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Spatial Distribution of Coal-Fired Power Plants in China

Lunyu Xie, Ying Huang, and Ping Qin

Abstract

Coal has fueled China's fast growth in the last decades, but it also severely pollutes the air and causes many health issues. The magnitude of the health damage caused by air pollution depends on the location of emission sources. In this paper, we look into the spatial distribution of coal-fired power plants, the major emission sources in China, and investigate the determining factors behind the distribution. We see an overall increase in installed coal-fired power capacity in recent years, with capacity leaps in some provinces. We find that the driving factors are economic development and expansion of electricity grid coverage; the latter factor plays a key role in provinces that are less developed but have abundant coal resources.We also find that firms react to utilization hours, which are assigned by the government, but not to electricity prices, which are set by the government as well. These findings suggest a way to reduce health damages caused by air pollution without harming the economy: attracting coal-fired plants to less populated areas by developing trans-province electricity trade and grid coverage.

Key Words: coal-fired power plant, economic geography, electricity price, factor endowment, installed power capacity, utilization hours

JEL Codes: Q32, Q41, R32

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Spatial Distribution of Coal-Fired Power Plants in China

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1. Introduction

Coal-fired power plants contribute significantly to greenhouse gases and local air pollution (World Bank 1997; Lopez et al. 2005; International Energy Agency 2012; Sueyoshi and Goto 2015). Although carbon dioxide from different locations contributes to greenhouse gases uniformly, the adverse effect of local pollutants on human health[1] and economic activities[2] depends highly on the spatial distribution of emission sources (Zhou et al. 2006; Greco et al. 2007). This implies that, holding total emissions unchanged, changing the spatial distribution of coal-fired power plants could reduce the health damages caused by air pollution. That is, it is possible to reduce the harm from power plants' emissions without harming the growth of an economy if a method can be identified to shift the location of power plants. In light of the fact that China accounts for half of the world's coal consumption (BP 2016) and uses half of that coal to generate electricity (International Energy Agency 2014), this paper investigates the spatial distribution of coal-fired power plants in China and identifies the factors driving the distribution.

A large literature, theoretical and empirical, studies the factors that potentially affect an industry's location. This literature can be divided into three main categories: the factor abundance hypothesis, new economic geography, and the pollution haven hypothesis. (1) The factor abundance hypothesis, pioneered by the Heckscher-Ohlin (HO) and Heckscher-Ohlin-Vanek (HOV) models, generally finds the importance of factor endowment in determining a country's production and export structure as well as an industry's location (Bowen et al. 1987; Davis et al. 1997; Romalis 2004; Gerlagh and Mathys 2011; Michielsen 2013). (2) New economic geography studies how economies of

*Lunyu Xie, Assistant Professor at Renmin University of China, lunyuxie@ruc.edu.cn. Ying Huang, Assistant Professor at Renmin University of China, yingh@ruc.edu.cn. Ping Qin (corresponding author), Associate Professor at Renmin University of China, pingqin@ruc.edu.cn.

[1]A partial list of literature on the impact of air pollution on human health includes Chay and Greenstone (2003), Neidell (2004), Currie and Neidell (2005), Currie et al. (2009), Coneus and Spiess (2012), Janke (2014), Luechinger (2014), and Tanaka (2015).

[2]For recent examples, see Ho and Nielsen (2007).

scale, transaction costs, and other geographical factors affect the spatial agglomeration of economic activities (Fujita 1988; Krugman 1991; Wen 2004). Some empirical studies combine the factor endowment hypothesis with new economic geography to investigate the determinants of firm location in practice (Ellison and Glaeser 1999; Midelfart-Knarvik et al. 2000; Crafts and Mulatu 2005; Gutberlet 2012). (3) The pollution haven hypothesis emphasizes the effect of environmental regulation, among other factors, on industries' location choices. A large empirical literature tests the existence of the hypothesis.[3] Although the findings are mixed, the baseline is that stringent environmental regulation does play a role in the location choices of highly polluting industries.

Most of the literature mentioned above, however, focuses on developed countries. Little attention is paid to developing countries and in particular to the siting decisions for coal-fired power plants. In China, electricity generated by coal is above 70 percent of the total electricity generation (China Energy Year Book 2013). With the massive use of coal for electricity generation, many cities in China are experiencing severe air pollution and policy-makers are faced with the difficult task of mitigating air pollution while supporting economic growth (World Bank 1997). Given that coal-fired power plants in China contribute greatly to air pollution and that the harm of the pollution varies across regions with different environmental capacity and population density (Ho and Nielsen 2007), it is important to look into the spatial distribution of coal-fired power plants in China and the driving factors behind the distribution.

The location choices for coal-fired power plants in China could differ from those in developed countries, which are market economies. In China, the electricity prices received by power firms are set by the central government and vary across provinces, and the utilization hours of power plants are allocated by the provincial government. This means that a power plant in China chooses price and potential utilization hours through location choice, instead of through production behavior, as in a market economy. Therefore, this paper also contributes to the literature by investigating how exogenously set prices and a production quota system affect an industry's spatial distribution.

We first build a dataset of provincial capacity of coal-fired power plants from 1998 to 2011. We then merge the dataset with location-specific characteristics, such as

[3] A partial list of the literature: Jaffe et al. (1995), Becker and Henderson (2000), List and McHone (2000), Greenstone (2002), Jeppesen et al. (2002), Taylor (2004), Kanbur and Zhang (2005), and Gong and Shen (2011).

coal reserves, GDP per capita, population, grid coverage, transportation capacity, electricity price, utilization hour quota, etc. With the provincial panel data, we look into the spatial distribution of power plants and empirically analyze the factors that drive this distribution.

We find that coal-fired power plants generally concentrate in the areas with large electricity markets. We also find that some provinces with abundant coal reserves had capacity leaps in recent years; the reason could be the development of the electricity grid. Furthermore, we find that a power plant reacts to utilization hours, but not to electricity prices. These findings imply that one way to shift coal-fired plants to areas with abundant coal resources but less population could be to encourage the construction of a trans-province electricity grid and the establishment of a trans-province electricity market.

The remainder of the paper is organized as follows. Section 2 introduces the framework of location decisions for coal-fired power plants. Section 3 looks into the evolution of power plants' spatial distribution and graphically investigates potential factors behind the distribution. Section 4 uses econometric models to formally investigate the correlation between the factors and the installed power capacity. Section 5 concludes.

2. Location Choice for Coal-Fired Power Plants

In 2002, China adopted a power industry reform with the purpose of encouraging the construction of power plants to alleviate the shortage of power supply. Before the reform, power generation, dispatch, transmission, and sale were integrated. They were planned by the central government and executed by the Ministry of State Electric Power Industry before 1998 and the State Power Corporation between 1998 and 2003. The 2002 reform separated power generation from power dispatch, transmission and sale. The State Power Corporation was divided into the State Grid Corporation and the Southern Grid Corporation. Generation firms were formed. Since then, the location choices of plants have been made by the generation firms, but the government has set the electricity price, which varies across provinces, and has allocated utilization hours across plants.[4] Therefore, resource endowment, market factors, and political factors all could have played a role in shaping the spatial distribution of power plants in China.

A location choice can affect a power plant's expected profit through affecting production costs. Transportation cost is one of the main costs. According to a report by the China Logistics Information Center, in 2011, about 60 percent of coal consumed in China was transported by rail, and, in some provinces, the transportation cost for coal amounted to about 40 percent of the retail price of coal. To save transportation costs, a firm may choose to build a plant close to coal resources. Besides transportation costs, transmission costs also could be high in some cases. In areas where grid coverage is low, connecting a large-capacity power generator to a grid usually involves extension or upgrade of the grid, which could be very costly in time and money.[5] To avoid such costs, a firm may want to build a plant where the grid coverage is more extensive. In sum, as proposed by the factor abundance hypothesis and new economic geography, a firm builds a plant in an area with abundant coal to save on transportation costs or in an area close to market to save on transmission costs. The firm must make tradeoffs if the two areas do not coincide, which is the case in China, as shown in Figure 1.

A location choice can also affect a power plant's profit through affecting electricity price and quantity of production, i.e., utilization hours. In China, electricity prices are set by the government, under rules that have been evolving. Before 2004, the operation period price policy set the electricity price for each power plant, with the aim of

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[4]The government also has the right to approve a firm's investments. Before 2004, a successful application needed go through examination and approval by the Development and Reform Commissions (DRC) at various levels: local, provincial and national. Before the application reached the provincial DRC, the application needed to get a "pass" from the higher levels, which usually took more than two years to obtain. The DRCs not only examined the social impacts of the investment, but also analyzed the profitability of the investment. After 2004, the application procedure was dramatically simplified. A pass is not needed and the examination on profitability is given back to the applicants. This change in application procedure could accelerate the development of the power section as a whole, as well as shift the location patterns of coal-fired plants. However, we will not be able to estimate the magnitude of the impact by regressions, because the sample to support the full specification only covers the years from 2004 through 2011, which is after the change in the approval process.

[5]To be connected to the grid, a firm needs to apply to the power grid company,which owns the grid in this area. Then, the firm either waits for the power line to be built by the grid company or builds the line by itself, in which case the grid company provides design diagrams, approves the construction before acceptance, and purchases back the line. In general, time cost dominates in the first case and financial cost dominates in the latter case.

securing a certain investment return rate. Therefore, plants with different construction costs had different prices. After 2004, a benchmark price policy replaced the operation period price policy and set electricity prices based on the average construction cost of all plants in the same province. Since then, the electricity prices received by plants have varied at the provincial level, rather than the plant level. The utilization hours are allocated by the provincial government.[6] In a province with a higher quota of hours and fewer firms, each firm is likely to get more hours, compared to a province with a lower quota or more firms.

In sum, the factors that potentially impact the spatial distribution of coal-fired power capacity in China include coal endowment, market size factors, electricity price, and utilization hour quota.

3. Data and Graphic Analysis

In this section, we first look into the spatial distributions of coal-fired power capacity over the years and then we investigate the driving factors discussed above.[7] We collect provincial level data from various sources, starting in the1990s and continuing through 2011. We describe the data in detail below and summarize them in Table 1.

3.1 Spatial Distribution of Power Capacity

Data on coal-fired power capacity are collected from the Compilation of Statistical Materials of the Electric Power Industry (1998–2011), which includes coal-fired power plants with capacity above 6000 kilowatt (KW).

Figure 2 compares the spatial distribution of coal-fired plants in 1998 and 2011. It shows that coal-fired plants were concentrated in the coastal areas in 1998. The capacity in Guangdong was more than 15 gigawatts (GW), followed by Shandong and Jiangsu,

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[6]The allocation generally involves several steps: the power plant files an application, the local grid company adjusts hours based on safety and dispatch capability, and the local government approves the hours. Before 2006, the allocation rule essentially was to divide hours equally across plants. In 2007, the State Council issued the “Announcement of Energy Saving Generation Dispatch” to give generation priority to those plants that are more efficient and less polluting.

[7]Besides the factors mentioned above, we also investigate the effect of environmental regulations on plants’ location choice. Given the difficulty in measuring the stringency of a regulation, we use expenditure on environment abatement as a proxy variable. The discussion of the data and the analysis results are available upon request.

each with capacity over 10 GW. By contrast, the capacity in most central and northwestern provinces was less than 5 GW. Capacity grew significantly during the period from 2008 to 2011 for all provinces, except for Tibet and Qinghai. In 2011, coal-fired power plants were still concentrated in coastal areas, where the average capacity was above 40 GW. Large growth in capacity was also seen in some inland regions such as Inner Mongolia, Shanxi and Henan, which are all abundant in coal. Their capacities in 2011 were more than 40 GW, the same magnitude as coastal areas in the same year.

Figure 3 illustrates the capacity trajectory of each province since 1998. Four features are observed. First, the capacity in all provinces at least doubled from 1998 to 2011, although the increase in capacity varies across provinces. Second, all provinces had slow growth in power capacity before the power industry reform in 2002. Third, with the reform, the more-developed provinces experienced a greater increase in capacity. The unbalanced development in capacity further widened the gap between the leaders in both economic development and power capacity and the other provinces. Last, Inner Mongolia, which was less economically developed but has abundant coal, experienced the most dramatic increase in installed capacity, from 7.7 GW in 1998 to 59.6 GW in 2011, and became the third largest province in capacity in 2011, slightly less than Jiangsu and Shandong. These features, observed in Figure 3, imply that the power demand due to economic growth may have consistently driven the increase of power capacity, while some other factors, such as coal endowment, may also have played a role.

3.2 Factor Endowment

Coal—We proxy a province's factor endowment by its coal reserve. Data on coal reserves are collected from the China Statistical Yearbook from 2003 through 2011. Before 2003, only national coal reserve data are available.

Figure 4 compares the provincial coal reserves and the gross capacity of coal-fired plants in 2011. The provinces are ordered based on the quantity of coal reserves. Inner Mongolia and Shanxi are the top two in coal reserves, while they are also among the top in power capacity in 2011. However, the positive correlation of coal reserves and power capacity is not clear for other provinces. For example, coal reserves in Jiangsu, Zhejiang, and Hainan are low, but power capacity is high. Notice that these provinces have a high level of economic development, and therefore a high demand for power. This suggests that, besides coal endowment, proximity to markets may be another driving force for the development of coal-fired plants. We will investigate market factors in the next subsection.

To further investigate the correlation between coal reserves and installed capacity, using data in all years (2003–2011), we depict in Figure 5, Panel A the scatter points and fitted lines of coal reserves and coal-fired power capacity. We find that the slope of the annual fitted lines increases over the years. The slope is 0.048 in 2003 and not statistically significant, while it is as large as 0.41 in 2011 and statistically significant at the 5 percent significance level. The reason could be that the provinces with abundant coal had more dramatic increases in power capacity in recent years, as shown in Figure 3.

Electricity Grid**—**Now the puzzle is why power capacity in the provinces with abundant coal leaped in recent years. One simultaneous phenomenon is the extension of the power grid in those areas. To investigate the correlation between grid and capacity, we use investment in the power grid to proxy the development of the grid.[8] Investment data are from the China Statistical Yearbook from 2003 through 2011.[9] Investment is defined as the total investments in a year for maintaining or building the power grid and replacing grid-related equipment. To measure the grid coverage in a province in a certain year, we accumulate all the investments in the current year and the previous years. That is, for each year, we use cumulative investment to proxy the grid coverage, and annual investment to proxy the grid development year.

In Figure 5, Panel B, we depict the scatter points of grid coverage and power capacity. As we discussed above, we expect a larger effect of grid development in the areas with abundant coal but low grid coverage. In the plot, we therefore distinguish the three provinces with the largest coal reserves, which are Shanxi, Inner Mongolia, and Shaanxi. The slope of the fitted line for the three provinces is much steeper than that for the other provinces, which confirms the hypothesis.

3.3 Economic Geographical Factors

Market Size—In determining the location of industries, the presence of transaction costs (e.g., high transmission costs induced by the low coverage of the electricity grid) means that the demand side matters and that geographical factors come

[8]It would be ideal to use the length of transmission lines at various voltage grades to measure the power grid coverage. But, lacking the power line data, we use investment data instead.

[9]The statistical standards are inconsistent before and after 2003. Therefore, the investment data before 2003 are not used in this study.

into play. In this section, we focus on the geographical distribution of demand and use the size of the electricity market to proxy it.

There are different ways to measure the size of the electricity market. Electricity consumption is a direct measurement; GDP per capita reflects the overall level of economic development, which demands energy; population reflects the size of the potential market. We collect electricity consumption data from the China Energy Statistical Yearbook, and obtain GDP and population data from the China Statistical Yearbook. Figure 6 depicts the scatter points of coal-power capacity versus the three market size variables in the first three plots. In the electricity consumption graph, the raw data points concentrate along an upward sloping line, indicating a strong positive correlation between capacity and electricity consumption. Although the graphs of GDP per capita and population also show positive correlations with power capacity, the relationship is weaker, because GDP per capita and population size work together to determine the electricity demand.

Coal Transportation Cost—A positive correlation between capacity and market size means that capacity concentrates in the areas with larger markets, which are areas far from coal, as shown in Figure 1. Therefore, coal transportation cost comes into play.

We use rail coverage to proxy coal transportation cost, because provinces with extensive rail coverage are expected to have lower transportation costs. We collect yearly rail mileage data at the provincial level from the China Statistical Yearbook, and depict the relationship of capacity and railway mileage in the fourth plot of Figure 6. Power capacity and rail mileage are positively correlated, as expected.

3.4 Electricity Price

Electricity price data are collected from the website of the National Development and Reform Commission, which adjusts the benchmark price. As shown by Figure 7, the price varies across provinces, with the highest (over 500 yuan per thousand kilowatt hours) in Guangdong in 2011, and the lowest (below 250 yuan) in Gansu in all years. Despite the large variation across provinces, the price trajectories in all provinces have the same pattern. The price increases gradually every year, with the largest increases in 2008 and 2011. The only exception is Inner Mongolia, where the price dropped in 2007.

To see how power capacity is correlated with benchmark price, in Figure 8 we depict the scatter points and fitted lines for each year from 2004 through 2011. We see an upward sloping fitted line for each year, indicating that areas with higher prices have more power capacity. However, we cannot yet conclude that capacity reacts to price, because areas with higher prices are also the areas with larger demand (the correlation between price and GDP per capita is 0.34). We therefore adopt a regression method in the next section to distinguish the roles of price and demand.

3.5 Utilization Hours

Data on firm-level utilization hours are collected from the Compilation of Statistical Material of the Electric Power Industry from 1995 through 2011, in which 1996, 1999, and 2001 are missing. All coal-fired power plants with installed capacity of more than 6 MW are included. We use the median of firm-level utilization hours to proxy the expected production quota. We choose median rather than mean to alleviate the influence of outliers. As shown in Figure 9, average and median utilization hours are different, but the difference remains stable.

Figure 10 depicts utilization hour trajectories of each province. We see that utilization hours go up and down over the years and vary dramatically across provinces. Most provinces remain above 4000 hours for all the years, while Guangxi remains below 3000 hours for most of the years.

Figure 11 depicts the correlation between utilization hours and power capacity. To avoid the problem of reverse causality, in which increase in capacity leads to lower average utilization, we use utilization hours in the last year (or the year before the last year if last year's data are missing) in Figure 11. We see a slightly upward sloping fitted line, indicating that there might be a weak correlation between utilization hours and capacity. Whether this correlation indicates that capacity reacts to utilization hours will be investigated by regressions in the next section.

4. Econometric Analysis

In the previous section, we graphically investigated the correlation between capacity and each of the potential driving factors. In this section, we employ a multiple regression to disentangle the contributions of the factors in shaping the spatial distribution of power capacity. In all regressions, we include year fixed effects to account for the effects of common shocks that are not captured by the control variables. We do not include province fixed effects, because we rely on the provincial variations to identify the effects of factors that vary across provinces but do not change much across years for the same province (e.g., coal reserves). That is, we choose "between estimator" over "within estimator." Regression results are shown in Table 2 for endowment and market factors, Table 3 for electricity price, and Table 4 for utilization hours.

4.1 Factor Endowment

We start with a regression with coal reserve as the only covariate, besides year fixed effects. As shown in Table 2, Column 1, the estimated coefficient is 0.18 and statistically significant; a one standard deviation increase in coal reserve (21.96 billion ton) leads to a 29 percent standard deviation increase in capacity (0.18 * 21.69 / 13.428 = 0.29). However, the R square shows that only 19 percent of the variation in capacity can be explained by the variation in coal reserve and time.

As we discussed in the last section, we expect an increase in power capacity when electricity grid becomes more developed, especially in the areas with abundant coal but low grid coverage. We use cumulative investment in the grid to proxy grid coverage, and current investment to proxy grid development. We therefore expect a positive coefficient of both current investment and cumulative investment, and a negative coefficient of their interaction term. The regression results are the same as expected, as shown in Table 2, Column 2. The R square is 0.584, much larger than that of the first regression. This suggests that the development of the electricity grid is critical to the development of power plants.

4.2 Economic Geographical Factors

We add in power consumption, as a proxy of market size, in Table 2, Column 3. As expected, the coefficient of power consumption is positive and statistically significant. However, power consumption is the equilibrium quantity of the market, decided by factors from both the demand side (namely the potential market size) and the supply side (namely the capacity of all power plants) simultaneously. We therefore use GDP per capita and population size, instead, to measure the potential market size in the following regressions. GDP per capita will represent the income effect and population size will represent the scale effect.

As shown in Table 2, Column 4, the coefficients of both GDP per capita and population are positive and statistically significant at the one percent significance level. R square is 0.58. These results indicate that market size is an important factor that drives location choice for coal-fired plants.

Locating close to market, however, may result in higher coal transportation costs because areas with abundant coal are usually far away from areas with a large market (Figure 1). Greater rail coverage may decrease coal transportation costs, and this lower cost attracts firms. We therefore expect greater capacity in provinces with greater rail coverage. In Table 2, Column 5, we add in rail coverage and indeed get a positive and statistically significant estimate of the coefficient of rail coverage.

In Table 2, Column 6, we include all the variables that represent factor endowment, market size, and possible constraints (electricity grid and rail coverage) to reflect their comprehensive effects. Compared to Column 3, the effects of coal reserves and cumulative investment in the power grid remain statistically significant, although their magnitudes decrease. A possible reason is that annual investment in the power grid is highly correlated with GDP per capita. As for market size, income effect, scale effect, and the effect of rail coverage, these also remain statistically significant, although their magnitudes decrease. R square in this regression is much higher than in the regressions in Columns 2 and 5, which separately consider endowment factors and market factors. These results indicate that both factor resources and market size are important factors in location choices for coal-fired power plants; their effects, however, are constrained by other factors such as electricity grid coverage and rail coverage.

4.3 Electricity Price

In Table 3, we investigate the effect of electricity price on the spatial distribution of coal-fired plants. First, we regress power capacity on electricity price only – current price in Column 1, last year's price in Column 2, and average price over time in Column 3. We have 240 price observations (30 provinces in eight years from 2004 through 2011), but only 210 price lag observations, because the first year's lag price data are missing. To make the regression results of the three price covariates comparable, we also drop the first year data for the regression of current price and that of average price over time. We find that the estimated coefficients of price variables are similar. This is expected, because, as we show in Figure 7, the provincial prices have similar trajectories. So, we are comfortable in picking any of them and we use average price over time for the rest of the analysis. In Column 4, we put back the first year to make use of the full dataset, and the results remain stable. The coefficient is 0.077 and significant at the 10 percent significance level. This indicates that the provinces with higher electricity prices do have larger coal-fired plant capacity.

Without controlling other variables, however, we can only interpret this result as a correlation. No matter whether a firm reacts to price, a positive correlation will be seen if the government sets the price higher in the provinces where the market is larger or the coal is abundant. We therefore add in endowment variables and market size factors in Column 5. We find that the estimated coefficient of price becomes much smaller and not significant. We also find that the coefficients of endowment variables and market factors remain stable by comparing Column 5 to Column 6, which repeats the regression in Table 2, Column 6, but with the same sample as Table 3, Column 5. This suggests that the firms do not actually react to the exogenous and stable electricity prices; they build plants where there is a large market or abundant coal.

4.4 Production Quota

In Table 4, we investigate how expected utilization hours affect a firm's location choice. We use median utilization hours over all plants in the same province in the last three years to proxy the expected utilization hours. We use lagged hours to avoid the reverse causality that a leap in capacity leads to lower average utilization hours, holding demand constant.

In Column 1, we regress capacity on lag hours only, and we find that the coefficients are small and not statistically significant. One thousand more utilization hours (more than one standard deviation more hours) only lead to one gigawatt more installed capacity (less than ten percent standard deviation more capacity).

Utilization hours are also correlated with demand and possibly other factors, so we add into the regression all the factors we discussed earlier. We are aware that adding all variables will lose sample size. To eliminate the impact of sample size, we restrict the regression in Column 2 to the same sample as Column 3, which includes all the variables. Column 2 shows that sample size has little impact on the estimated coefficients of hours. Column 3 shows that utilization hours do have some impact on firms' location choices – the coefficient of hours in the two years before the last year is statistically significant. However, the magnitude is not economically significant – one standard deviation more utilization hours leads to only 14 percent of a standard deviation more capacity installation. Compared to Table 3, Column 5, Table 4, Column 3 also shows that adding in the utilization hour variable has little effect on the variables of price, coal endowment, and market size.

5. Conclusion

In this paper, we investigate the spatial distribution of coal-fired power plants in China and the potential driving factors, which include coal endowment, market size factors, electricity prices, and utilization hours.

We find that, in China, coal-fired power plants are located in the areas where the demand is greater, especially in the earlier years of our sample. Although these areas are far from where the coal is, a developed railway system in China ensures that coal transportation cost is lower than the cost of electricity grid expansion. However, with the development of the electricity grid in areas with abundant coal, power plants started to locate in coal-rich areas, thus saving transportation costs, now that power transmission costs are dramatically lowered by the grid expansion. We also find that, when choosing location, firms do not react to electricity prices, which are set by the government, are stable over the years, and vary across provinces. However, firms do react to production quota, i.e., allowable utilization hours.

These findings have important policy implications for reducing the harm caused by power generation without harming the economy. Air pollution has larger adverse effects in the areas with large markets, because in those areas population density is high and the scale of economic activities is large. By contrast, the areas with abundant coal are usually less developed areas, with lower population density. This implies that one way to reduce the harm of air pollution is to shift power plants from where the market is to where the coal is. By identifying the factors driving the choice for location of coal-fired plants, this paper suggests that such a shift could be induced by lowering the transmission costs for plants built in the areas abundant in coal and increasing their utilization hours. The measures to achieve this goal may include encouraging the construction of a trans-province electricity grid and the establishment of a trans-province electricity market.

References

Becker, R., and V. Henderson. 2000. Effects of Air Quality Regulations on Polluting Industries. *Journal of Political Economy* 108(2): 379-421.

Bowen, H.P., E.E. Leamer, and L.A. Sveikauskas. 1987. Multicountry, Multifactor Tests of the Factor Abundance Theory. *The American Economic Review* 77(5): 791-809.

B.P. 2016. BP Energy Outlook 2035.

Chay, K.Y., and M. Greenstone. 2003. The Impact of Air Pollution on Infant Mortality: Evidence from Geographical Variation in Pollution Shocks Induced by a Recession. *Quarterly Journal of Economics* 118(3): 1121-1167.

Coneus, K., and C.K. Spiess. 2012. Pollution Exposure and Child Health: Evidence for Infants and Toddlers in Germany. *Journal of Health Economics* 31(1): 180-196.

Crafts, N., and A. Mulatu. 2005. What Explains the Location of Industry in Britain, 1871-1931? *Journal of Economic Geography* 5: 499-518.

Currie, J., M. Neidell, and J.F. Schmieder. 2009. Air Pollution and Infant Health: Lessons from New Jersey. *Journal of Health Economics* 28(3): 688-703.

Currie, J., and M. Neidell. 2005. Air Pollution and Infant Health: What Can We Learn from California's Recent Experience? *Quarterly Journal of Economics* 120(3): 1003-1030.

Davis, D.R., D.E. Weinstein, S.C. Bradford, and K. Shimpo. 1997. Using International and Japanese Regional Data to Determine When the Factor Abundance Theory of Trade Works. *The American Economic Review* 87(3): 421-446.

Ellison, G., and E.L. Glaeser. 1999. The Geographic Concentration of Industry: Does Natural Advantage Explain Agglomeration? *The American Economic Review* 89(2): 311-316.

Fujita, M. 1988. A Monopolistic Competition Model of Spatial Agglomeration: Differentiated Product Approach. *Regional Science and Urban Economics* 18(1): 87-124.

Gerlagh, R., and N.A. Mathys. 2011. Energy Abundance, Trade and Industry Location. FEEM Working Paper No. 3.2011.

Greenstone, M. 2002. The Impacts of Environmental Regulations on Industrial Activity: Evidence from the 1970 and 1977 Clean Air Act Amendments and the Census of Manufactures. *Journal of Political Economy* 110(6): 1175-1219.

Gong, J., and K. Shen. 2011. Regional Distribution and Environment Pollution of Energy-intensive Industries in China. *The Journal of Quantitative and Technical Economics* 2: 20-36 (Chinese).

Greco, S.L., A.M. Wilson, J.D. Spengler, and J.I. Levy. 2007. Spatial Patterns of Mobile Source Particulate Matter Emissions-to-exposure Relationships across the United States. *Atmospheric Environment* 41(5): 1011-1025.

Gutberlet, T. 2012. Cheap Coal, Market Access, and Industry Location in Germany 1846 to 1882. University of Arizona. Working Paper.

Ho, M.S., and C.P. Nielsen. 2007. Clearing the Air: The Health and Economic Damages of Air Pollution in China. MIT Press.

International Energy Agency. 2012. Carbon-dioxide Emissions from Fuel Combustion Highlights. http://www.iea.org/co2highlights/co2highlights.pdf.

International Energy Agency. 2014. World Energy Balances.

Jaffe, A.B., S.R. Peterson, P.R. Portney, and R.N. Stavins. 1995. Environmental Regulation and the Competitiveness of US Manufacturing: What Does the Evidence Tell Us? *Journal of Economic Literature* 33: 132-163.

Janke, K. 2014. Air Pollution, Avoidance Behavior and Children's Respiratory Health: Evidence from England. *Journal of Health Economics* 38: 23-42.

Jeppesen, T., J.A. List, and H. Folmer. 2002. Environmental Regulations and New Plant Location Decisions: Evidence from a Meta- analysis. *Journal of Regional Science* 42(1): 19-49.

Kanbur, R., and X. Zhang. 2005. Fifty Years of Regional Inequality in China: A Journey through Central Planning, Reform, and Openness. *Review of Development Economics* 9(1): 87-106.

Krugman, P. 1991. Increasing Returns and Economic Geography (No. w3275). National Bureau of Economic Research.

List, J.A., and W.W. McHone. 2000. Measuring the Effects of Air Quality Regulations on “Dirty” Firm Births: Evidence from the Neo-and Mature-regulatory Periods. *Papers in Regional Science* 79(2): 177-190.

Lopez, M.T., M. Zuk, V. Garibay, G. Tzintzun, R. Iniestra, and A. Fernandez. 2005. Health Impacts from Power Plant Emissions in Mexico. *Atmospheric Environment* 39(7): 1199-1209.

Luechinger, S. 2014. Air Pollution and Infant Mortality: A Natural Experiment from Power Plant Desulfurization. *Journal of Health Economics* 37: 219-231.

Michielsen, T.O. 2013. The Distribution of Energy-intensive Sectors in the USA. *Journal of Economic Geography* 13(5): 871-888.

Midelfart-Knarvik, K.H., H.G. Overman, S.J. Redding, and A.J. Venables. 2000. The Location of European Industry. Economic Papers No. 142. European Commission, D-G for Economic and Financial Affairs, Brussels.

Neidell, M.J. 2004. Air Pollution, Health, and Socio-economic Status: The Effect of Outdoor Air Quality on Childhood Asthma. *Journal of Health Economics* 23(6): 1209-1236.

Romalis, J. 2004. Factor Proportions and the Structure of Commodity Trade. *The American Economic Review* 94(1): 67-97.

Tanaka, S. 2015. Environmental Regulations on Air Pollution in China and Their Impact on Infant Mortality. *Journal of Health Economics* 42: 90-103.

Taylor, M.S. 2004. Unbundling the Pollution Haven Hypothesis. *Advances in Economic Analysis and Policy* 3(2).

Sueyoshi, T., and M. Goto. 2015. Environmental Assessment on Coal-fired Power Plants in U.S. North-east Region by DEA Non-radial Measurement. *Energy Economics* 50: 125-139.

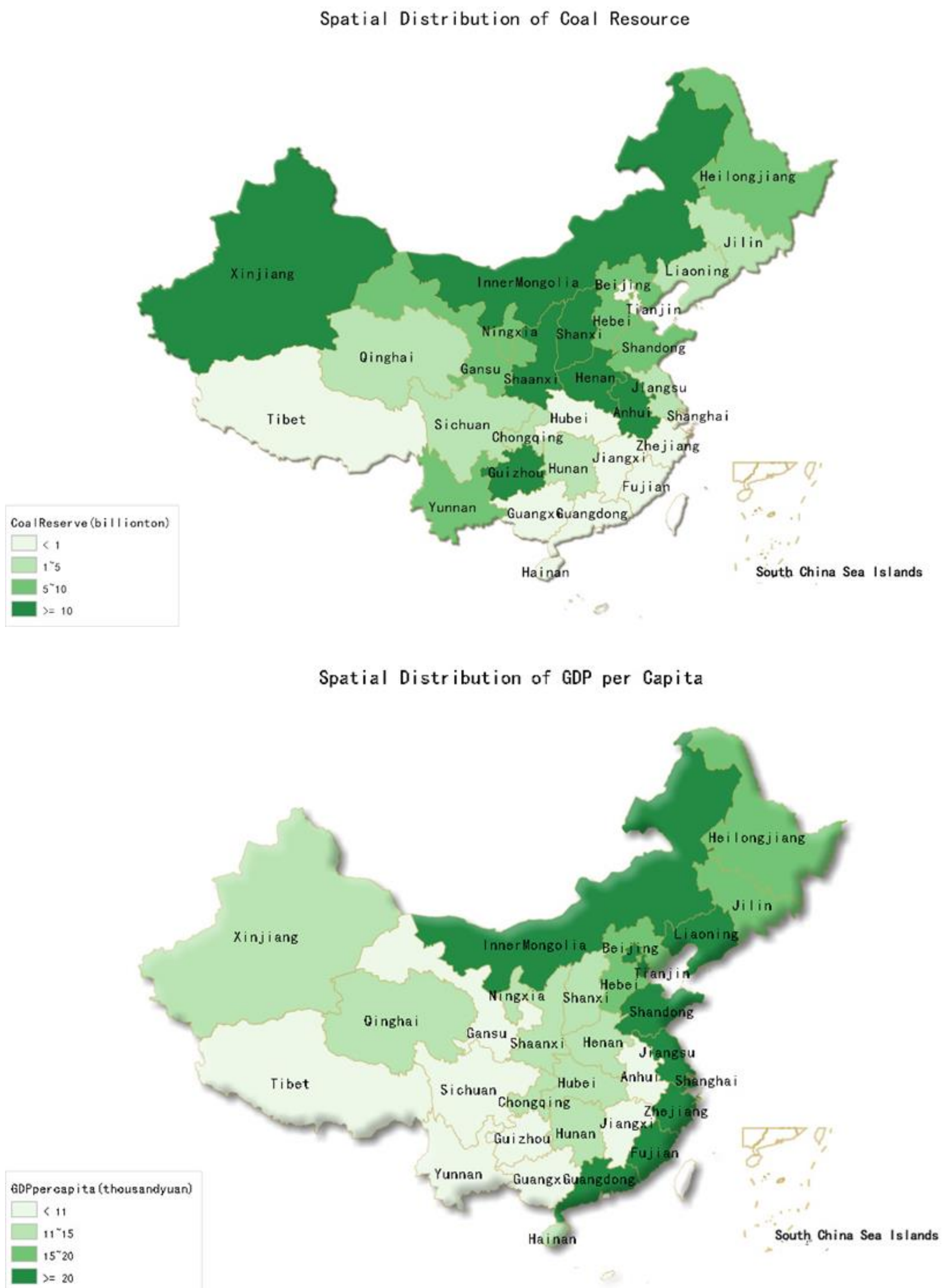
Wen, M. 2004. Relocation and Agglomeration of Chinese Industry. *Journal of Development Economics* 73(1): 329-347.

World Bank. 1997. Clear Water, Blue Skies: China's Environment in the New Century.

Zhou, Y., J.I. Levy, J.S. Evans, and J.K. Hammitt. 2006. The Influence of Geographic Location on Population Exposure to Emissions from Power Plants throughout China. *Environment International* 32(3): 365-373.

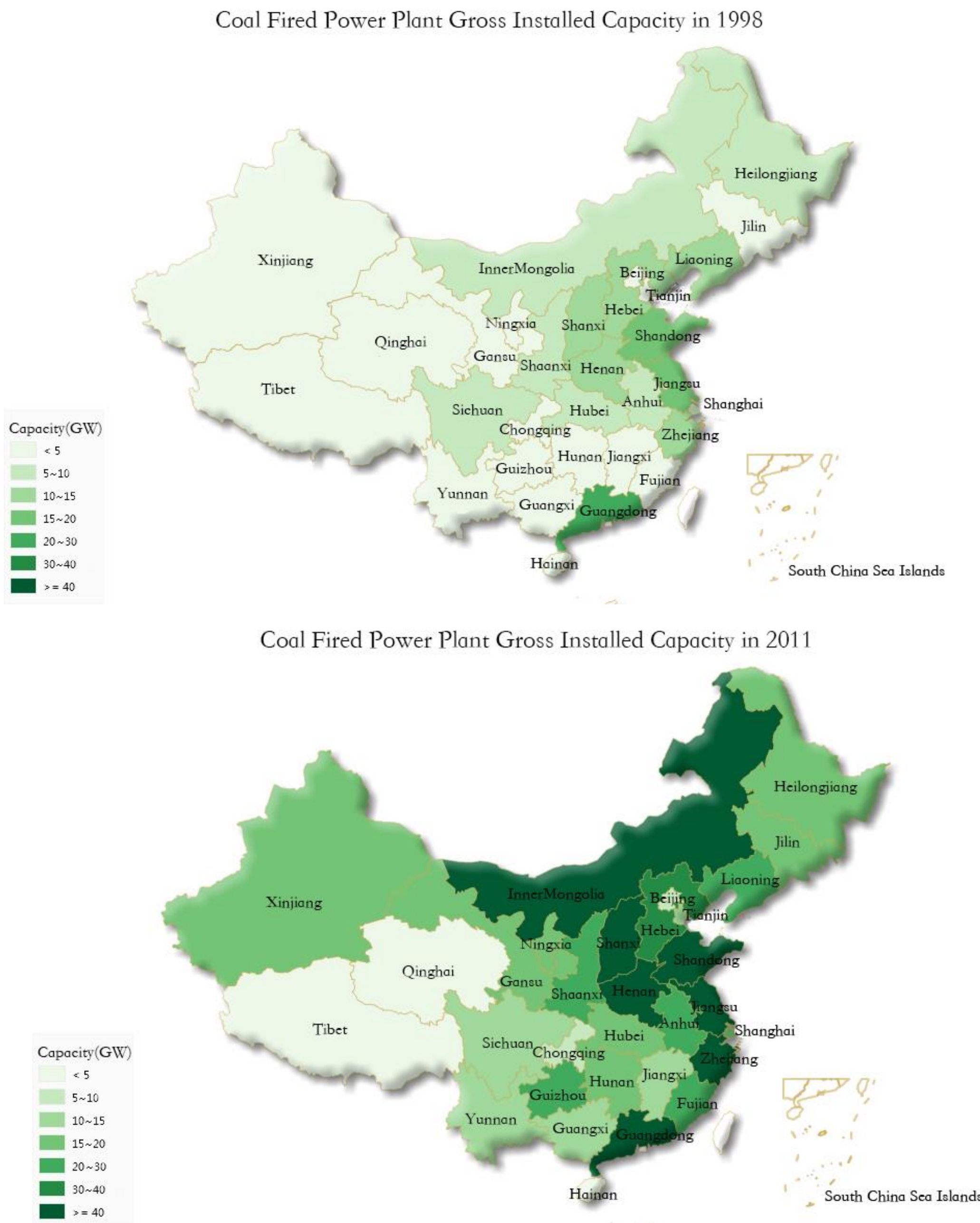
Figures and Tables

Figure 1. Spatial Distributions of Economic Development and Coal Resources in China



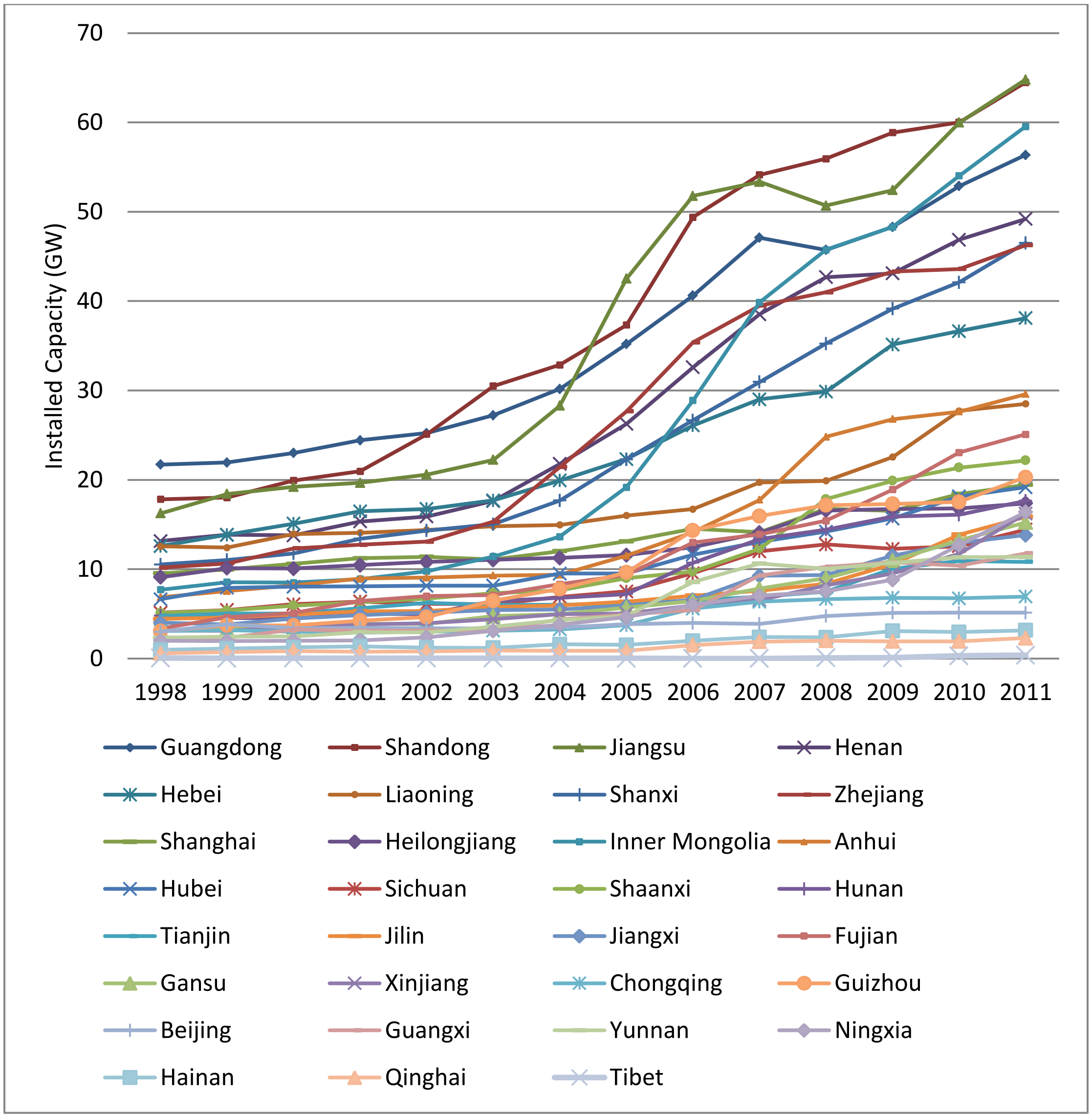
Notes: Data are from the China Statistical Yearbook, and are average values over years from 2003 through 2011.

Figure 2. Gross Installed Capacity of Coal-Fired Plants at Province Level



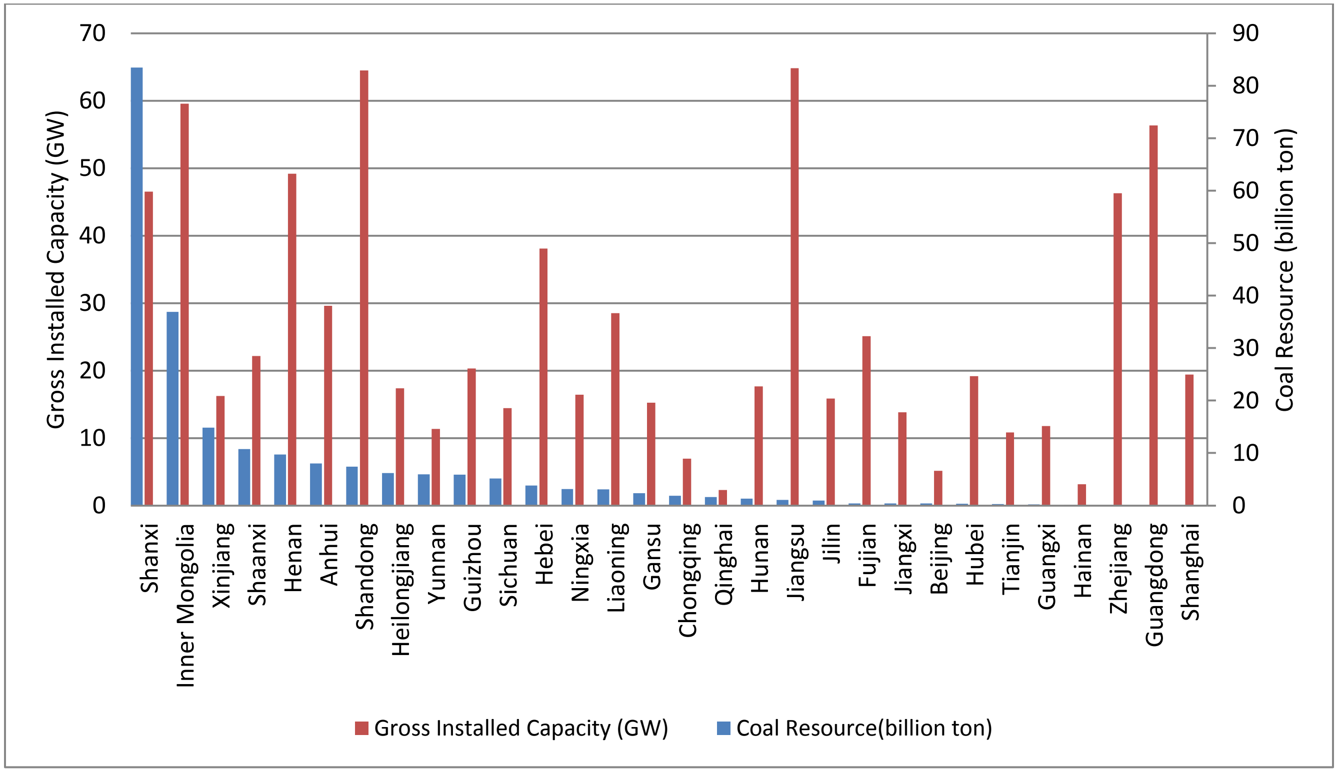
Notes: Data are from the Compilation of Statistical Materials of the Electric Power Industry (1998-2011), which includes coal-fired power plants with capacity above 6000 kilowatts (KW).

Figure 3. Provincial Trajectories of Power Capacity from 1998 through 2011



Notes: Data are from the Compilation of Statistical Materials of the Electric Power Industry (1998-2011), which includes coal-fired power plants with capacity above 6000 kilowatts (KW). The provinces in the legend are ordered based on their installed capacities in 1998.

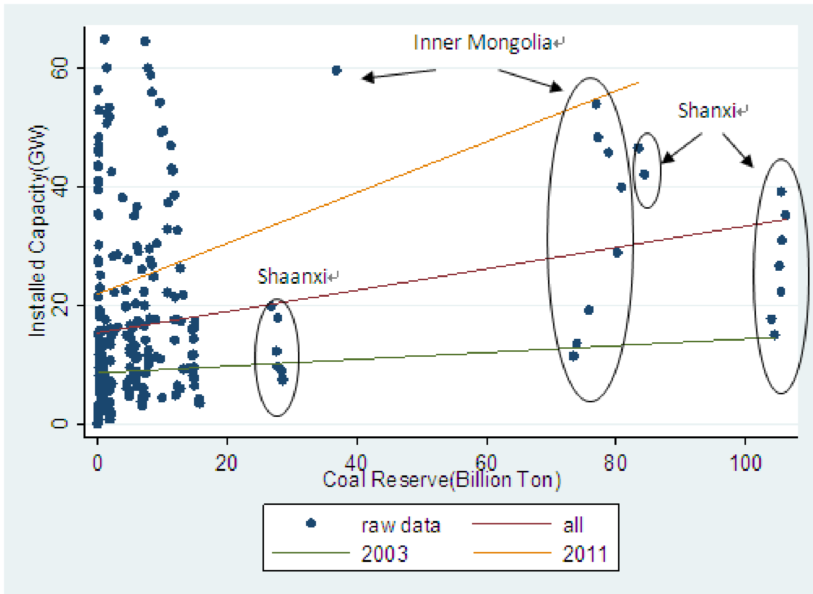
Figure 4. Coal-fired Power Capacity and Coal Reserves at Province Level in 2011



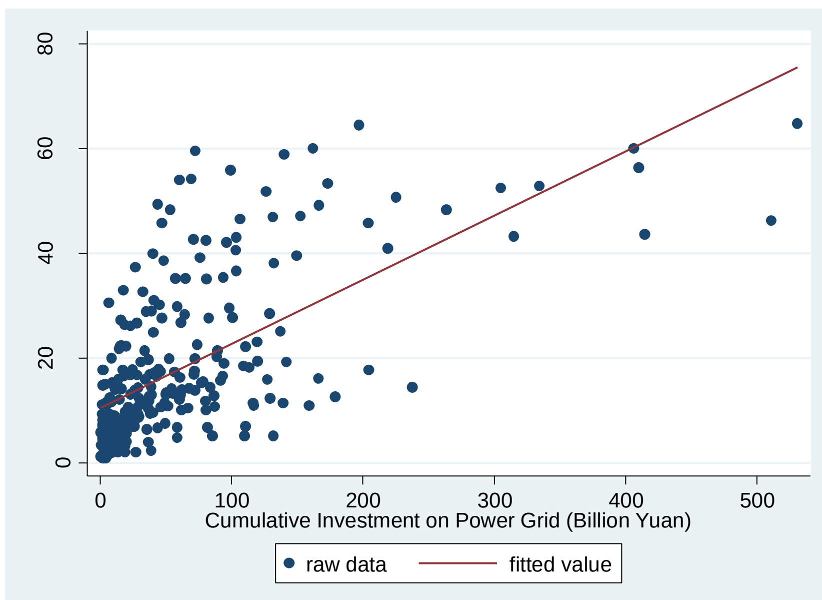
Notes: Data are from the China Statistical Yearbook 2011.The provinces are ordered based on their installed capacities in 2011.

Figure 5. Factor Endowment and Power Capacity

Panel A. Coal Reserve and Capacity

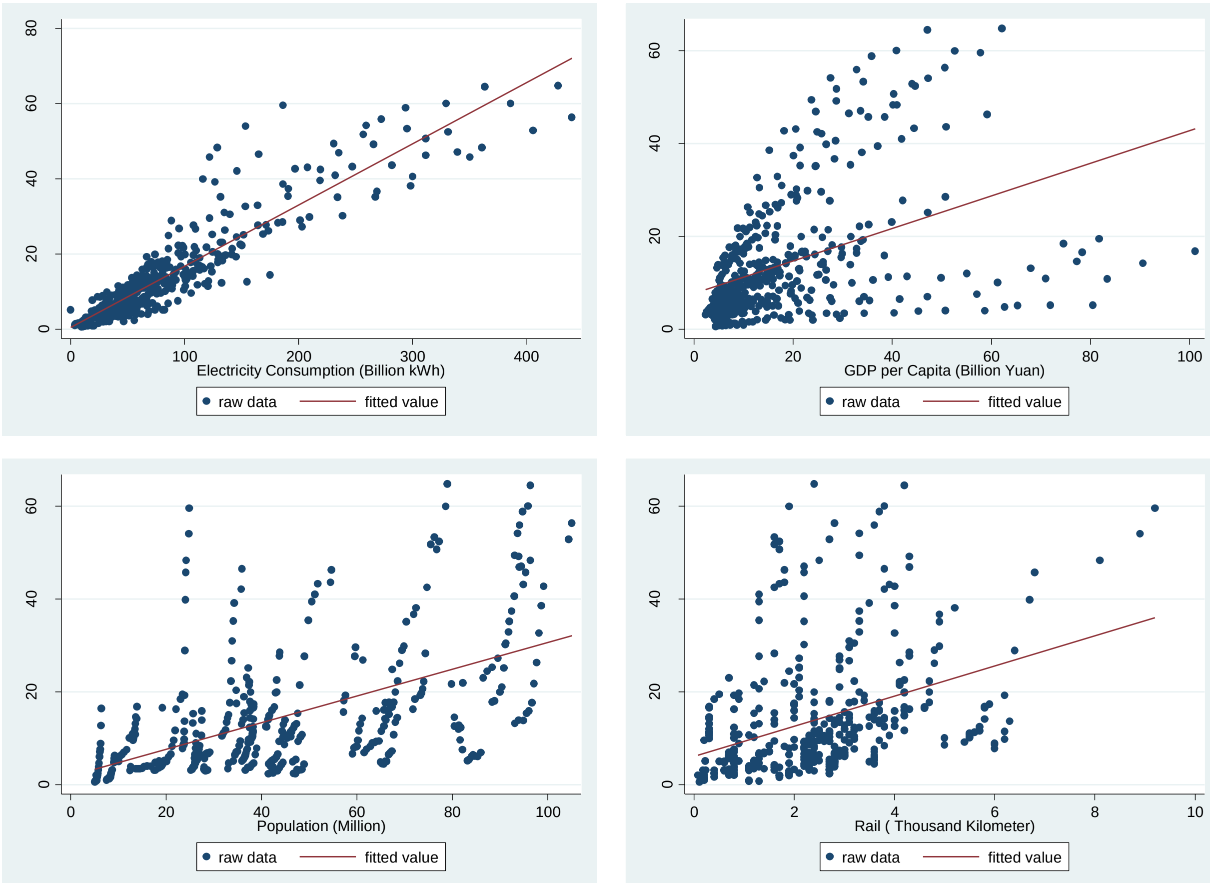


Panel B. Power Grid Coverage and Capacity



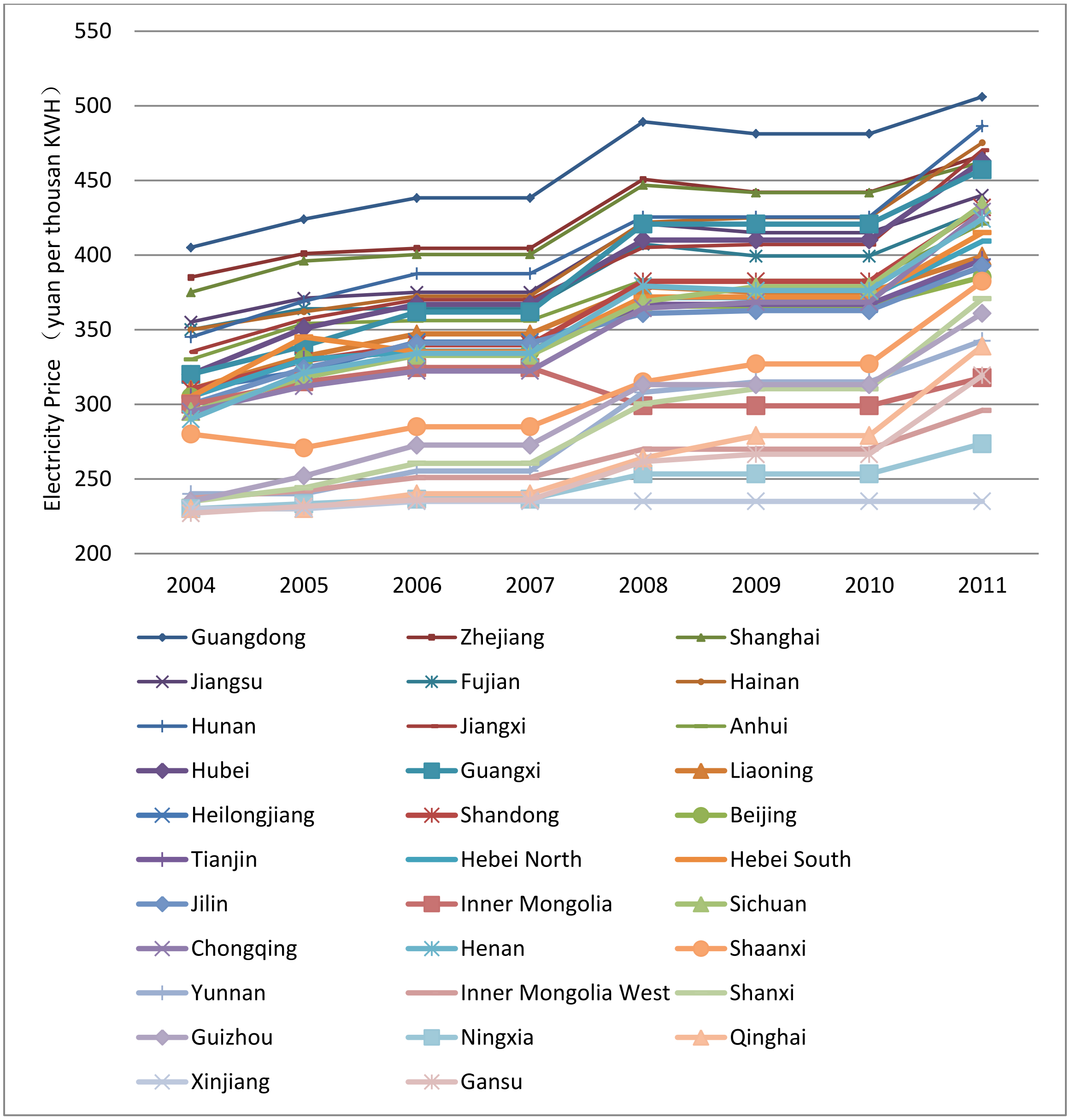
Notes: Data on coal reserve and power grid investment are collected from the China Statistical Yearbook from 2003 through 2011. Panel A plots the correlation between coal reserve and installed capacity. Dots are yearly data at provincial level. Lines are fitted for all data points, 2003, and 2011, respectively. Panel B plots the correlation between investment in the power grid and the installed power capacity. Dots are yearly data at provincial level. The steeper line is for Shanxi, Inner Mongolia, and Shaanxi and the other line is for the rest of the provinces.

Figure 6. Market Size and Power Capacity



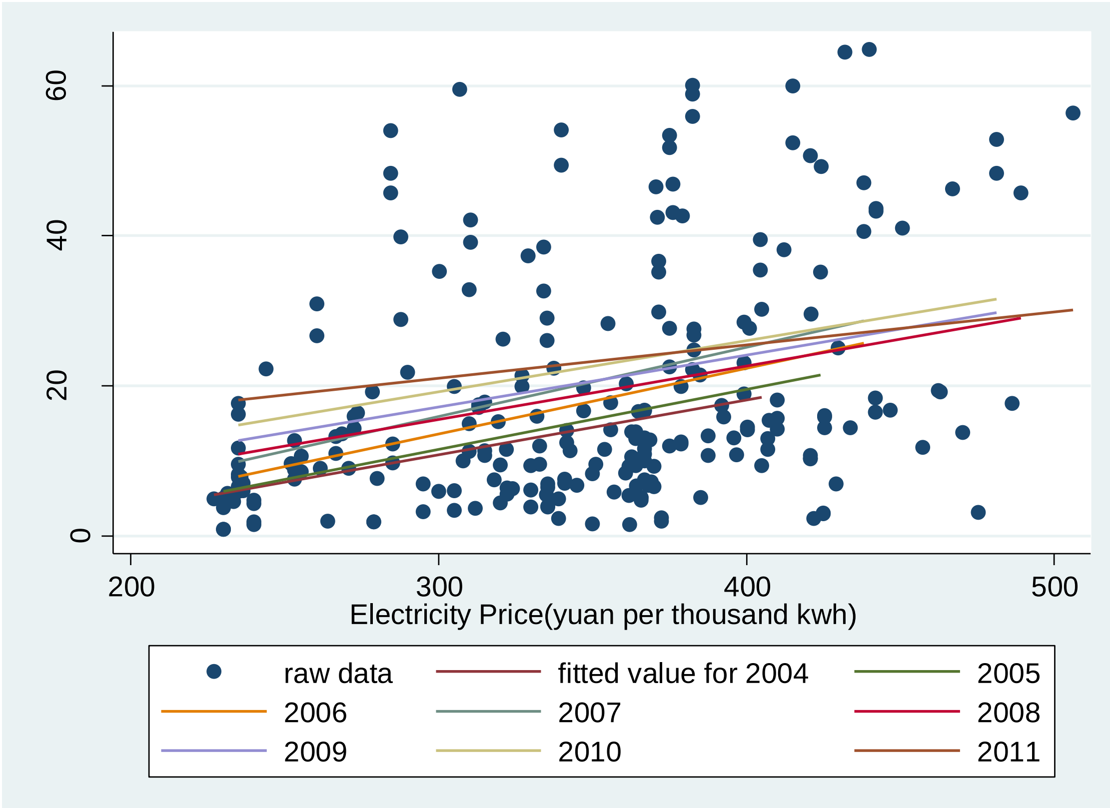
Notes: The first three graphs depict the correlation between market size and power capacity. Market size is measured as electricity consumption, GDP per capita, and population, respectively. The last graph depicts the correlation between rail and power capacity. Data on electricity consumption are from the China Energy Statistical Yearbook. Data on GDP, population, and rail are from the China Statistical Yearbook.

Figure 7. Provincial Electricity Price Trajectories from 2004 to 2011



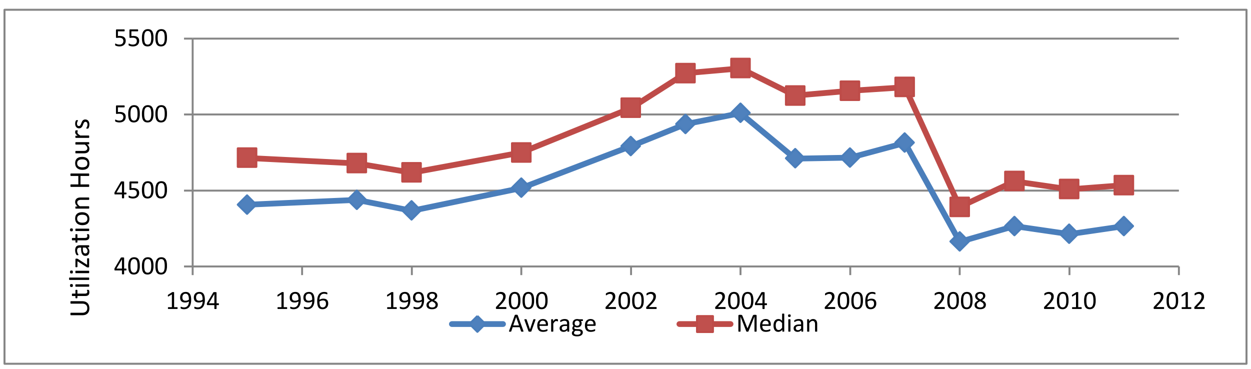
Notes: Benchmark price data are from the website of the National Development and Reform Commission, which adjusts benchmark price annually. Provinces in the legend are ordered based on their prices in 2004.

Figure 8. Electricity Price and Capacity



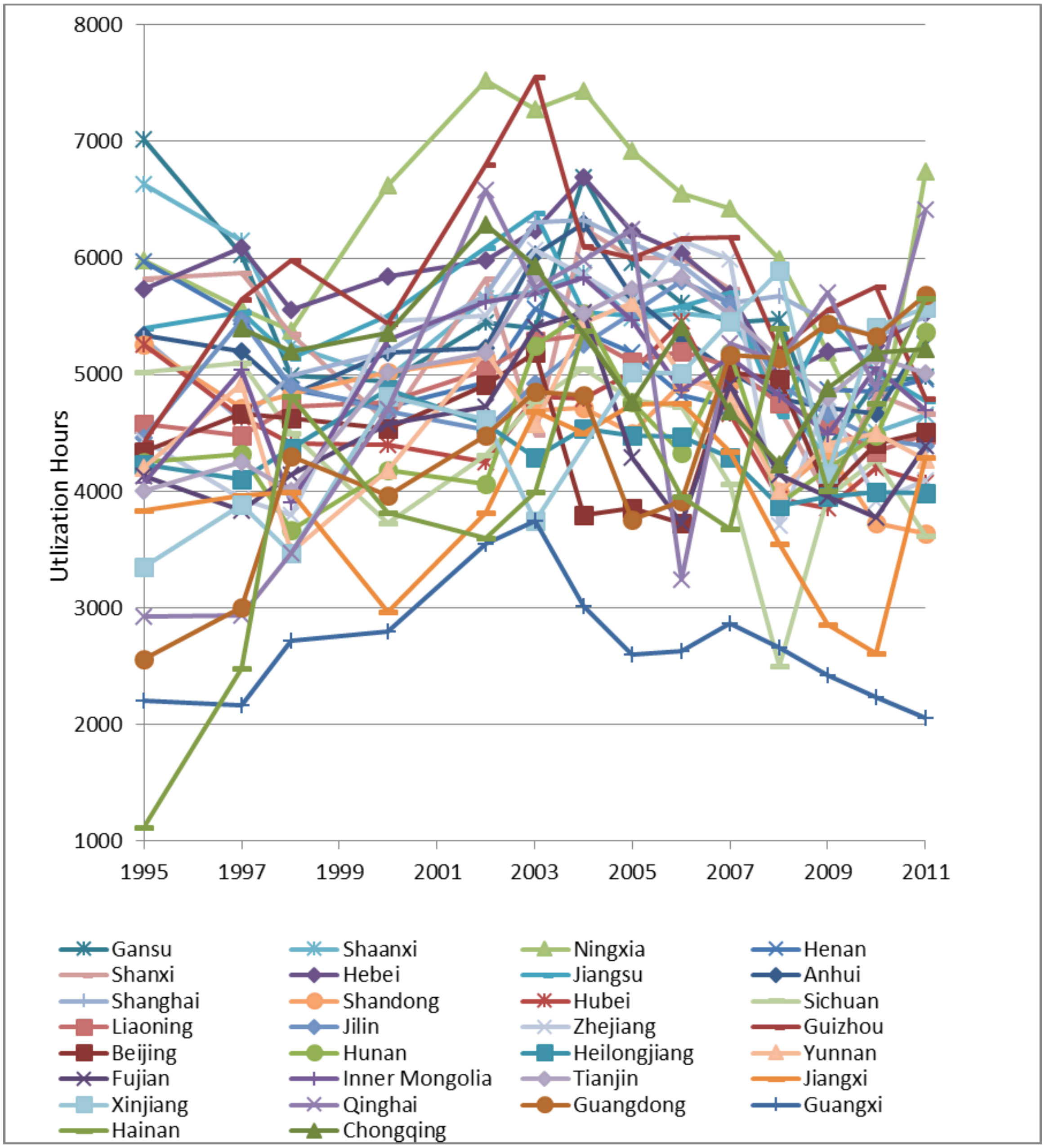
Notes: Benchmark price data are from the website of the National Development and Reform Commission, which adjusts benchmark price annually. Dots are raw data from 2004 through 2011. Lines are fitted values for an individual year, respectively.

Figure 9. Overall Trajectories of Utilization Hours



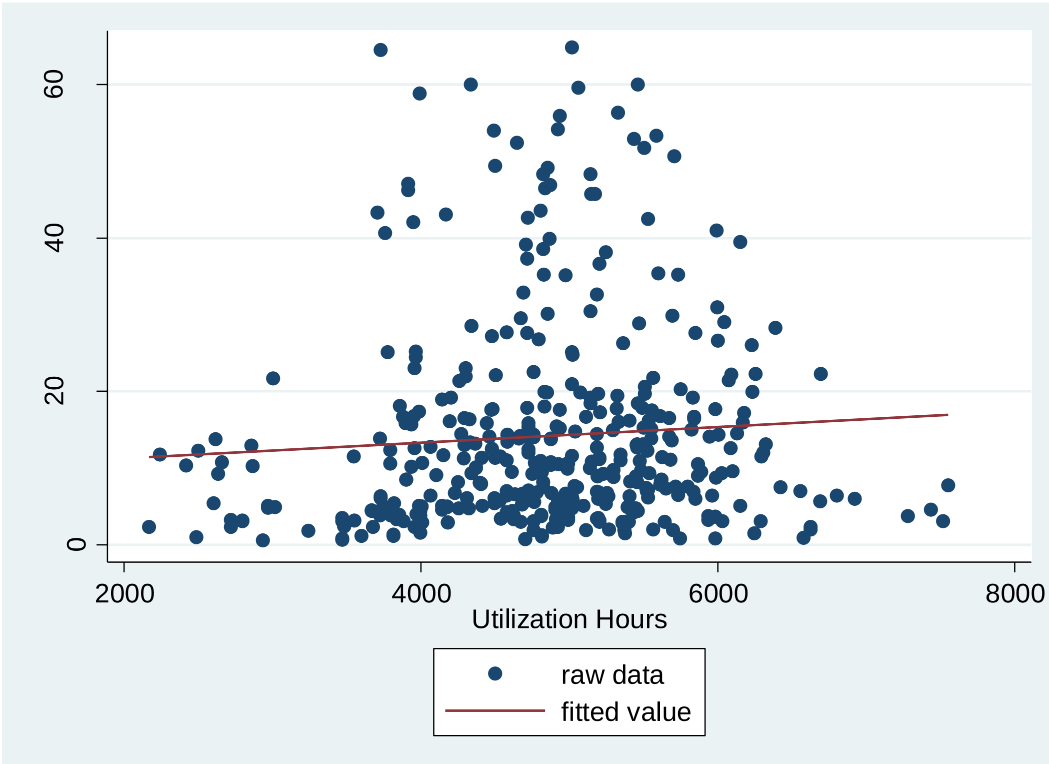
Source: China Power Plant Annual Statistics.

Figure 10. Provincial Trajectories of Utilization Hours



Notes: Firm level utilization hour data are collected from China Power Plant Annual Statistics from 1995 through 2011, in which 1996, 1999, and 2001 are missing. Provinces in the legend are ordered based on their median utilization hours in 1995. Chongqing is at the end in the legend; however, this is only because data on its hours for 1995 are missing.

Figure 11. Utilization Hours and Capacity



Notes: Firm level utilization hour data are collected from China Power Plant Annual Statistics from 1995 through 2011, from which 1996, 1999, and 2001 are missing. Provincial utilization hours are medians of firm-level hours. Dots are provincial hours in the last year or the year before the last year if the last year data are missing.

Table 1. Summary Statistics

		Mean	Std. Dev.	Min	Max	Obs	Data Source
Dept. Variable	coal-fired power plant installed capacity (GW)	14.221	13.428	0.583	64.800	420	1
Factors							
Endowment Factors	coal reserve (billion ton)	10.385	21.690	0.000	106.151	270	2
	investment on power grid (billion yuan)	16.320	18.737	0.263	124.482	270	1
	cumulative investment on power grid (billion yuan)	59.387	79.607	0.263	530.751	270	4
Market Factors	electricity consumption (billion kWh)	84.453	75.793	0.003	439.902	420	3
	GDP per capita (thousand yuan)	18.640	16.346	2.302	101.146	420	2
	population (million)	42.980	26.351	5.028	105.049	420	2
	rail coverage (thousand km)	2.506	1.532	0.080	9.200	420	2
Political Factors	electricity price (yuan per thousand kwh)	347.025	65.181	227.000	506.000	240	5
	utilization hours (hour per year)	4908.623	899.085	2059.000	7553.500	358	1

Notes: Data source: 1 - Compilation of Statistical Materials of Electric Power Industry, 2 - China Statistical Yearbook, 3 - China Energy Statistical Yearbook, 4 - calculated. Number of observations: 30 provinces (including municipalities directly under the central government and autonomous regions) are included. Hong Kong, Macao, Taiwan, and Tibet are excluded because data is lacking; years from 1998 through 2011 are covered, except that data before 2003 are not available for coal resource, investment in power grid, water, and variables calculated from them, 5 - Provincial Development and Reform Commissions.

Table 2. Effects of Coal Endowment and Market Factors on Installed Capacity of Coal-Fired Power Plants

Dept. variable: Installed Capacity of Coal-fired Power Plants						
	(1)	(2)	(3)	(4)	(5)	**(6)**
coal reserve	0.180***	0.215***				**0.200*****
	(0.052)	(0.051)				**(0.026)**
investment on power grid		0.193				**0.010**
		(0.172)				**(0.192)**
cumulative investment on power grid		0.226***				**0.079****
		(0.057)				**(0.033)**
investment * cumulative investment		-0.001**				**-0.000**
		(0.001)				**(0.000)**
power consumption			0.159***			
			(0.015)			
GDP per capita				0.284**	0.344***	**0.241****
				(0.114)	(0.111)	**(0.095)**
population				0.371***	0.331***	**0.269*****
				(0.062)	(0.073)	**(0.065)**
rail coverage					2.411*	**1.525****
					(1.309)	**(0.661)**
Constant	7.650***	5.736***	-0.387	-9.656***	-14.596***	**-11.079*****
	(1.828)	(1.233)	(0.857)	(3.063)	(3.761)	**(3.774)**
Observations	270	270	270	270	270	**270**
Rsquare	0.192	0.584	0.824	0.576	0.627	**0.755**

Notes: Mixed OLS. All specifications have year dummies. Standard errors are clustered at provincial level. *, **, *** represent 10%, 5%, and 1% significance level.

Table 3. Effects of Electricity Price on Installed Capacity of Coal-Fired Power Plants

Dept. variable: Installed Capacity of Coal-Fired Power Plants	(1)	(2)	(3)	(4)	**(5)**	(6)
price	0.072					
	(0.043)					
price in the last year		0.079*				
		(0.044)				
average price over time			0.079*	0.077*	**-0.020**	
			(0.044)	(0.041)	**(0.033)**	
coal reserve					**0.207*****	0.220***
					(0.030)	(0.031)
investment on power grid					**0.001**	0.004
					(0.202)	(0.195)
cumulative investment on power grid					**0.071***	0.069*
					(0.036)	(0.035)
investment * cumulative investment					**-0.000**	-0.000
					(0.000)	(0.000)
GDP per capita					**0.273****	0.245**
					(0.117)	(0.096)
population					**0.311*****	0.288***
					(0.092)	(0.072)
rail coverage					**1.463***	1.553**
					(0.782)	(0.737)
Constant	-9.801	-10.742	-14.553	-15.818	**-6.291**	-12.317***
	(12.922)	(12.657)	(14.501)	(13.717)	**(9.247)**	(3.927)
Observations	210	210	210	240	**240**	240
Rsquare	0.133	0.142	0.143	0.174	**0.760**	0.758

Notes: Mixed OLS. All specifications have year dummies. Standard errors are clustered at provincial level. *, **, *** represent 10%, 5%, and 1% significance level.

Table 4. Effects of Utilization Hours on Installed Capacity of Coal-Fired Power Plants

Dept. variable: Installed Capacity of Coal-Fired Power Plants			
	(1)	(2)	(3)
hours lagged one year	0.000	0.001	0.000
	(0.001)	(0.001)	(0.001)
hours lagged two years	0.001	0.001	0.001
	(0.000)	(0.001)	(0.001)
hours lagged three yeas	0.001	0.001	0.002***
	(0.001)	(0.001)	(0.001)
average price over time			0.007
			(0.037)
coal reserve			0.195***
			(0.024)
investment on power grid			-0.048
			(0.182)
cumulative investment on power grid			0.076**
			(0.035)
investment * cumulative investment			-0.000
			(0.000)
GDP per capita			0.228*
			(0.120)
population			0.303***
			(0.100)
rail coverage			1.828**
			(0.797)
Constant	-1.302	-0.279	-32.383**
	(7.639)	(11.799)	(15.556)
Observations	420	240	240
Rsquare	0.236	0.108	0.785

Notes: Mixed OLS. All specifications have year dummies. Standard errors are clustered at provincial level. *, **, *** represent 10%, 5%, and 1% significance level.