Assessing the impact of regulatory reforms on China’s electricity generation industry

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ABSTRACT

In the past two decades, China has experienced a series of regulatory reforms in its electricity industry, aimed at improving power production efficiency. The central planning system was broken up and the market-oriented modern enterprise system was established. Furthermore, the former vertically integrated electricity utilities were divested and the generation sector was separated from the transmission and distribution networks. In this paper, we intend to estimate the impact of regulatory reforms on production efficiency of fossil-fired generation plants using the plant-level national survey data collected in 1995 and 2004. Applying the econometric method of Differences-in-Differences, we estimate the effects of these reforms on the demand for inputs of employees, fuel and nonfuel materials. The results show that the net efficiency improvement in labor input associated with the regulatory reforms is roughly 29% and the gains in nonfuel materials are about 35%, while there is no evidence of efficiency gains in fuel input associated with the electricity reforms.

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1. Introduction

Since 1980s, the world electricity industry has experienced a series of deregulations pioneered by Chile, England and Wales, and Norway. The former vertically integrated electricity utilities were divested and the generation plants were separated from the transmission and distribution networks, and the competitive wholesale and retail electricity markets were also introduced.

China’s electricity industry is one of the largest systems in the world, and like the reforms in other areas it has also experienced an evolutionary process of reforms since the foundation of the People’s Republic of China in 1949. The former central planning system, the Ministry of Electricity Power (MEP) and regional Bureau of Electricity Power (BEP), has been broken up and the market-oriented modern enterprise system has been established. The investments from local governments, domestic enterprises and foreign investors in generation sector have been allowed since 1985 and the proportion of common financing generation plants (CFGPs) increased rapidly. In 2002, the Chinese government published a blueprint for the electricity reform. The former vertically integrated public utility, State Power Corporation (SPC), was divested and the generation sector was separated from the transmission and distribution sectors. Recently, the introduction of the wholesale electricity market is also in process.

One of the main purposes of the regulatory reforms is to improve the production efficiency of the electricity industry, while the question of whether moving from the central planning system to a deregulated electricity market can bring additional improvement in production efficiency still remains open. Though the electricity restructuring has been studied intensively, the main foci are market construction and exercise of market power (Borenstein et al., 2002; Joskow and Kahn, 2002; Wilson, 2002; Wolfram, 1999, etc.). Little effort has been devoted to quantifying the ex-post operating efficiency gains from the electricity restructuring, possibly because it is difficult to get firms’ detailed cost data or it is too early to conclude.

2 In the literature, these common financing generation plants are also called independent power producers or IPPs, in that they are independent of transmission networks, that is, not directly subordinate to the transmission networks.

3 As Woo et al. (2006) have pointed out, deregulation of the electricity industry may result in a series of problems, such as market power, price volatility, stranded cost, etc. Electricity deregulation should proceed with extreme caution.
Mainly, there are two streams of research trying to estimate the impact of regulatory reforms on generation plants. The first stream employs the aggregated country-level panel data and takes the industrial end-user price, ratio of industrial to residual price, capacity utilization rate and distance of actual from optimal reserve margin as the proxies of efficiency. The second stream uses more detailed plant-level panel data and the method of Differences-in-Differences.

The first stream can be traced back to Steiner (2000), he assesses the impact of liberalization and privatization on performance in the generation sector of the electricity supply industry, using a panel of 19 OECD countries over the period 1986–1996. His results show that unbundling of the generation sector, easy access to transmission networks, and the introduction of the private ownership and the competitive market influence the performance of the generation sector significantly.


The second stream is pioneered by Fabrizio et al. (2007). Using plant-level panel data, they evaluate the impact of regulatory reforms on the USA generation industry, based on the method of Differences-in-Differences. They show that investor-owned utilities (IOUs) in restructuring regimes reduced their labor and nonfuel material expenses by 3–5% relative to IOUs in states that have not restructured their markets. The estimated efficiency gains are even larger when compared to the municipal and federal plants: 6% reduction in labor use and 12% reduction in nonfuel material expenses, but there is little evidence of improvements in fuel efficiency.

Under the same Differences-in-Differences framework, Bushnell and Wolfram (2005), focused on fuel efficiency and using more detailed unit-level data from January 1997 to December 2003, further examine the impact of the divestiture reform of USA generation plants on the operational efficiency of fuel usage. Their results suggest that the fuel efficiency at divested plants is improved on average by about 2% relative to their non-divested counterparts. However, most of this gain is matched by non-divested plants in states that have adopted a strong form of incentive regulation. Thus, they conclude that the bulk of the efficiency improvement should be attributed to incentive rather than ownership changes.

In this paper, we intend to estimate the impact of the regulatory reforms on China's electricity generation plants. Following Fabrizio et al. (2007), we assess the production efficiency improvements in inputs of labor, fuel and nonfuel materials based on 2 years of plant-level national survey data, using the method of Differences-in-Differences. The difference between Fabrizio et al. (2007) and this paper is that, we use a pooled cross-sectional model rather than their panel data model. Our results indicate that the regulatory reforms have greatly improved the production efficiency of the generation plants in labor and nonfuel material inputs, while there is no evidence of efficiency gains in fuel input associated with the electricity reforms. The net efficiency improvement in labor input associated with the regulatory reforms is roughly 29% and the gains in nonfuel materials are about 35%.

The remainder of this paper is organized as follows: Section 2 reviews the history of China's electricity industry reforms. Section 3 presents the empirical model and the estimation strategy. Section 4 is data and descriptive statistics. Section 5 reports the results of the empirical analysis and Section 6 is the robustness test. The last section concludes.

2. History of China's electricity restructuring

China's electricity industry is the second largest system in the world. At the end of 2007, its installed capacity and power generation were about 713 gigawatt (GW) and 3256 million megawatt-hours (MWH), respectively. Within the installed capacity, fossil-fired units (mainly coal-fired) occupied about 77.73%, hydro units of about 20.36%, while nuclear and other energy types accounted for no more than 2%.6

With the foundation of the People's Republic of China in 1949, the electricity industry was put into the central planning system under the ideal of constructing socialism. From then on, all the electricity assets (including generation, transmission and distribution) were state-owned and the electricity investments mainly relied on the central government, while the local governments, foreign investors and private investors were not allowed to invest in electricity industry (Yang, 2006).

The governance of the whole industry was performed through a complicated pyramidal hierarchy. MEP and its regional branches BEP managed all the electricity assets. Generation, transmission and distribution sectors were vertically integrated, under the rationale of minimizing the costs of coordination between these functions and of financing the development of power system (Bacon and Besant-Jones, 2001). Almost all the managers of the electricity plants were selected and designated by the government. All the enterprise managers were also government officials and had corresponding administrative ranks in the governmental hierarchy. China's electricity industry never managed to step beyond the systematic framework of the “unification of government and business function” and “as a state monopoly operation” (Xu and Chen, 2006).

Along with the general market-oriented economic reform initiated in 1979, the electricity industry has also experienced a long march of restructuring. Like those in other areas, reforms in the electricity industry are also an evolutionary process, characterized as “groping for stones to cross the river”. Mainly, there were three reforms in China's electricity industry:

- The 1985s reform in investment institution. With the development of the economy since the 1979s reform, the demand for electricity grew rapidly and power shortage became more serious than ever. In order to attract more investments to develop the electricity industry and relieve the bottleneck of power shortage, in 1985, the central government began to allow local governments, enterprises and foreign companies to invest in generation sector, but investments in transmission

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5 In this paper, we only consider the electricity system in mainland of China. As to the electricity reforms of Hong Kong and Taiwan, please see Ngan et al. (2006) and Wang (2006).

6 The data are from the report of the China Electricity Council. www.ce-c.org.cn/zh/index.asp.


4 In their paper, they take heat rate as the indicator of the operational efficiency of fuel usage.
and distribution sectors were still forbidden. The newly founded CFGPs were not directly subordinate to the transmission networks from the very beginning since they were not funded by MEP. Usually, CFGPs had long-term buying contracts with the transmission networks and obtained the regulated profits.

- CFGPs developed rapidly thereafter. By the end of 1990s, the proportion of generating capacity controlled by the central government reduced to less than 50% and the proportion of investment funds from the central government reduced to about 44.6% between 1996 and 2000. The financing gap was remedied by local governments, domestic enterprises and foreign investors (Yang, 2006).

- The 1997s reform of management system. The main purpose of this reform is to separate the administrative function from the business function of the plants owned by MEP. In 1997, the State Council decided to establish a new public utility, SPC, to take over all the electricity assets from MEP, including generation plants, transmission and distribution networks. SPC was an independent market entity, designated to manage the daily operation of the electricity system. MEP was dismantled and its administrative and decision-making functions were transferred to the State Economic and Trade Committee (SETC). Since then, the administrative authority and business function were formally separated.

- The 2002s reform of divestiture of generation and transmission. The main purpose of this reform is to divest the generation plants from the transmission sector and to introduce competition in generation sector. In 2002, the State Council enacted a blueprint of the electricity restructuring, based on the international practices of deregulation. The vertically integrated public utility, SPC, was dismantled and its generation assets were reallocated to five big generation corporations, while its transmission and distribution assets were inherited by two transmission companies.9

In 2003, the central government created a new independent regulator, State Electricity Regulatory Commission (SERC), to carry out the ongoing regulatory reforms, supervise the operation of electricity markets and establish the laws and rules of the electricity markets. In the same year, SERC began to introduce wholesale electricity competition into generation sector and some mock regional wholesale markets were founded. However, the trial of regional wholesale market competition was soon suspended because of a nationwide shortage of power.10

To summarize, from 1995 to 2004, there were mainly two regulatory reforms in China’s electricity industry. The first reform was the separation of the administrative function from the business function of the state-owned enterprises. The symbolic events were the elimination of MEP and the foundation of SPC. The second reform was the divestiture of the generation plants from the transmission and distribution networks. The symbolic event was the dismantlement of SPC. Both of these two reforms only affected the plants directly subordinate to the former MEP (later SPC), i.e. the directly subordinate generation plants (DSGPs), while CFGPs were never affected. The purpose of this paper is to assess the impact of these two reforms on the production efficiency of the generation plants, using the national survey data collected in 1995 and 2004.

3. Empirical model

For a single-output production process, the production efficiency can be assessed by estimating whether a plant is maximizing its output given its inputs and whether it is using the best mix of inputs given their relative prices. The technical process of transforming inputs into outputs is characterized by production function, and a plant is efficient on technical ground if it is on the production frontier. However, the production frontier criterion ignores the costs of the inputs. Actually, a plant can be on its production frontier and produce its maximum possible outputs but not minimizing its costs. But cost minimization assumes that, given the input costs, firms choose the optimal mix of inputs that minimizes the costs of producing a given level of output. Following Fabrizio et al. (2007), we explore the impact of electricity sector restructuring on the production efficiency by specifying a production function and then deriving the relevant input demand equations implied by cost minimization.

We assume that electricity generation plant \( i \) has the following Leontief production technology, a strategy employed by Fabrizio et al. (2007):

\[
Q_i^d = \min \{g(E_i, I_i^F, e_i^F) \cdot Q_i^p (K_i, L_i, M_i, I_i^F, e_i^F) \exp(e_i^s)\} 
\]

where \( Q_i^d \) is actual output of firm \( i \) and \( Q_i^p \) the probable output; \( E_i \) the firm \( i \)'s fuel input and the function \( g(\cdot) \) transforms fuel input \( E_i \) into electricity energy. For simplicity, we assume that function \( g(\cdot) \) is monotonically increasing in \( E_i \); \( K_i, L_i \) and \( M_i \) are, respectively, inputs of capital, labor and nonfuel materials of firm \( i \); \( I_i \) is the vector of parameters, and \( e \) is unobservable disturbances with mean zero. The disturbance \( e_i^s \) incorporates the productivity shocks which are known to the manager in advance of scheduling labor and nonfuel material inputs but are not observable to the econometrician; \( e_i^s \) is the disturbance specific to real output which we assume a form of multiplicative shock \( \exp(e_i^s) \). The shock \( e_i^s \) may be negative or positive due to the system dispatch: the generation unit may be unexpectedly shut down due to some technical problems or run more intensively than anticipated. If the shock \( e_i^s \) is negative, the actual output is less than the probable output since the term \( \exp(e_i^s) \) is less than 1; and if the shock \( e_i^s \) is positive, the actual output is more than the probable output since the term \( \exp(e_i^s) \) is more than 1. The term \( e_i^F \) is the disturbance specific to fuel input.

Conventionally, the output of a generation plant is represented by the net energy that the generation unit produces over some period, and it is measured by annual MWH. In general, the probable output (denoted by \( Q_i^p \) ) which the firm is prepared to produce given its available inputs, is different from the actual output (denoted by \( Q_i^d \) ) called by the system dispatcher, since the system dispatcher must balance total production with real-time demand. Actually, the dispatch of the electricity system is impacted by many factors, including the realization of electricity demand, the locations of the generators, the constraints of the transmission networks, and the availability of the other generators. In sum, the probable output is related to inputs of labor and materials, while the actual output is what we can observe.

The inputs of capital, labor, fuel and nonfuel materials are different. According to the arguments of Fabrizio et al. (2007), capital can be considered as fixed cost because it rarely changes during its life. Labor and nonfuel material inputs are usually set in advance of actual production based on the expectation of electricity demand and they can be adjusted in the medium run.

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9 The five IPPs are China Huafeng Corporation, China Datang Corporation, China Huadian Corporation, China Guodian Corporation and China Power Investment Corporation, and the two independent transmission companies are State Grid Company and China Southern Grid Company.

10 The electricity shortage began from 2002 and became more serious in the following two years. According to the reports, 16 provinces out of 31 suffered from blackouts in 2003 and the number grew to 27 provinces in 2004. See the following two pieces of news: http://www.people.com.cn/GB/jingji/1045/2266548.html and http://info.electric.lc360.com/html/001/008/004/156626.htm.
The inputs of labor and nonfuel materials determine the probable output. Compared to the aforementioned three inputs, fuel can be adjusted in the short run and it varies in response to the real-time system dispatching. Another prominent character of the fuel input is that it is usually not substitutable by other three inputs, while labor, nonfuel materials and capital are possibly substitutable to produce the same amount of probable output to some extent.

Given the above explanations of the production technology, the production function characterized in Eq. (1) is appropriate to describe the power plants’ production process.

Furthermore, we model the probable output as a Cobb-Douglas function of labor and nonfuel materials, embedding capital effects in a constant term \( Q_0(K) \), which is also the strategy adopted by Fabrizio et al. (2007)

\[
Q^* = Q_0(K) (L_i)^{\lambda} (M_j)^{\gamma^M} \exp(\epsilon^p_i) 
\]

(2)

where \( \lambda \) and \( \gamma^M \) are parameters specific to labor and nonfuel materials, respectively. The probable output disturbance is exponential.

Given labor’s wage \( W_i \) and nonfuel material price \( S_i \), a cost-minimizing generation plant solves the following optimization problem:

\[
\min_{L_i,M_i} W_i L_i + S_i M_i
\]

subject to \( Q^*_i = Q_0(K_i) (L_i)^{\lambda} (M_i)^{\gamma^M} \exp(\epsilon^p_i) \)

(3)

The first-order condition gives us two conditional factor demand equations:

\[
L_i = (\lambda^*/Q^*_i)W_i 
\]

(4)

\[
M_i = (\gamma^M/Q^*_i)S_i 
\]

(5)

where \( \lambda \) is the Lagrange multiplier of the constraint. Since we do not observe the probable output and only the actual output is observed, we replace the probable output \( Q^*_i \) in the factor demand equations with the actual output \( Q^A_i \) through the equation \( Q^A = Q^* \exp(\epsilon^A_i) \).

Taking logarithm of both sides of Eq. (4), we get the following logarithmic labor demand equation:

\[
\ln(L_i) = x^A_i + \ln(Q^A_i) - c^L_i - \ln(W_i) 
\]

(6)

where \( x^A_i = \ln(\lambda^*/Q^*_i) \) is the constant term. Eq. (6) will hold with error, because there may be differences across firms in the coefficients of the production function \( (\gamma^M_i) \) or in the shadow value of the probable output constraint \( (\lambda) \), or there may be measurement error in labor used by the plant. So we rewrite Eq. (6) as

\[
\ln(L_i) = x^L_i + \ln(Q^L_i) - c^L_i - \ln(W_i) + \epsilon^L_i 
\]

(7)

where \( \epsilon^L_i \) measures the remaining error in the labor demand function.

Similarly, taking logarithm of both sides of Eq. (5) and adding the error term, we get the nonfuel material demand function with error

\[
\ln(M_i) = x^M_i + \ln(Q^M_i) - c^M_i - \ln(S_i) + \epsilon^M_i 
\]

(8)

which has the same explanation as the labor demand function.

Fuel demand function is a little different from those of labor and nonfuel materials. From the above production function, we know that \( Q^A_i = g(E_i, \Gamma^F, \epsilon^F_i) \). To get the fuel demand function, we need to take only the inverse of this equation since we have already assumed that function \( g(.) \) is monotonically increasing, that is \( E_i = g^{-1}(Q^A_i, \Gamma^F, \epsilon^F_i) \). Note that the price of fuel input does not enter into the fuel demand function since fuel is the only short-run input and has no substitutes. To be consistent with the demand function of labor and nonfuel materials, we specify the following log–log relationship for fuel input, as Fabrizio et al. (2007) have done

\[
\ln(E_i) = x^F_i + \ln(Q^F_i) + \epsilon^F_i 
\]

(9)

In order to estimate the impact of regulatory reforms on the efficiency of generation plants, we need to separate the generation plants into two groups, the control group and the treatment group. The criterion to distinguish the two groups is whether the policy changes are specific to that group and have altered the market environment of that group. The group influenced by the policy changes is called the treatment group, while the uninfluenced one is the control group. In our data set, the plants directly subordinate to the former MEP (later SPC) form the treatment group and CFGPs form the control group, since the regulatory reforms of 1997 and 2002 only affected DSGPs, while leaving CFGPs unchanged. We therefore add a dummy variable MEP to capture the variations between the control group and the treatment group. If plant \( i \) is formerly owned by MEP, dummy variable MEP equals 1, otherwise it is 0.

Besides the heterogeneity between the control group and the treatment group, it is also possible that the generation plants’ production efficiency changes over time. It is reasonable to think that the generation plants have made an improvement in efficiency from 1995 to 2004 even in the same group because of technological progress. To capture the variations of the generation plants over time, we add a second dummy variable YEAR2004, which equals 1 if the data were collected in 2004 and 0 if they were collected in 1995.

Although we have controlled the variations over groups and periods, we still need another dummy variable, MEP*YEAR2004, to capture the net restructuring effects. It equals 1 only when both MEP and YEAR2004 equal 1. The coefficient of the term MEP* YEAR2004 is called average treatment effect, which is what we are most interested in since it reflects the net effect of the policy changes.

We thus get the following basic regression model:

\[
\ln(N) = \beta_0^N + \beta_1^N \ln(Q^A_i) + \beta_2^N \ln(P^N) + \beta_3^N MEP* YEAR2004 + \beta_4^N MEP + \beta_5^N YEAR2004 + u
\]

(10)

where \( N \) represents the inputs (labor, fuel and nonfuel materials, respectively); \( Q^A \) is the actual output of the generation plants; \( P^N \) represents the corresponding price of input \( N \). It must be noticed that the price of fuel does not enter the regression equation. MEP, YEAR2004 and MEP* YEAR2004 are the dummy variables explained above; \( u \) is the error term combining the deviation of actual output from probable output \( (\beta_2^N \ln(A^N)) \), and the input \( N \)-specific productivity shock to plant \( i (\epsilon^N_i) \), that is, \( u = \beta_4^N \ln(A^N) + \beta_5^N \).

4. Data and descriptive statistics

We use annual plant-level data for the fossil-fired generation plants. The data set includes 2 years of cross-sectional data, collected by the National Bureau of Statistics of China in 1995 and 2004, respectively. The 1995 data were collected in the Third National Industry Survey and the 2004 data were collected in the First National Economy Survey, both of which include all the fossil-fired generation plants of China in that year and are relatively more reliable than other official statistic data since they are nationwide plant-level survey data. The Third National Industry Survey in 1995 includes 7.34 million firms from 98 industries, and the First National Economy Survey in 2004 includes 51.21 million firms from 98 industries, both of which are the authoritative and nationwide surveys. In this paper, we only focus on the data of fossil-fired generation plants collected in these two surveys.
detailed operation statistics of the generation plants, such as the location of the plant, ownership of the plant, year of building, number of employees, total wages, nonfuel material expenses and fuel expenses, etc.

Table 1 reports the summary statistics of the data in 1995 and 2004. Firms are separated into two groups: the first group is made up of the plants owned by the former MEP (later SPC) which were eventually divested from the transmission networks, and the second group is made up of CFGPs that were never integrated with the transmission networks. We use DSGPs to represent the first group and CFGPs the second group. The first three rows summarize employees, fuel expenses and nonfuel expenses, scaled by the plant’s gross output value, and the fourth summarizes ages of the plants.

From Table 1, we can see that CFGPs use more labors and less fuel expenses in 1995, and the differences in means are both significant at 1% level, while the mean difference in nonfuel expenses is not significant. It is also significant at 1% level that CFGPs tend to be 16 years younger on average.

We can also find that the differences in means of labor, fuel expenses and age of the plant are still significant at 1% level in 2004. Compared to the 1995 result, both restructured and non-structured groups have reduced their usage of labor input in 2004, but the extents of the reductions are different. The restructured group reduced their labor input more fiercely, thus the difference in means of the two groups decreased. As to fuel expenses, the treatment group has reduced their fuel expenses greatly, while the control group increased their fuel expenses slightly. This results in the change of the sign of the mean difference. In the following regression analysis, we will control all these factors and get the net effect of the restructuring.

Usually, the output of the generation plant is characterized by the total energy output of the plant over some period, measured by annual net MWH. Unfortunately, such data are unavailable in our data set. What we have is the gross output value, which is the product of net energy output and wholesale price. The gross output value is an imperfect choice because this index incorporates the price factor, which is difficult to control with regard to unavailability of the wholesale price data. Furthermore, there is no uniform wholesale price for the regulated power generation plants. Actually, the regulated wholesale price for the generation plants in China is really a mess. The Chinese government has set a specific price for almost every newly built generation plant since 1985, even the different units in the same plant may have different regulated wholesale prices, and sometimes, the difference between two plants can be very large (Yang, 2006).

Since the gross output value is disturbed by the impact of price, we have to substitute it with a proxy variable (Wooldridge, 2006). One of the adequate proxy variables is the total thermal power output of the province where the plant is located. The provincial thermal power output data are available in the Yearbook of Chinese Electricity Industry and we use GENERATION to denote it. Frankly speaking, the province-level output is also not perfect, since it is the summation of outputs of plants in one province and it can only reflect partially the output of a certain generation plant. Meanwhile, it also reduces variation in the data and may have a negative influence on the results of empirical analysis. However, it is still the best choice with regard to the current data set. In other words, given that the plant-level output is unavailable, the province-level output is a substitutive variable superior to the plant-level gross output value contaminated by the impact of price. Furthermore, even the plant-level output itself contains some interferential information. As pointed out by Fabrizio et al. (2007), it is still imperfect because the electricity output is multi-dimensional. Aside from the electricity power, the output of a generation plant should also include some other components like reliability services, voltage support and frequency control, while all of which have not been reflected in the output data. Therefore, the variable of the plant-level output may underestimate the actual output level of the generation plants, which makes it highly possible that the bias caused by using the province-level output is no more than that caused by using the plant-level output.

In our specification, the problem of endogeneity deserves caution. This endogeneity problem comes from the simultaneity of input N and the actual plant output. For example, a positive disturbance may increase the quantity of input, while the increased usage of input in turn may increase the plant output. Contrarily, if the output is increased, the usage of input will surely increase. To solve the endogeneity problem, we choose the provincial electricity demand as an instrument variable. This is
also the most frequently used method in the literature. Provincial electricity demand is highly related with the firms’ energy output, but should be unaffected by productivity shocks. The data of provincial electricity demand can be derived from the Yearbook of Chinese Electricity Industry.

The data on labor, wage, fuel expenses and nonfuel expenses are all collected in our 1995 and 2004 data set. We use EMPLOYEES to denote the labor variable, which is a count of full-time employees working in the generation plants in 1995 and 2004, respectively, rather than those assigned to the power generation plants, i.e. those laid-off workers are excluded.

What matters is that our fuel data are not the quantity of fuel that each plant has used, but the total expenditure that the plant has paid for the usage of fuel, which includes the fuel price factor. Additionally, we cannot use the average provincial fuel prices to divide fuel expenses to get each plant’s real fuel input for the following reasons:

First, in our data set, we cannot tell whether the plants are using coal, oil or gas as fuel input. It may be the case that the different units in the same plant are using different types of fuel input, while different types of fuel have different heat rates and prices.

Second, even though most of the generation plants use coal as fuel input in China, it is still difficult to exclude the price factor because of the complexity of China’s coal market. In 1990s, the Chinese government began to deregulate the coal market and use the market mechanism to fix the coal prices, but the price of the coal for the electricity plants is still under price cap regulation (of course, the quantity of regulated coal for electricity firms is limited, only the large state-owned generation plants can get the quotas). Thus, two types of coal can be bought by the generation plants, market- and regulation-based coal, and the price gap between these two types of coal can be very large (Wang, 2007). In our data set, we cannot tell whether the generation plants bought coal at market price or at regulated price.

Third, from our data set, we cannot tell where the plants bought their fuel since they could buy it from any province other than the provinces they were located in. If we divide fuel expenses by the uniform average provincial fuel price, it could be really misleading.

Therefore, we will use provincial fuel usage as a proxy for plant-level fuel input. Though provincial fuel usage is aggregated index and will reduce the variations among the plants, it should still be better than fuel expense since it is the quantity of fuel usage. In view of different heat rates of different types of fuel inputs (coal, oil and gas), we convert fuel usage to tons of standard coal (million tons) by the reported annual standard coal consumption rate of power supply and provincial thermal power generation. These data are available in the Yearbook of Chinese Electricity Industry. We denote it as STANDARD COAL.

We have information on nonfuel material input, which includes all nonfuel operation and maintenance expenses, such as those for maintenance supervision, coolants, repairs and engineering, etc. We use NONFUEL EXPENSES to denote this variable. In our data set, this variable is not an ideal measurement of nonfuel materials, because it reflects expenditures rather than quantities. We cannot exclude the influence of the price and have to lose some precision. To get rid of the influence of inflation, we also deflate the 2004 data to the 1995 basis by using the deflator of fuel and power.

In our data set, we have data on total wages for each plant in 1995 and 2004. In order to get the average wage of each generation plant, we divide the total wage of each plant by the corresponding total full-time employees in 1995 and 2004. We denote this new variable WAGES, which is exactly the price of labor input. Note that the workers’ incomes include not only the wages but also some allowances, but we do not count the allowances into the variable WAGES because some state-owned generation plants also pay the retired workers’ retirement pensions, while these retirement pensions are exactly included in the allowance account. To get rid of the influence of inflation, the 2004 data are also deflated to the 1995 basis by the consumer price index (CPI).

We do not have reasonable price index for the nonfuel materials, not only because they consist of many inputs including maintenance expenses, repairs and coolants, etc., and we do not know the quantities of each input the firms have used, but also because the prices that each firm faced are different and it is difficult to learn these private information. Therefore, we follow Fabrizio et al. (2007) to set the price of nonfuel material to be a constant and get a price coefficient of one. At the same time, recall that the price of fuel input does not appear in the conditional factor demand function.

As a transitional and developing country, the regional development of China is unbalanced and the development level of the provinces where the generation plants are located may well affect the firms’ production efficiency. Traditionally, researchers divide the whole country into four areas according to the development levels of the provinces: east-coast, northeast, central and west.12 East-coast area is the most developed region in China. Usually, the generation plants in this region have more advanced technologies and better-trained workers, but the prices of inputs in this region are also much higher than those in the other three regions, since natural resources such as coal, oil and gas are rare in this region. The generation firms must pay much higher transportation costs to get the same quantity of fuel inputs. It is worth to note that during 2000–2004, China experienced a great shortage of electricity energy, especially for the provinces in the east-coast region. During the great shortage, many obsolete generating units were used again to cope with the shortage. This may reduce the average productivity efficiency of the generation plants located in the shortage provinces.

We, thus create two dummy variables, EAST and WEST, to control the variations over regions.14 If the generation plant is located in east-coast region, we set the dummy variable EAST equal to 1 and dummy WEST equal to 0; if the generation plant is located in west region, we set dummy WEST equal to 1 and dummy EAST equal to 0; if the generation plant is located in central and northeast areas, both of the dummy variables EAST and WEST equal to 0.

5. Estimation

According to Eq. (10), we estimate the impact of electricity reforms on EMPLOYEES, NONFUEL EXPENSES and STANDARD COAL with the following basic regressions:

\[
\ln(N) = \beta_0 + \beta_1 \ln(GENERATION) + \beta_2 \ln(PRICE^N) + \beta_3 \ln(MEP) + \beta_4 \ln(YEARE2004) + \beta_5 \ln(MEP \times YEAR2004) + \beta_6 \ln(EAST) + \beta_7 \ln(WEST) + u
\]

\( \beta_5 \) is what we are most interested in since they measure the net effect of the regulatory reforms on the generators’ usage of inputs. A negative sign of \( \beta_5 \) would imply increased operational efficiency.

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12 East-coast region includes Beijin, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Guangxi; northeast region includes Liaonin, Jilin and Heilongjiang; central region includes Shanxi, Inner Mongolia, Anhui, Jiangxi, Henan, Hubei and Hunan; west region includes Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang and Tibet.

14 Usually, northeast and central areas are considered as one region since they have almost the same development level.
associated with the regulatory reforms. We first estimate the model with ordinary least squares (OLS) regression and then run the two-stage instrumental variable (IV) regression with the provincial electricity demand as an IV. The regression outcomes are listed in the following tables.

Table 2 reports the results of labor input regressed on the corresponding explanatory variables. The first two columns summarize the results from the basic OLS estimation, treating the output as exogenous. The second two columns are the results derived from the two-stage IV regression, taking the provincial electricity demand as the instrumental variable of \textit{GENERATION}. The coefficients of variable MEP*YEAR2004 suggest statistically and economically significant declines in labor use associated with the restructuring regulation. The labor input declines by roughly 29% by OLS estimation and roughly 32% by two-stage IV estimation, which are all significant at 1% confidence level. The improvement of the productivity efficiency associated with the regulatory reforms is surprisingly large.

We now discuss the other variables. The coefficient of variable $\ln(\text{GENERATION})$ derived from OLS estimation is positive and significant at 1% level, this means that, on average, labor input will increase by about 0.28% with a 1% increase in output. This is consistent with our expectation and common sense. The coefficients of variable EAST by both OLS and two-stage IV estimations are all significant at 1% level with the same sign in the two estimations. This means that, on average, the plants in east-coast region use less labor than the plants in northeast and central areas for the same output of energy. The gaps are, respectively, 60% and 52% by OLS and two-stage IV estimations. The OLS coefficient of variable YEAR2004 is negative, and this means that firms’ usage of labor input decreases by roughly 21% from 1995 to 2004, but it is only significant at 5% level in the OLS estimation. The coefficients of variable MEP are interesting, implying that the plants formerly directly subordinate to MEP tend to use more labor than CFGOs. Both OLS and IV estimations show that the labors DGPs used are almost one and half of CFGOs. To some extent, this explains why the government wants to restructure the electricity industry.

Table 3 reports the results of fuel input regressed on the corresponding independent variables, and almost every coefficient is significant at 1% level except for the variable MEP*YEAR2004. From the outcomes in the table, we can see that the coefficients of variable MEP*YEAR2004 are about 0.004, but both of them are not significant even at 10% level, meaning that there is no evidence of gains in fuel efficiency from the electricity restructuring. This finding is similar to that of Fabrizio et al. (2007).

Frankly speaking, with our aggregated data, it may be difficult to measure the efficiency gains sufficiently precisely. As Fabrizio et al. (2007) has pointed out, fuel efficiency at a plant is heavily influenced by factors such as the allocation of output across units at a plant, the number of times its units are stopped and started, and for how long the units were running below their capacity. To measure fuel efficiency more precisely, we need more detailed plant-level or even unit-level fuel data to control these operational characteristics. Here, we point out our limitation. Improving our understanding of fuel-efficiency effects is an important direction for future research.

The coefficients of $\ln(\text{GENERATION})$ tell us that fuel input increases by about 0.99% with a 1% increase in output. The coefficients of EAST and WEST show that the plants located in east-coast region use about 5.57% less fuel than the plants located in central and northeast areas, while the plants located in west area use about 3.55% more than the plants located in central and northeast areas. This outcome is not surprising since east-coast area is the most developed region and west area is the least developed one in China. Usually, the plants located in more developed regions have more advanced technology, thus higher fuel efficiency.

The negative sign of the coefficients of variable YEAR2004 means that the fuel efficiency of the plants in 2004 is about 7.6% higher than that in 1995. This may be highly related to the

Table 2

<table>
<thead>
<tr>
<th>Dependent variable: $\ln(\text{EMPLOYEES})$</th>
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<tbody>
<tr>
<td>Independent variables</td>
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<tr>
<td>------------------------</td>
</tr>
<tr>
<td>$\ln(\text{GENERATION})$</td>
</tr>
<tr>
<td>$\ln(\text{WAGES})$</td>
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<tr>
<td>YEAR2004</td>
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<tr>
<td>MEP</td>
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<tr>
<td>MEP*YEAR2004</td>
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<tr>
<td>EAST</td>
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<tr>
<td>WEST</td>
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<td>CONSTANT</td>
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Notes: (1) Number of observations is 2161. (2) IV estimation uses provincial demand as the instrument of the variable GENERATION. (3) *** denotes significant at 1%; ** denotes significant at 5%; * denotes significant at 10%.

Table 3

<table>
<thead>
<tr>
<th>Dependent variable: $\ln(\text{STANDARD COAL})$</th>
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<tbody>
<tr>
<td>Independent variables</td>
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<tr>
<td>------------------------</td>
</tr>
<tr>
<td>$\ln(\text{GENERATION})$</td>
</tr>
<tr>
<td>YEAR2004</td>
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<tr>
<td>MEP</td>
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<tr>
<td>MEP*YEAR2004</td>
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<td>EAST</td>
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<td>WEST</td>
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</table>

Notes: (1) Number of observations is 2397 for OLS estimation and 2395 for IV estimation. (2) IV estimation uses provincial demand as the instrument of the variable GENERATION. (3) *** denotes significant at 1%; ** denotes significant at 5%; * denotes significant at 10%.

Table 4

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<thead>
<tr>
<th>Dependent variable: $\ln(\text{NONFUEL EXPENSES})$</th>
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<tr>
<td>Independent variables</td>
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<td>------------------------</td>
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<tr>
<td>$\ln(\text{GENERATION})$</td>
</tr>
<tr>
<td>YEAR2004</td>
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<tr>
<td>MEP</td>
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<tr>
<td>MEP*YEAR2004</td>
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<tr>
<td>EAST</td>
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<td>WEST</td>
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<td>CONSTANT</td>
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Notes: (1) Number of observations is 2005. (2) IV estimation uses provincial demand as the instrument of the variable GENERATION. (3) *** denotes significant at 1%; ** denotes significant at 5%; * denotes significant at 10%.

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15 If we use the formula $(e^t - 1) \times 100$ to calculate the impact of restructuring on labor input, the efficiency improvement is roughly 25.5–27.3%.
improvement of technology. The results of Table 3 also demonstrate that fuel efficiency of DSGPs is about 1.7% higher than that of CFGPs.

Table 4 reports the estimation results of nonfuel material expenses regressed on corresponding independent variables. Almost all the coefficients are significant for both OLS estimation and two-stage IV estimation, except for the dummy variable WEST. The coefficient of Differences-in-Differences estimator MEP*YEAR2004 shows that nonfuel material expenses decrease roughly by 35% because of the regulatory reforms and it is significant at 5% level. The results also show that nonfuel material expenses will increase roughly by 0.18% to 0.23% if the energy output increases by 1%. The coefficient of variable EAST is positive and significant at 1% level, meaning that the nonfuel material expenses of the plants located in east-coast region are 24% higher on average than those of the plants located in west, central and northeast areas. This makes sense if we consider the effects of power shortage aforementioned. The same arguments fit to explain the coefficient of MEP since the government used to ask the state-owned plants to overrun in order to relieve shortage.

### 6. Robustness test

To check robustness of our benchmark regressions illustrated in Tables 2–4, we use the method of randomization inference (Rosenbaum, 1999; Bertrand et al., 2001), which is based on group jackknife approach (Shao and Tu, 1995) and requires none of homoskedasticity, normal or independent distribution of residuals across individuals, and any large sample approximation.

Following Bertrand et al. (2001), we repeat the regression of Eq. (11) by randomly choosing about half of units in the data set, namely 1000 observations. We adopt a process ad hoc to simulate random choice of the observations: first, we create a new variable NUMBER as an index numbering units in the whole sample; second, we choose a subsample consisting of the first 1000 observations as a start point; third, we renew the subsample time and again replacing 10, 20 and 50 observations each time, respectively, in the 1000-observation subsample with 10, 20 and 50 new ones from the rest of the whole sample. We try 10, 20 and 50, respectively, in order to prevent random choice from being dependent on any certain rule of choosing subsamples. Then according to the key idea of randomization inference, we test whether the estimations of the coefficient $\beta_5$ of MEP*YEAR2004 got from repeated regressions with random choice of observations are statistically different from 0. Table 5 lists the results.

Comparing Table 5 with Tables 2–4, we find that the results of our benchmark regressions suffer trivial influence. In sum, conclusions stemmed from the empirical analysis we have done with national survey data are robust.

### 7. Conclusions

In this paper, we try to estimate the impact of the regulatory reforms on production efficiency of the fossil-fired generation plants in China, based on the plant-level national survey data collected in 1995 and 2004. Between 1995 and 2004, there were mainly two regulatory reforms in Chinese electricity industry. The first is the abolishment of the central planning system and the establishment of the market-oriented modern enterprise system in 1997, and the second is the divestiture of the generation sector from the transmission and distribution sectors.

Following Fabrizio et al. (2007), we use the method of Differences-in-Differences to estimate the production efficiency changes associated with the regulatory reforms, focusing on generation plants’ input demands for labor, fuel and nonfuel materials. What differs is that their econometric model is based on panel data, while we use pooled cross-sectional data. Our results show that the regulatory reforms between 1995 and 2004 have improved the generation plants’ production efficiency in labor and nonfuel material inputs greatly. The net efficiency improvement in labor input associated with the regulatory reforms is roughly 29% and the gains in nonfuel materials are about 35%, while there is no evidence of efficiency gains in fuel input associated with the electricity reforms.

Our research is quite preliminary, and many works remain to be done. We do not consider seriously many events happened in the electricity industry likely to induce deviations, such as the great shortage, the reforms of the coal industry and the environmental consideration,16 because of the data constraint.

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16 Chinese government has realized the severity of environmental pollution. In the current five-year-plan from 2006 to 2010, the blueprint mandates energy...
As noted by Fabrizio et al. (2007), the regulatory reforms may not only have medium-run impact on factor inputs, but also play a long-run role in the investments of generation plants. However, in our research, only medium-run effects are considered. Anyway, the overall assessments of the effects of China’s electricity sector restructuring on the electricity industry need more detailed data and a longer time span to get conclusive results.

Acknowledgements

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References


(footnote continued) usage per unit of GDP should be cut by 20%. More detailed discussion can be found in Zhang (2007).