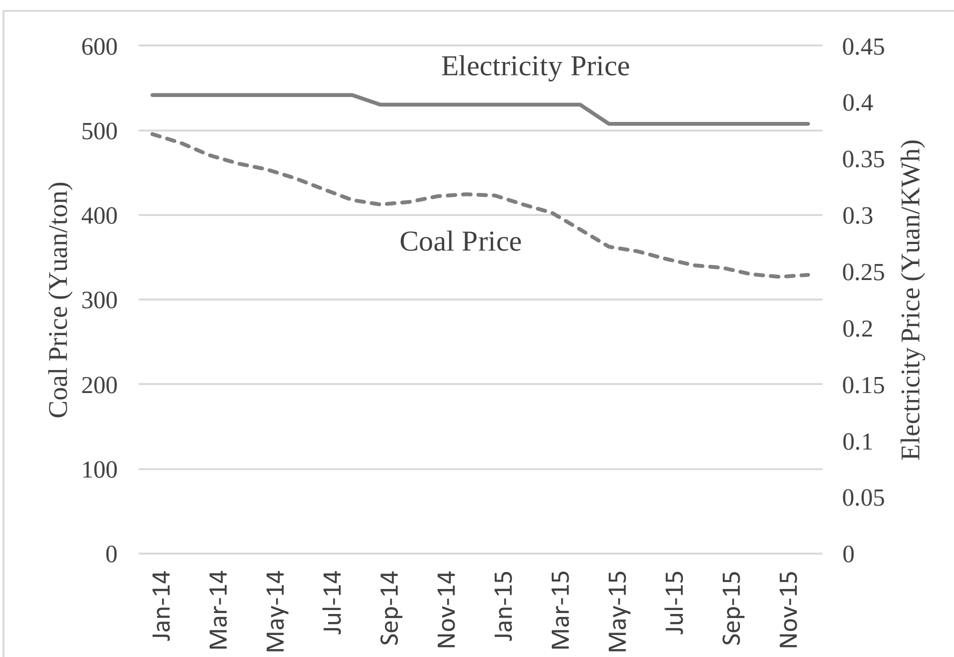
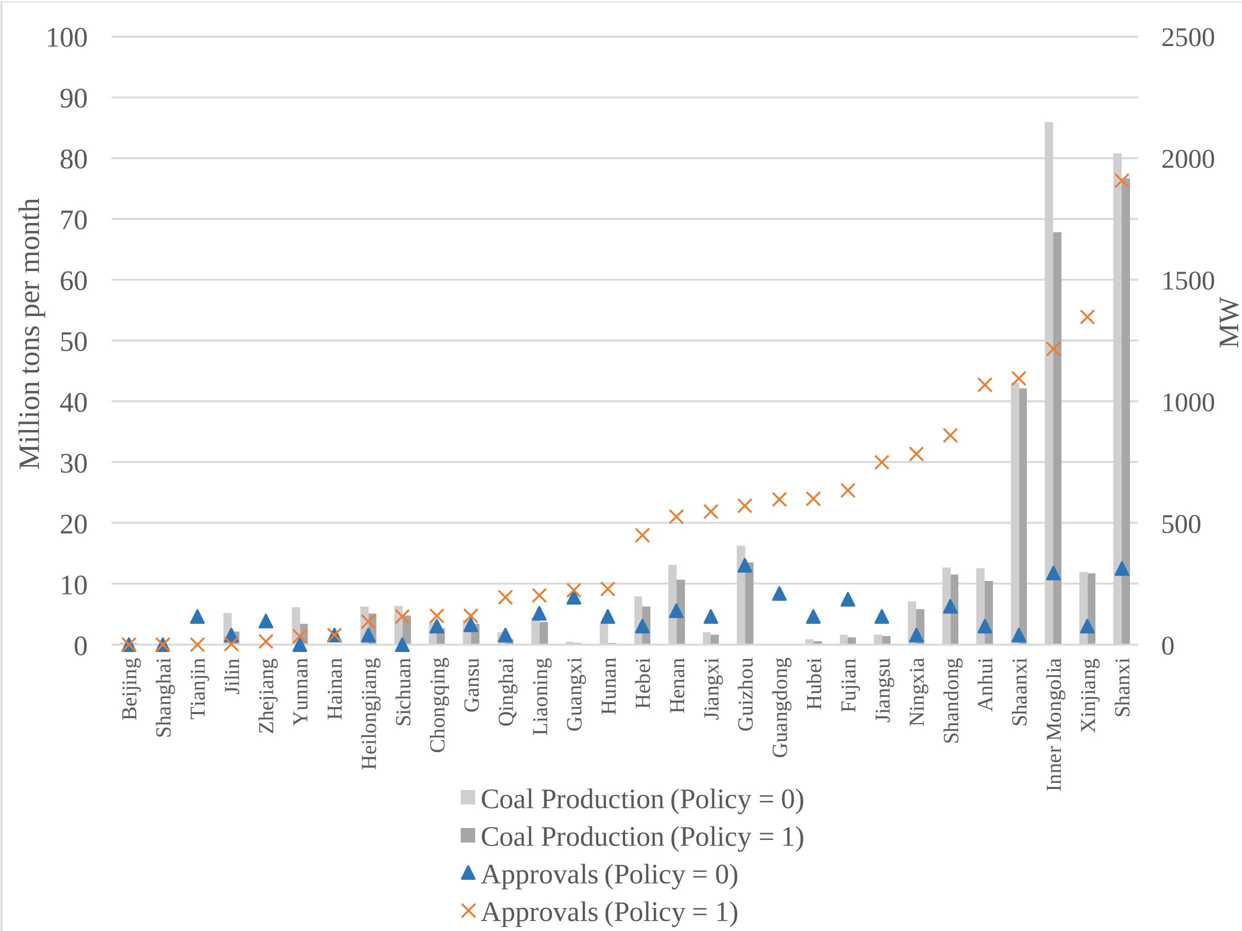


Figure 6. National Average Electricity Wholesale Price and Coal Price, 2014-2015



Source: NDRC, coal price from NDRC Price Monitoring Center, available since 2014

Figure 7. Monthly Coal Production and Average Capacity Approved by Province



Notes: monthly coal production and coal power capacity approved by province, before and after decentralization of approval authority in 2014

Sources: monthly coal production data from http://energy.ckcest.cn/home

Table 1. Curtailment Rates of Connected Wind and Solar PV Power in Chinese Provinces

	Wind Curtailment			Solar PV Curtailment	
Province	2014	2015	2016	2015	2016
Gansu	11%	39%	43%	31%	30.45%
Hebei	12%	10%	9%		
Heilongjiang	12%	21%	19%		
Inner Mongolia	9%	18%	21%		
Jilin	15%	32%	30%		
Liaoning	6%	10%	13%		
Ningxia	0%	13%	13%	9.30%	7.15%
Shanxi	0%	2%	9%		
Xinjiang	15%	32%	38%	26%	32.23%
Yunnan	4%	3%	4%		

Sources: National Energy Adminiatration (NEA) of China

Table 2. Generation Capacity and Electricity Demand Growth from 2010 to 2015

Installation	Unit	2010	2015	Change
Coal Power	GW	660	884	224
Hydro Power	GW	220	319	99
Wind Power	GW	31	128	97
Solar Power	GW	0.86	42	41
Natural Gas Power	GW	26	66	40
Nuclear Power	GW	11	27	16
Total Installed Capacity	GW	949	1467	518 (55%)
Total Electricity Consumption	Trillion KWh	4.2	5.8	1.60 (38%)
Estimate of Average Operation Hours	Hours per year	4425	3954	-471

Sources: National Bureau of Statistics in China, authors' compilation

Table 3. Implementation of Approval Authority Decentralization

Month	Capacity Approved by Central Government (%)	Projects Approved by Central Government (%)
2014 Jan - 2014 May	84.2%	82.4%
2014 June - 2014 Oct	84.7%	76.5%
2014 Nov - 2015 March	9.0%	9.2%
2015 Apr - 2015 Aug	0.0%	0.0%

Table 4. Capacity and Projects Approved Before and After Policy Issuance

Period	Number of Projects Approved	Total Capacity Approved	Average Capacity Per Project
Before	56	57440	1026
After	253	239696	947
Total	309	297136	962

Table 5. Summary Statistics

Variable Name	Obs.	Mean	Std. Dev.	Min	Max
Monthly Capacity Approved (megawatt)	1,020	298.17	822.24	0	6600
Monthly Capacity Approved Per Capita (watt/person)	1,020	9.76	42.30	0	795.22
Lagged Monthly Moving Averages of Marginal Profit (cents/KWh)	1,020	19.35	4.17	8.36	28.33
Lagged Monthly Moving Averages of Coal Production (million ton)	1,020	10.79	20.13	0	89.74
Lagged Annual Operation Hours	1,020	4.47	0.80	1.88	6.17
Lagged Annual GDP Growth Rate	1,020	8.92	4.03	-0.17	20.18

Table 6. The effect of decentralization on capacity approved – linear regression

	(1)	(2)	(3)
VARIABLES	Capacity Approved	Capacity Approved	Capacity Approved
1(Policy)	389.4***		358.2***
	(86.02)		(100.4)
Lagged Marginal Profit		99.90***	25.41
		(26.52)	(26.82)
Lagged Operational Hours		84.13	142.5
		(86.57)	(91.78)
1(season 2)	82.53	48.59	64.99
	(73.52)	(71.43)	(71.96)
1(season 3)	133.6	78.26	115.1
	(89.66)	(84.15)	(87.82)
1(season 4)	138.9**	123.7**	115.5*
	(63.10)	(60.06)	(61.19)
Provincial Fixed Effects	Yes	Yes	Yes
Observations	1,020	1,020	1,020
R-squared	0.062	0.048	0.064
Number of provinces	30	30	30

Standard errors clustered by province in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Notes: Monthly coal power capacity approved by province, June 2013 to March 2016. Regressions include provincial fixed effects. Standard errors are clustered by province. Marginal profits are lagged moving averages of past 12 months for each province (extrapolation method in Appendix Figure A3). Annual operation hours are lagged 1 year for each province.

Table 7. The effect of decentralization on capacity approved – negative binomial

VARIABLES	(1) Capacity Approved	(2) Capacity Approved	(3) Capacity Approved
1(Policy)	1.561***		1.127***
	(0.175)		(0.271)
Lagged Marginal Profit		0.394***	0.156*
		(0.0574)	(0.0815)
Lagged Operational Hours		-0.0724	0.00543
		(0.330)	(0.336)
1(season 2)	0.250	0.334	0.301
	(0.217)	(0.228)	(0.224)
1(season 3)	0.297	0.208	0.304
	(0.215)	(0.224)	(0.222)
1(season 4)	0.406**	0.530**	0.466**
	(0.189)	(0.206)	(0.207)
Provincial Fixed Effects	Yes	Yes	Yes
Observations	952	952	952
Number of provinces	28	28	28

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Notes: Monthly coal power capacity approved by province, June 2013 to March 2016. Negative binominal regressions include provincial fixed effects of means and variances. [23] Standard errors are heteroskedastic robust. Marginal profits are lagged moving averages of past 12 months for each province (extrapolation method in Appendix Figure A3). Annual operation hours are lagged 1 year for each province.

[23] See footnote 18.

Table 8. Heterogeneity by provincial coal production – linear regression

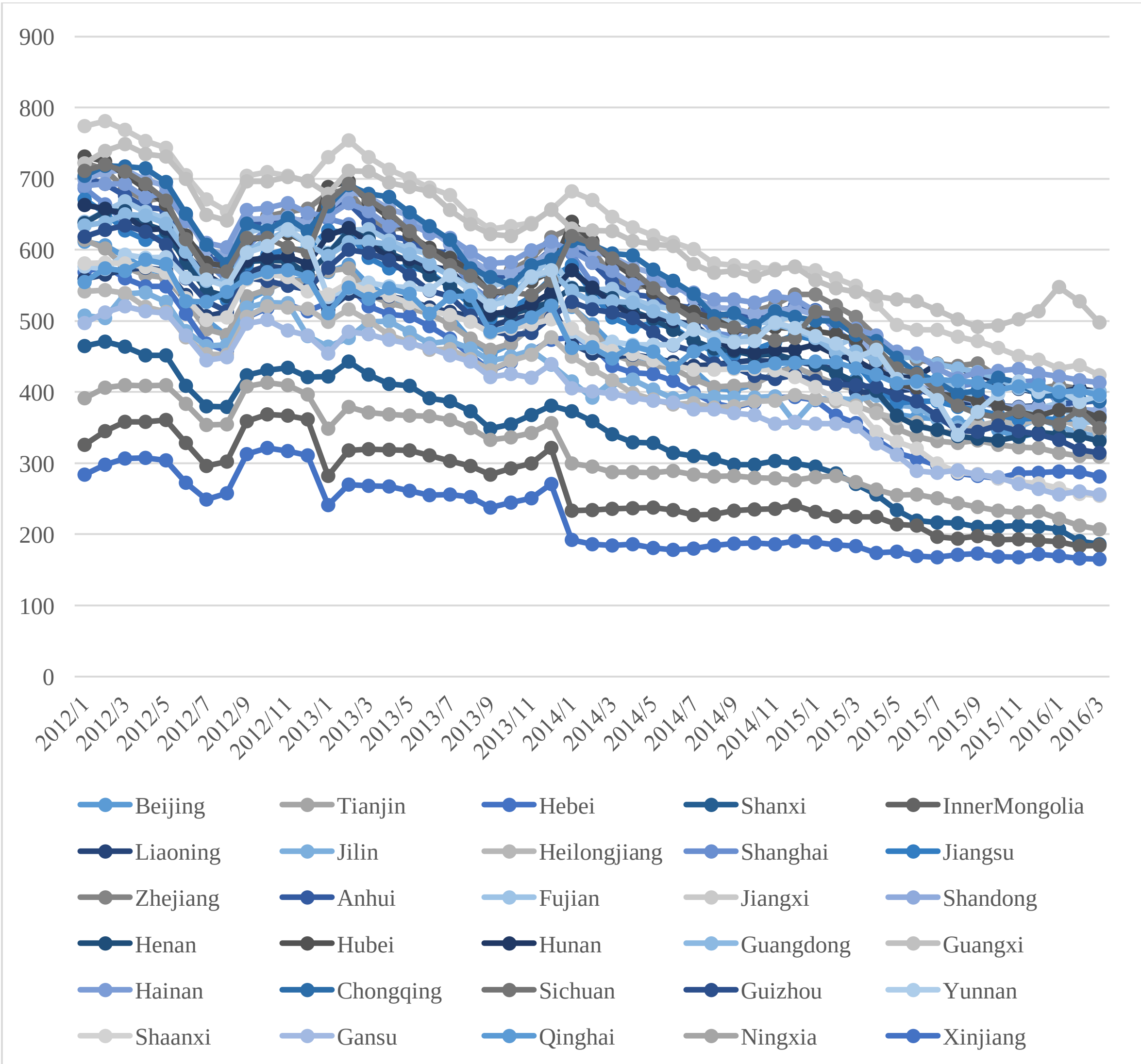
VARIABLES	(1) Capacity Approved	(2) Capacity Approved	(3) Capacity Approved
1(Policy)	241.7***	189.3**	172.1*
	(66.25)	(90.13)	(88.19)
Lagged Coal Production	9.365	8.262	5.548
	(10.04)	(10.47)	(9.547)
1(Policy) x Lagged Coal Production	15.07***	14.95***	15.48***
	(2.621)	(2.573)	(2.628)
Lagged Marginal Profit		22.19	52.96*
		(25.00)	(27.22)
Lagged Operational Hours		43.36	-22.15
		(75.70)	(90.32)
Lagged GDP Growth Rate			28.15**
			(12.00)
1(season 2)	80.96	76.42	14.69
	(73.61)	(74.86)	(91.28)
1(season 3)	135.3	128.5	58.77
	(89.98)	(89.58)	(102.1)
1(season 4)	137.5**	132.4**	50.78
	(63.12)	(63.11)	(80.49)
Provincial Fixed Effects	Yes	Yes	Yes
Observations	1,020	1,020	1,020
R-squared	0.099	0.100	0.104
Number of provinces	30	30	30

Standard errors clustered by province in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Notes: Monthly coal power capacity approved by province, June 2013 to March 2016. Regressions include provincial fixed effects. Standard errors are clustered by province. Coal production and marginal profits are lagged moving averages of past 12 months for each province (extrapolation method for marginal profits is in Appendix Figure A3). Annual operation hours and GDP growth rates are lagged 1 year for each province.

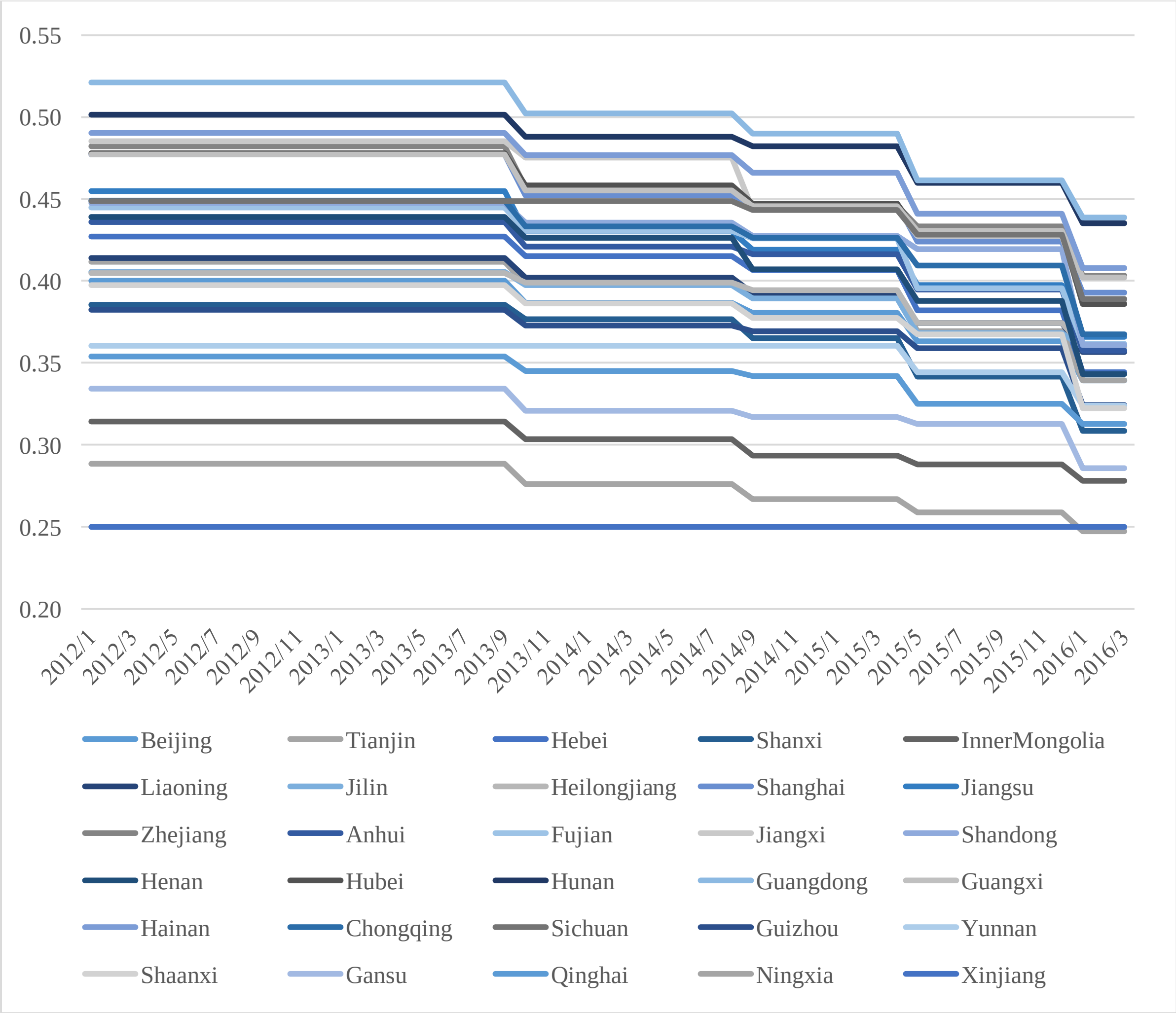
Appendix

Figure A1. Declining Coal Prices in China from 2012 Jan to 2016 March



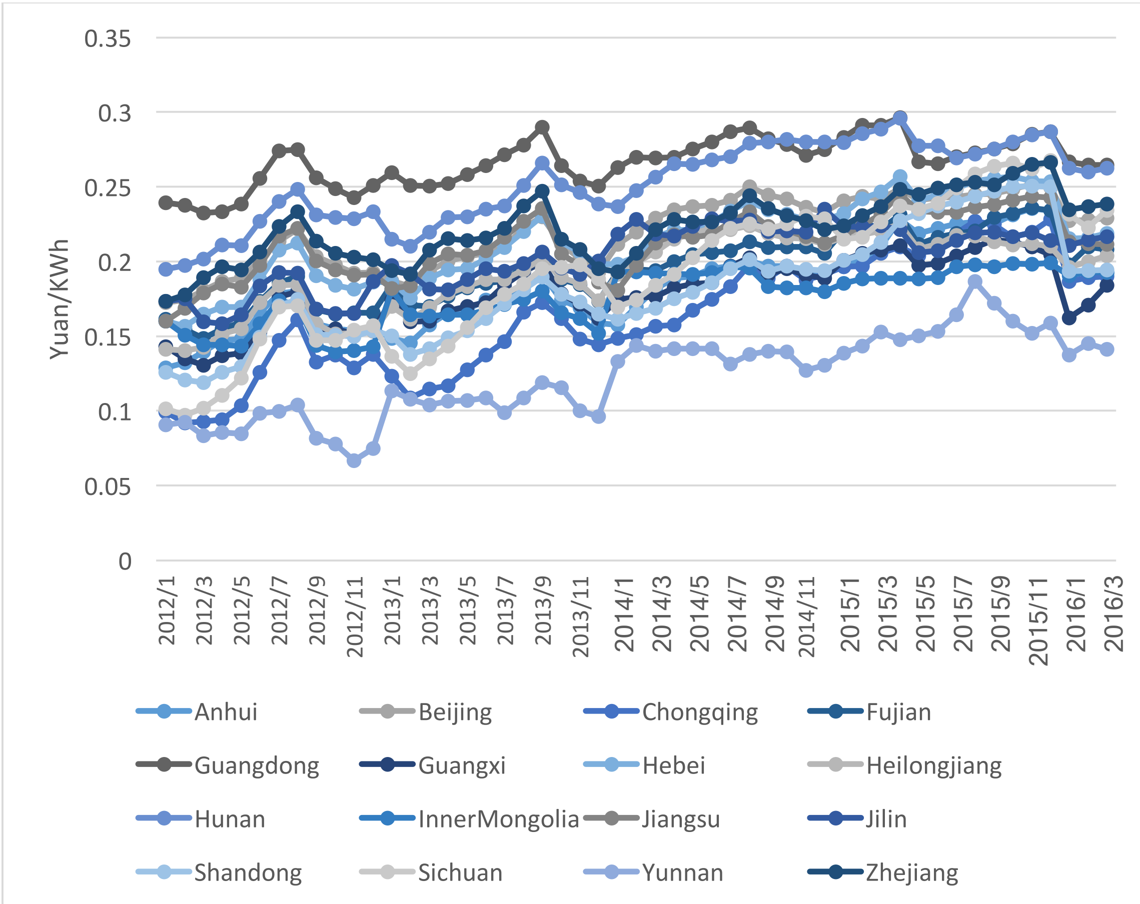
Notes: Coal prices from January 2014 to 2016 March are released by NDRC Price Monitoring Center. They are normalized prices to represent coals of 5,000 kcal (calorific value) in each province. Hence, we call them "normed coal prices" in this study. The monitoring area covers 30 provinces (except Tibet). The prices are sampled from the province's main coal Power generation enterprises, main coal production enterprises, main coal transport ports and coal traders, including more than 1,600 enterprises. Prices before 2014 are imputed using monthly coal prices published by Shanghai Coal Trading Center. Provincial variances are introduced from NDRC's monitored prices in 2014.

Figure A2. Wholesale Electricity Prices of Coal Power Generation, 2012 January to 2016 March



Sources: NDRC, figure shows the benchmark prices for desulfurized coal-power electricity. By end of 2014, 91.4% of coal power generation units have gas desulfurized.

Figure A3. Average Marginal Profits of Coal Power Generation, 2012 January to 2016 March



Notes: Marginal Profit is calculated as $Ongrid\ Price - Normed\ Coal\ Price * Normed\ Coal\ Consumption\ Rate$, where normed coal consumption rates (5,000 kcal coal) are converted from provincial "standard coal consumption rates (7,000kcal coal)" published in China Electric Power Annual Development Reports.