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A research on productivity change and efficiency determinants of Chinese power generation industry: In view of parametric approach

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ABSTRACT

This paper employs B-C (95) model to conduct a parametric efficiency analysis with a panel data set covering 27 provinces, municipalities and autonomous regions in the period from 2000 to 2010. Results show that the productivity of Chinese power generation industry increased by 1.37 percent per year on average and the majority of the growth came from technical progress. Our empirical study also shows coal-electricity pricing linkage scheme had little impact on power plants' motivation to improve efficiency.

KEYWORDS

Power generation industry; Parametric method; TFP change; Coal-electricity pricing linkage scheme, China.

INTRODUCTION

The paper is designed to achieve two purposes. Firstly, it calculates the TFP change and its sources by using parametric method, with an aim to compare its results with that from non-parametric method conducted by Li et al.[1]. Secondly, we attempt to obtain information concerning factors that may influence efficiency of power plants in China.

Both non-parametric and parametric method estimate the relative efficiency of decision making unit (hereinafter, DMU）by the ratio of practical outputs (or costs in case of cost function）to the outputs that the DMU would have achieved if it had been as efficient as DMUs on the frontier. Given that efficiency scores are much sensitive to selected samples by which the production (or cost) frontier is constructed, empirical results obtained from different samples are less comparable and then conclusions and insights based on this kind of comparison need to be handled with caution. However, both empirical results and the resulting implications could be more robust if they are based on the same sample but estimated by different methodologies.

From the viewpoint of methodology, non-parametric method, when compared with the parametric method, has advantages in avoiding arbitrary function specification and distributional assumptions imposed on error terms, while suffering from its inability to deal with any statistical errors[2]. For example, as far as our research is concerned, any possible impacts of the snow disaster in 2008 on the power generation in China, either positive or negative, will be treated as efficiency changes, either plus or minus, in the estimation of non-parametric method, while be treated properly as disturbance in parametric method. On the other hand, the assumptions of independent and identical distribution on error terms imposed by parametric method makes the estimates of efficiency less universal. Taking all those things into consideration, we decided to compare two estimating tools in this investigation with the aim of obtaining a full picture regarding productivity changes of power plants in China.

The remainder of the paper is structured as follows. Section 2 depicts methodologies used in this study. Section 3 reports descriptive statistics and the results of the productivity estimates. Due to the limitation on the length of this paper, only key results from two different studies are compared in the section 4, in addition to some concluding comments.

Wang et al.[3] provided a detailed literature review regarding the empirical application of efficiency estimating method in electricity industry, while See and Coelli[4] presented a comprehensive review on determinants of technical efficiency of power plants.

METHODOLOGY

Parametric approach for decomposing productivity change

Solow[5] lays the foundation for calculating productivity change (which is termed as residual or TFP), which is defined as the rate of change in output per unit of an aggregate measure of input, by means of econometric method. However, in terms of source components of productivity change, Solow’s measurement of productivity change is just technical change (namely, shift in frontier) under assumptions of constant returns to scale and fully technical efficiency (i.e. assuming technical efficiency equals to one). By mitigating assumptions regarding constant returns to scales imposed on technology, Denny et al.[6] decompose productivity change into technological change and economies of scale. Further to that, under constant returns to scale assumption and production frontier framework, Nishimizu and Page[7] decompose productivity change into technical efficiency change and technical change. Finanlly, Kumbhakar[8] succeeds in decomposing productivity change into technical efficiency change, technical change and scale effects and illustrating, with pane data sets, the developed theoretical framework in the case of production function, cost function and profit function, respectively.

Supposing a stochastic frontier production function could be expressed as:

$$y_{it} = f(x_{it}, t)\exp(v_{it})\exp(-u_{it}) \quad \textbf{(1)}$$

Where y_{it} denotes the output of the i th firm ($i=1,...,N$) in time period t ($t=1,...T$), $f(\cdot)$ represents the production technology, x_{it} stands for the vector of input variables, t is the time trend variable and v_{it} is error term. u_{it} captures non-negative time-variant inefficiency term, measuring the proportion by which actual y_{it} falls short of maximum possible output ($f(x_{it},t)\exp(v_{it})$, labeled as stochastic frontier output). Technical efficiency is then calculated by $y_{it}/f(x_{it},t)\exp(v_{it})=\exp(-u_{it})\leq 1$.

Incorporating time trend variable into the production function means the existence of exogenous technical change, which could shift the production frontier. By taking log and then derivative of production frontier with respect to time t, the rate of exogenous technical change (hereinafter, TC) could be measured, namely:

$$TC_{it}=\frac{\partial \ln(f(x_{it},t)\exp(v_{it}))}{\partial t} \quad \textbf{(2)}$$

By definition, the overall productivity change is also affected by change in technical efficiency among different time period with given input quantities. In order to measure this change, we take log derivative of equation (1) with respect to time, and then obtain the following formulation.

$$\frac{\ln(y_{it})}{\partial t}=TC_{it}+(-\frac{\partial u_{it}}{\partial t}) \quad \textbf{(3)}$$

Where $(-\frac{\partial u_{it}}{\partial t})$ represents TEC, or the rate of technical efficiency change. Productivity change defined in equation (3) assumes input quantities unchanged. When input quantities are also changeable, the rate of TFP change（hereinafter, TFPC）can be defined as:

$$TFPC=\frac{\dot{TFP}}{TFP}=\frac{\dot{y}}{y}-\sum_{j}s_{j}\frac{\dot{x}}{x} \quad \textbf{(4)}$$

Where $s_{j}=w_{j}x_{j}/\sum_{j}w_{j}x_{j}$ and w_{j} being the price of input x_{j}. Differentiating equation (1) provides:

$$\frac{\dot{y}}{y}=\frac{\partial \ln y}{\partial t}=\frac{\partial \ln f(x,t)}{\partial t}+\sum_{j}\frac{\partial \ln f(x,t)}{\partial \ln x_{j}}\times\frac{\partial \ln x_{j}}{\partial x_{j}}\times\frac{dx_{j}}{dt}-\frac{\partial u}{\partial t}$$

$$=\frac{\partial \ln f(x,t)}{\partial t}+\sum_{j}\varepsilon_{j}\frac{\dot{x}_{j}}{x_{j}}-\frac{\partial u}{\partial t} \quad \textbf{(5)}$$

Where $\sum_{j}\varepsilon_{j}=\sum_{j}\frac{\partial \ln y}{\partial \ln x_{j}}$ is the measure of returns to scale and ε_{j} is input elasticity defined at the production frontier, $f(x,t)$. By making use of formulation (4) and (5), we finally get the equation proposed by Kumbhakar (2000).

$$TFPC=\frac{\partial \ln f(x,t)}{\partial t}-\frac{\partial u}{\partial t}+(\sum_{j}\varepsilon_{j}-1)\sum_{j}\lambda_{j}\frac{\dot{x}}{x}+\sum_{j}(\lambda_{j}-s_{j})\frac{\dot{x}}{x} \quad \textbf{(6)}$$

Where $\lambda_j = \varepsilon_j / \sum_j \varepsilon_j$.

In equation (6), the rate of TFP change is decomposed into four aspects, the rate of technical change, the rate of technical efficiency change, the rate of scale economy change and the rate of allocative efficiency change. In other words, the sum of the rate of TFP change can be expressed as follows:

$$TFPC = \frac{\partial \ln \mathrm{TC}}{\partial t} + \frac{\partial \ln \mathrm{TEC}}{\partial t} + \frac{\partial \ln \mathrm{SEC}}{\partial t} + \frac{\partial \ln \mathrm{AEC}}{\partial t} \quad \textbf{(7)}$$

In the case of no input price information, equation (7) could be written as:

$$TFPC = \frac{\partial \ln \mathrm{TC}}{\partial t} + \frac{\partial \ln \mathrm{TEC}}{\partial t} + \frac{\partial \ln \mathrm{SEC}}{\partial t} \quad \textbf{(8)}$$

Parametric approach for calculating productivity change

In order to measure productivity change using equation (6), we need to specify stochastic frontier production function model for panel data, which was originally developed by Aigner et al.[9] and Meeusen et al.[10], extended by so many researches such as Pitt and Lee[11], Schmidt and Sickles[12], Battese and Coelli[13,14], Greene[15,16]. Since we intend to not only calculate the TFP change, but also identify factors influencing technical efficiency of power plants in China, we decide to choose the model developed by Battese and Coelli[14] (hereinafter, B-C (95)) which can achieve the above-mended research objective.

The translog form of B-C (1995) can be written as:

$$\ln Y_{it} = \beta_0 + \beta_1 \ln L_{it} + \beta_2 \ln K_{it} + \beta_3 t + \frac{1}{2}\beta_4 (\ln L_{it})^2 + \frac{1}{2}\beta_5 (\ln K_{it})^2 + \frac{1}{2}\beta_6 \ln L_{it} \ln K_{it}$$
$$+ \frac{1}{2}\beta_7 t^2 + \beta_8 t \ln L_{it} + \beta_9 t \ln K_{it} + V_{it} - U_{it} \quad \textbf{(9)}$$

$$U_{it} = \delta_0 + \delta_1 GDP_{it} + \delta_2 auxi_{it} + \delta_3 coal_{it} + \delta_4 util_{it} + \delta_5 stru_{it} + \delta_6 reg_{it} \quad \textbf{(10)}$$

Where Y_{it}、 L_{it} and K_{it} represents power generated, labor input and installed capacity of power generation of the *i-th* province at t time period. equation (10) is used to identify factors that affect technical inefficiency of power plants, GDP_{it} is used to show the regional economic development level which may affect efficiency from demand side, $auxi_{it}$ stands for the ratio of auxiliary power to power generated, auxiliary power is consumed by the power plants during their production process, capturing the technical efficiency of installed generator sets, $coal_{it}$ represents fuel consumption, being also used to capture the efficiency of installed generator sets, $util_{it}$ represents utilization rate of installed capacity and $stru_{it}$ represents the share of power generated by fueling coal in total power generated in observation, both variables may impact efficiency from supply side. reg_{it} is a dummy variable to capture the impacts of “coal-power pricing linkage scheme” which is implemented from 2005 in China.

Following equation (6), (8) and (9), we may get the formula to calculate subcomponents of TFP change, this is:

$$TC_{it} = \frac{\partial \ln f(x,t)}{\partial t} = \beta_3 + \beta_7 t + \beta_8 \ln L_{it} + \beta_9 \ln K_{it} \quad \textbf{(11)}$$

$$TEC_{it} = \frac{TE_{it}}{TE_{i,t-1}} - 1 = \frac{U_{i,t-1}}{U_{i,t-1}} - 1 \quad \textbf{(12)}$$

In order to calculate scale efficiency change, the elasticity of labor and installed capacity is necessary, which can be obtained by:

$$\varepsilon_{L,it} = \frac{\partial \ln f(x,t)}{\partial \ln L_{it}} = \beta_1 + \beta_4 \ln L_{it} + 0.5\beta_6 \ln K_{it} + \beta_8 t$$

$$\varepsilon_{K,it} = \frac{\partial \ln f(x,t)}{\partial \ln K_{it}} = \beta_2 + \beta_5 \ln K_{it} + 0.5\beta_6 \ln L_{it} + \beta_9 t$$

Further to that, on the condition of $\dot{x} / x \approx \ln x_{it} - \ln x_{i,t-1}$, the SEC_{it} can be expressed as:

$$SEC_{it} = (\varepsilon_{L,it} + \varepsilon_{K,it} - 1)\left[\frac{\varepsilon_{L,it}}{\varepsilon_{L,it} + \varepsilon_{K,it}} \left(\ln L_{it} - \ln L_{i,t-1} \right) + \frac{\varepsilon_{K,it}}{\varepsilon_{L,it} + \varepsilon_{K,it}} (\ln K_{it} - \ln K_{i,t-1}) \right] \quad \textbf{(13)}$$

DATA AND RESULTS

Data collection

Our empirical study covers a panel data for 27 provinces, autonomous regions and municipalities during the period 2000 to 2010. In line with Lam et al.[17] and[3], each provincial region is taken as a decision making unit in the output-based non-parametric method. Electric power generated by power plants is employed as the output variable, and labor and capital are two inputs used in power generation, labor input is the number of employees in power plants, capital is measured with installed generating capacity. The detailed information on data collection and processing is shown in TABLE 1, while TABLE 2 provides a summary statistics of the variables used in the calculation process. GDP is adjusted for inflation using GDP index and is measured in Chinese RMB of year 2000.

TABLE 1: Data source and processing

Variable	Description	Unit	Data sources	Data processing
Y_{it}	Power generated	10^9 kwh	China power yearbook	Exclusive auxiliary power consumption
L_{it}	Labor	Person	China labor Statistics yearbook	The number of the electricity, heat production and supply industry in used instead
K_{it}	Installed Capacity	10^5 kw	China power yearbook	
GDP_{it}	Regional GDP	10^9 RMB	China statistics yearbook	Real GDP (2000 constant price)
$auxi_{it}$	Power consumed	%	China power yearbook	Power consumed/ Power generated
$coal_{it}$	Fuel consumption	g/kwh	China power yearbook	Standard coal equivalent consumed/ power generated
$util_{it}$	Utilization rate of installed capacity	%	China power yearbook	Working hour/ 8760 hour
$stru_{it}$	Power generation structure	%	China power yearbook	Power/ power generated
reg_{it}	Policy dummy	0 or 1		0 for year 2000-2004 1 for year 2005-2010

TABLE 2: The mean of variables during the sample period

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Y_{it}	485	526	587	677	785	892	1020	1163	1228	1309	1501
L_{it}	9.96	10.00	10.19	10.27	10.34	10.31	10.39	10.43	10.37	10.38	10.76
K_{it}	1131	1202	1266	1389	1582	1849	2227	2565	2824	3111	3423
GDP_{it}	3523	3539	3543	3641	3855	4039	4144	4346	4620	4536	4795
$auxi_{it}$	6.08	6.11	5.99	6.05	5.82	5.82	5.85	5.84	5.75	5.61	5.41
$coal_{it}$	369	360	358	362	353	345	341	331	323	317	311
$util_{it}$	0.50	0.50	0.53	0.58	0.61	0.60	0.57	0.56	0.52	0.50	0.52
$stru_{it}$	0.76	0.77	0.78	0.81	0.80	0.78	0.80	0.81	0.79	0.80	0.79
reg_{it}	0	0	0	0	0	1	1	1	1	1	1

Results and discussions

(a) Model estimation and hypotheses testing

Parameters included in equation (9) and (10) are estimated by using FRONTIER 4.1 developed by Coelli[18] and presented in TABLE 3. The hypothesis test results from TABLE 4 confirm that the translog production model is more appropriate for these data in comparison to the Cobb-Douglas production model. They also indicate that technical change does exist in Chinese power generation industry, however, this kind of technical changes is not Hicks neutral one, which means the intercept of the function shifts but the slope does not.

TABLE 3: Estimated parameters of the translog B-C (95) model

Variables	Coefficients	T-statistic	Variables	Coefficients	T-statistic
Constant	-2.218	-4.107***	Constant	1.34	13.324***
Labor	-0.378	-2.255*	GDP	-0.000006	-2.239***
Capital	1.684	8.396***	$auxi$	0.008	1.238
t	-0.074	-3.232***	$coal$	-0.0004	-0.174
Labor^2	-0.039	-1.075	$util$	-1.722	-25.362***
Capital^2	-0.132	-3.414***	$stru$	-0.117	-2.327***
$Labor \times Capital$	0.146	2.157**	reg	0.007	0.456
t^2	0.001	0.953	$\hat{\sigma}^2$	0.003	11.715***
$t \times Labor$	-0.009	-2.05**	$\hat{\gamma}$	0.891	7.973***
$t \times Capital$	0.013	2.698***			
LR test			514.514 > $\chi^2_{0.99}(1)$=7.88		

***, ** and * refer to 1%, 5% and 10% significance levels respectively.

TABLE 4: Results of hypotheses testing

Test	Null hypothesis (H_0)	Test statistic	Critical value ($\chi^2_{a=0.05}$)	Decision
Cobb Douglas	$H_0 : \beta_{4-9}=0$	29.216	12.592	Reject H_0
Technical change	$H_0 : \beta_{3,7,8,9} = 0$	514.864	9.488	Reject H_0
Neutral technical change	$H_0 : \beta_{8,9} = 0$	8.138	5.992	Reject H_0

The results of the Maximum-likelihood estimates for the parameter in equitation (9) and (10) are reported in TABLE 3. The signs of the coefficients are inconsistent with theoretical expectations, but analogous to some of existing results, the negative coefficient of labor input, for example, is the same as[19] who also reports a minus relationship between labor input and electricity generated in Chinese power industry during the period of 2001-2007. These results mean labor input is in a state of decreasing marginal returns, namely power plants in China are overstaffing. To the extent that many central and local governments are the biggest shareholders of those power plants and creating jobs, in addition to profits maximization, is of significant importance, those estimated results are in accordance with status quo in China. It deserves to be noted that the existence of personnel redundancy in power generation industry is also reported in countries other than China[20].

The relationship between capital input and power generation is also different from standard economic textbook. Our model predicts that 1 percent increase in capital input will bring 1.684 percent increase in power generation, instead of being below 1 percent. Theoretically speaking, the presence of increasing marginal returns often originates from technical spillover and exists mainly in knowledge-intensive industry. As for modern power industry, it is undoubtedly both capital-intensive and technology-intensive given that a large of technology is embedded in generator sets. In 2002, the Chinese State Power Corporation, which had been the vertical monopolist in electric industry, was separated into five independent power generation group corporations. In order to acquire market share as soon as possible, the top five increased sharply their installed capacity simultaneously, leading to an investment rush in electricity generation[21]. [22]shows that there was a 98.3 percent growth in generation capacity in the whole nation and 173 percent growth in the top five during the period from 2005 to 2009. It is that knowledge-intensive equipment investment that leads to an increasing marginal return of capital input, which is expressed in the form of a big-than-one elasticity coefficient. This inference is also confirmed by the large shifts of production frontier which will be examined in more detail at the next subsection. Finally, we observe that the sum of two production elasticities is 1.286, which exhibits increasing returns to scale.

Now we turn to coefficients of determinants of inefficiency U_{it}, as can be seen in TABLE 3, all the signs of coefficient but that of reg_{it} are consistent with expectations: the rapider the regional economic growth, the less the self-consumption of power during the generation, the less the consumption per unit power generated, the higher the utilization rate of installed capacity and the bigger the share of coal-fueling power in the total power generated, the bigger the inefficiency will be, notwithstanding coefficients of $auxi$ and coal are not statistically important.

By Coal-electricity Pricing Linkage Scheme, it means when the price of thermal coal rises or falls by 5% or more over a continuous period of 12 months, power plants are allowed to add 70% of that coal price change to the electricity pricing formula, pre-determined by the central regulatory agency, but are required to absorb 30% of the price change by cost saving, with an aim to prevent power plants from passing all of the price changes onto electricity end consumers. By using several SFA models, Li et al.[23] shows that even under the 10/90 cost-sharing proportion between power plants and end power user, there are as many as 20 percent of the sample or 44 observations with efficiency scores below 10% in the true random effects model. Conclusions hereby is any rational power plant managers tend to give up cost saving plan from the very beginning when facing an unrealistically high cost-sharing proportion which is pre-determined by the regulator who do not hold the accurate cost information of the regulated power plants and Consequently, Coal-electricity Pricing Linkage Scheme will have few material impacts on the efficiency of power plants.

The conclusion made by[23] is confirmed by T-test for the coefficient of *reg* with a value of 0.456. In fact, On December 25, 2012, the State Council of China announced a new policy entitled “Guideline on Thermal Coal Market Reform”, according to which the cost-sharing proportion between power plants and end power user changed from 30/70 to 10/90.

(b) Productivity change and its sources

TABLE 5 shows statistic summary of productivity change index and its decomposition calculated by parametric method. As we can see, the average TFP change per year over the sample period is about 1.37 percent and technical progress accounts for the majority of TFP change（about 67%). Our results are in line with[24] and could be explained by the process of Chinese electricity industry regulatory reform. Since technical progress means a shift in the production frontier, resulting mostly from innovation, which could be embedded in new equipment investment. As have been mentioned above, during the first decade of the 21th century, active investments in generator sets were made by both the big five generators and local power plants, it follows that innovations embedded in new generating units shifted the frontier and served as the main sources of TFP change in Chinese electric power industry, as being showed in coefficient of capital input and source of TFP change.

TABLE 5: Productivity change index and its decomposition by parametric method

	TC	*TEC*	*SEC*	*TFP*
2001	-0.11%	2.17%	-0.13%	1.93%
2002	0.03%	7.19%	-0.13%	7.09%
2003	0.23%	6.93%	-0.23%	6.92%
2004	0.47%	3.33%	-0.36%	3.44%
2005	0.75%	-0.27%	-0.48%	0.00%
2006	1.06%	-3.81%	-0.67%	-3.42%
2007	1.33%	-1.36%	-0.54%	-0.57%
2008	1.58%	-4.76%	-0.41%	-3.59%
2009	1.84%	-5.37%	-0.44%	-3.97%
2010	2.03%	4.30%	-0.45%	5.88%
Average*	0.92%	0.83%	-0.38%	1.37%

*the results are arithmetic means of individual index

While as far as SEC is concerned, results show a decrease of 0.38 percent per year on average, which implies that in all the years of the last decade, the contributions from scale efficiency change to productivity change of China electricity generation industry was minus. According to[23], the decrease in scale efficiency mainly originated from excessive investments. That is, except that Beijing and Hainan have been in increase returns to scale for the sample period, Jiangxi and Heilongjiang have occasionally been in that tendency, all other regions have been in a situation of decreasing returns to scale, or in a situation of excessive investment in installed capacity.

Finally, we turn to TEC, another source of TFP changes. Estimated results show a 0.83 percent increase per year on average, accounting for a second biggest share in total TFP changes. Further to that, a trend of increase during the first half and decrease over the second half of the last decade can be seen.

We argue that this tendency may be in line with the situation of Chinese electricity industry in last decade. As mentioned above, the vertical monopolist of The State Power Corporation of China was dismantled in 2002 and five independent power generation group corporations were established, which compete in power generation sector against each other and other existing little independent power plants. The pressures from market competition as well as relatively low efficiency in monopoly period made efficiency improvement of newly founded top five possible. Furthermore, other existing power plants became having to promote efficiency in face of competition from big rivals. All of those contributed to technical efficiency gains from 2000 to 2005 in spite of rises in coal price. However, with increasing number of idle staffs and loss of motivation for mangers to struggle with bad business environment due to sharply increasing price of coal and low utilization rates, the technical efficiency began changing from an upward tendency to a downward tendency.

CONCLUDING REMARKS

This study investigated productivity change of Chinese power generation industry with the same date set as Li et al. (2013). As was expected, results from two methods show somewhat different values in some aspects. However, the following conclusions, which are supported by results from both methodologies, can be drawn with confidence: the productivity of Chinese power generation industry increased from 1.37 percent to 2.2 percent per year on average, the majority of the productivity growth came from progress of technology, embedded in newly invested generator sets, the contribution to TFP change from scale efficiency was minus due to low capacity utilization rates, which was the reasonable choice of managers faced with soaring coal price and below cost power price. As to technical efficiency, it increased in the first half of the last decade as a result of deregulation implemented in electricity industry in 2002, and changed to minus from the middle of the last decade due to soaring coal price and other accompanying problems.

From methodology perspective, we argue that the combination of non-parametric and parametric method could give a more accurate picture on TFP change and its decomposition when we are not sure which method is better in empirical case studies, e.g., by merging results from both methods, we were convinced that Chinese installed generation capacity was in a state of excessive supply and there existed a turning point in the middle of last decade with respect to technical efficiency.

From policy perspective, it seems that the coal-power price linkage scheme, which was launched from 2005, played little role in incentivizing power plants to implement cost-reducing actions. Further investigation is needed to explore the reason for failure of that linkage scheme, given that it is valid in Japan and is still in force in China.

When thinking of productivity change of China's electricity generation industry in the next few years, we argue that TFP growth through progress of technology from equipment investments may be hard to be achieved given the fact of excessive installed capacity and decreasing growth rate of Chinese economy from now on. If that is the truth, technical efficiency improvements will be, and should be the main source of productivity growth of Chinese power generation industry.

Finally, as having been mentioned in[23], non-availability of reliable and consistent panel data on coal inputs prevents it from entering as an input into the SFA model and may influence estimating results and corresponding inferences. We will refine our research by gathering more reliable data set in the future.

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