Efficiency of electricity use and productivity change of electricity in China: A nonparametric approach

Sheung Chi Chow and Xu Wenjing and Wu Xiaoyang

Hong Kong Baptist University, Hong Kong Baptist University, Hong Kong Baptist University

December 2014

Efficiency of electricity use and productivity change of electricity in China: A nonparametric approach

Sheung Chi Chow, Department of Economics, Hong Kong Baptist University
Xu Wenjing, Department of Economics, Hong Kong Baptist University
Wu Xiaoyang, Department of Economics, Hong Kong Baptist University

Abstract

This paper tries to investigate efficiency of electricity use of 30 administration regions and productivity change of electricity in China for the period 2003-2008. We use the Data Envelopment Analysis (DEA) method to measure the efficiency of electricity use and productivity change of electricity. From an empirical perspective, we provide a framework to investigate the situation of relative efficiency of electricity use and the growth rate of electricity's productivity. The results indicate that the efficiency gap between regions is very large and the east areas have a higher level of electricity efficiency than the western areas. Moreover, both the technical and efficiency change in China from 2003 to 2008 is also slow. Based on these results, we propose some reasons behind and also give some suggestions about it.

Keywords: Productivity analysis, efficiency of electricity use, productivity change of electricity, Malmquist productivity index, DEA

Section 1 Introduction

Demand for electricity in China has increased around 10% annually. The current installed Chinese national power-generating capacity (792.5 GW) is second only to that of the United States (1032 GW). Among all these power-generating capacity in China, around 80% of them are using coal to generate electricity (Mcelroy et al, 2009). Because of this reason, electricity generation and air pollution are in fact inevitably linked in China because using coal to generate electricity could create a lot of Carbon emission. Carbon emission has already caused much damage to China's environment and China citizen's health. For example, according to You and Xu (2010) the areas where pH values of rain were less than 5.6 have now spread to almost half of China's total area. And after accounting this acid rain's damage on Chinese public health and agriculture, according to You and Xu (2010), the total economic loss in China was around 176.42 billion RMB in 2000.

Without slowing down the economic growth, in order to stop this kind of pollution problems getting worse, policy marker might want to consider policy that can make the economy remain its current level of electricity consumption but on the other hand the economy could still use that electricity to produce more output. Before designing such policies, information about efficiency of electricity use or more generally information about the productivity of electricity is needed.
Unfortunately on a regional or national level, to our knowledge, not much information about it is available. This paper tries to provide such kind of information by construct efficiency score of electricity use in different regions. The idea of efficiency of electricity use is similar to

traditional energy efficiency index that takes energy into account as a single input to produce GDP output (e.g Patterson, 1996). The efficiency scores come from the DEA method what we will use should provide a better indicator than a simple output-input (O/I) ratio because it allows more flexible assumption on the return to scale. This paper also provides the Malmquist productivity index which incorporates electricity as input so as to produce economic output (GDP) in order to provide a general picture about the productivity change of electricity in China.

This paper is designed as follows. Section 2 describes the definition and estimation method of the efficiency score and the Malmquist productivity index. The description of the data and results are reported in Section 3. Section 4 will be the conclusion.

Section 2 Methodology

The Malmquist productivity index was introduced as a theoretical index by Caves et al. (1982) and has been modified by Färe et al. (1985) and Färe et al. (1994).

Assuming a production technology set S of period, the output based distance function $d_o^k\left(y^j, x^j\right)$ with output vector y and input vector x in period j is defined as:

$$d_o^k\left(y^j, x^j\right) = sup\left\{\theta: (\theta y^j, x^j) \in S^k\right\}$$

The distance θ measures the inverse of the factor by which the production of all output quantities could be increased when the decision making unit is efficient. The θ will be the efficiency score of decision making unit in our study, the higher efficiency score it has the higher relative efficient it has. With this definition then the Malmquist productivity index is constructed as:

$$m_o(y^{t+1}, x^{t+1}, y^t, x^t) = \frac{d_o^{t+1}(y^{t+1}, x^{t+1})}{d_o^t(y^t, x^t)}\left[\frac{d_o^t(y^{t+1}, x^{t+1})}{d_o^{t+1}(y^{t+1}, x^{t+1})} \times \frac{d_o^t(y^t, x^t)}{d_o^{t+1}(y^t, x^t)}\right]^{1/2}$$

Where the term $\frac{d_o^{t+1}(y^{t+1}, x^{t+1})}{d_o^t(y^t, x^t)}$ could be interpreted as efficiency change ΔTE and the term $\left[\frac{d_o^t(y^{t+1}, x^{t+1})}{d_o^{t+1}(y^{t+1}, x^{t+1})} \times \frac{d_o^t(y^t, x^t)}{d_o^{t+1}(y^t, x^t)}\right]^{1/2}$ could be interpret as technical change $\Delta TECH$. That means the TFP change could be decomposed into two components: efficiency change and technical change as follow:

$$m_o(y^{t+1}, x^{t+1}, y^t, x^t) = \Delta TE(y^t, x^t, y^{t+1}, x^{t+1}) \times \Delta TECH(y^t, x^t, y^{t+1}, x^{t+1})$$

Efficiency change measures the change in relative efficiency between year t and $t+1$. It reflects whether production is getting closer to or farther away from the production frontier. Technical change captures the shift in technology between the two periods. It indicates whether or not technical progress occurred at the input–output combination for a particular region.

We use a non-parametric linear-programming approach to estimate the Malmquist productivity index. If there are n decision making unit, the output-oriented LP problem for estimation of $d_o^k(y^j, x^j)$ under variable returns to scale for decision making unit i is defined as follows:

$$[d_o^k(y^j, x^j)]^{-1} = \max_{\phi,\lambda} \theta,$$

Subject to

$$-\theta y_{ij} + Y_k\lambda \geq 0$$

$$x_{ij} - X_k\lambda \geq 0$$

$$\lambda \geq 0$$

$$N1'\lambda = 1$$

where θ is a scalar, λ is a $n \times 1$ vector of constraints and $N1$ is a $N \times 1$ vector of one.[1]

Section 3 Data and Results

The data electricity consumption (EC) and gross regional product (GRP) that used for estimation are collected from China Statistical Yearbook from 2004- 2009. [2]The collected panel data set contains 30 regions data from 2003-2008. Descriptive statistics of the data are presented in table 1, in addition, the output-input (O/I) ratio is also calculated in table 1.

Table 1: Descriptive statistics

	GRP		EC		O/I ratio
	Mean	SD	Mean	SD	Mean
2003	4635	3661	629	444	7.36
2004	5306	4205	725	522	7.32
2005	6151	4981	825	606	7.45
2006	7063	5775	945	698	7.47
2007	8059	6532	1085	800	7.43
2008	9035	7176	1144	833	7.89
Average	6708		892		7.52

[1] For details see Coelli (1996).
[2] The GRP we use in the analysis is deflated by CPI from China Statistical Yearbook which uses 2003 as base year.

For a first glance, both GRP and EC have increased significantly overtime but the O/I ratio haven't. This information may provide us some evidence that the productivity of electricity or efficiency of electricity use hasn't changed much over time. In order to have a more accurate and clear picture about the productivity change and efficiency of electricity, the results from our model are presented in following tables and figure.[3] In table 2 the relative efficiency score of different regions are presented.

Table 2: Relative efficiency score of different regions

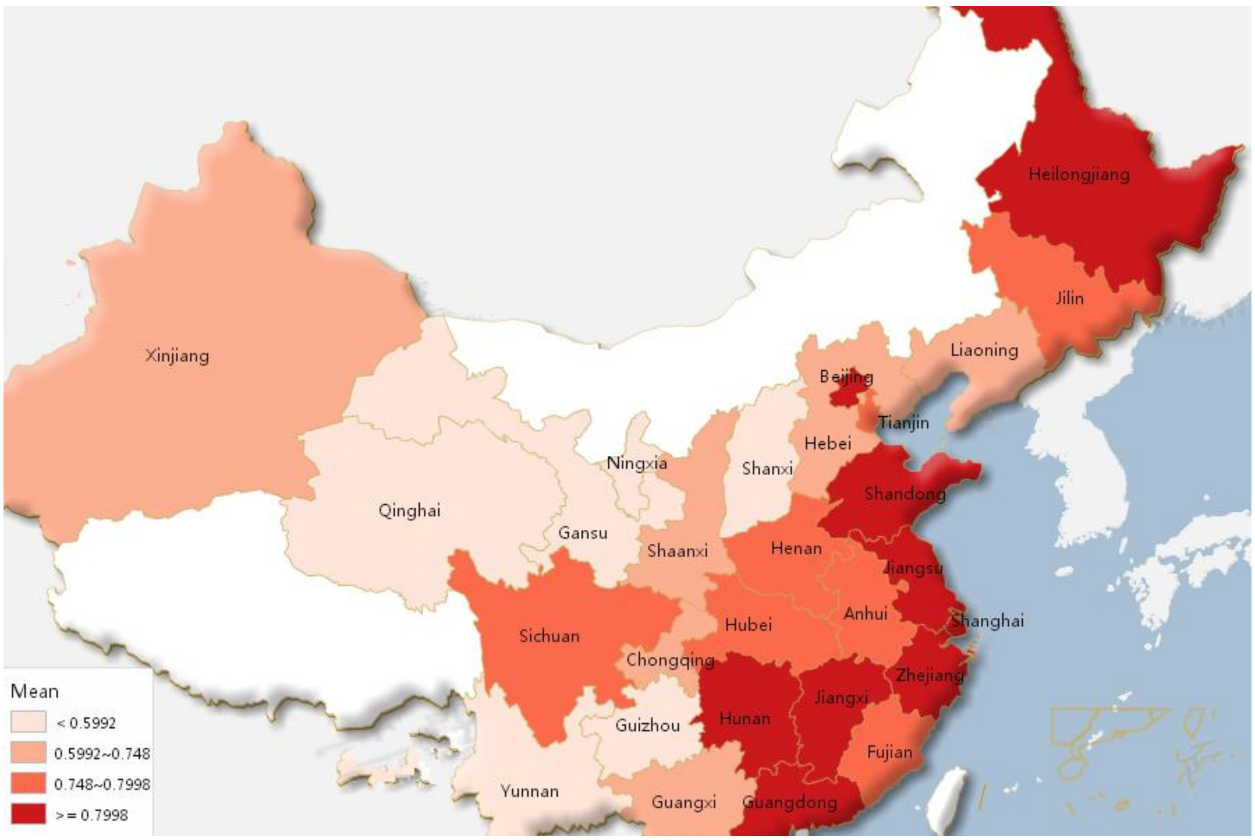
	2003	2004	2005	2006	2007	2008	Mean
Beijing	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Tianjin	0.78	0.77	0.80	0.79	0.74	0.82	0.78
Hebei	0.71	0.69	0.68	0.66	0.65	0.66	0.67
Shanxi	0.41	0.42	0.41	0.39	0.38	0.41	0.40
Inner Mongolia	0.53	0.49	0.50	0.48	0.45	0.49	0.49
Liaoning	0.72	0.66	0.69	0.70	0.72	0.76	0.71
Jilin	0.73	0.71	0.80	0.82	0.83	0.87	0.79
Heilongjiang	0.78	0.77	0.82	0.81	0.80	0.82	0.80
Shanghai	0.94	0.95	0.92	0.93	0.95	0.91	0.93
Jiangsu	0.98	0.94	0.92	0.91	0.91	0.91	0.93
Zhejiang	0.90	0.90	0.83	0.83	0.84	0.80	0.85
Anhui	0.82	0.78	0.77	0.74	0.72	0.73	0.76
Fujian	0.84	0.79	0.77	0.76	0.76	0.75	0.78
Jiangxi	0.86	0.87	0.86	0.83	0.78	0.79	0.83
Shandong	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Henan	0.73	0.75	0.78	0.79	0.78	0.79	0.77
Hubei	0.76	0.75	0.74	0.75	0.76	0.80	0.76
Hunan	0.83	0.82	0.84	0.82	0.82	0.88	0.83
Guangdong	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Guangxi	0.63	0.64	0.66	0.65	0.63	0.64	0.64
Hainan	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Chongqing	0.78	0.75	0.74	0.67	0.67	0.71	0.72
Sichuan	0.74	0.73	0.73	0.74	0.76	0.79	0.75
Guizhou	0.33	0.31	0.34	0.30	0.29	0.32	0.32
Yunnan	0.64	0.57	0.52	0.49	0.47	0.48	0.53
Shaanxi	0.59	0.56	0.59	0.61	0.60	0.64	0.60
Gansu	0.33	0.32	0.33	0.33	0.32	0.31	0.32
Qinghai	0.23	0.21	0.22	0.21	0.21	0.21	0.22
Ningxia	0.19	0.17	0.17	0.15	0.15	0.17	0.17
Xinjiang	0.73	0.70	0.71	0.68	0.63	0.59	0.67
Mean	0.72	0.70	0.70	0.69	0.69	0.70	0.70

[3] To find the results, we use the Deep program kindly provided by Coelli(1996).

Among all 30 regions, Ningxia, Qinghai, Guizhou and Gansu have the lowest relative efficiency as well as Hainan, Guangdong, Shandong and Beijing have the highest efficiency on average. From table 2 we can also see that differences on efficiency between regions are very huge.

This kind of huge inequality may due to the different technology on electricity machine and infrastructures between regions. According to Sul (2011), the difference of the electricity machines and infrastructure could lead to different machine running efficiency. Since the electricity machines and infrastructures of Ningxia, Qinghai, Guizhou and Gansu are insufficient comparing to other areas, as a result they will have a low efficiency than other regions because of this reason.

Figure 1: Average efficiency score (2003-2008) of different regions



We also label all 30 regions according to their relative efficiency in figure 1. In figure 1, darker color means that region has a higher relative efficiency; brighter color means that region has a lower relative efficiency. From figure 1, we find that most efficient regions are located in the east part of China. The regional electricity efficiency is very imbalanced. Based on this observation, one may consider that industrial structure could be one reason for the big gap of electricity efficiency of different regions. For example, Beijing, one of the highest ranked regions, is the only one region whose third industry ratio is more than 50% according to Li and Hu (2012). Ningxia and Qinghai on the other hand have a very low third industry ratio.

Table 3: Decomposition of Malmquist index (Annual average)

year	Technical Change	Efficiency Change	Productivity Change
2004	0.926	0.97	0.898
2005	0.994	1.009	1.003
2006	1.049	0.979	1.027
2007	1.041	0.985	1.025
2008	1.024	1.028	1.053
mean	1.006	0.994	1.000

The mean value of Malmquist index is 1, which implies that the productivity of electricity remained almost the same from 2004 to 2008. To have a clearer picture we then decompose it into two parts.

The mean value of technical change is only 1.006 which implies that on average technology didn't change much from 2004 to 2008.The way the government subsidy the R&D projects could be one reason of the slow change. Although Chinese government made many policies to augment the R&D expenditure, there isn't some specific measures and supervision mechanism to ensure the quality of the R&D projects. Besides, some direct government subsidies may lead to inverse effect of technology development, which is called the "inverse subsidy effect" (Li and Hu, 2012). For example, a region may have more pollution problems because of its slow technology process. But in reality, this kind of region may receive more subsidies to develop new ways for pollution treatment. So the regional companies may rely on the subsidies without researching new technologies. In that way, government's subsidies don't bring about a positive effect on the progress of technology.

On the other hand, the mean value of efficiency change is 0.994 implies that on averagely efficiency is decreasing. The slow development on electricity infrastructure could be one reason of it. The slow development on electricity infrastructure is slow in China for many years, and always lags behind the investment of China's basic infrastructure and the GDP, which directly leads to the slow pace of the electric construction and the shortage of the electricity supply. What's more, the China's industrial structure change is slow too. In the West part of China, primary industry and secondary industry take the higher proportion of the industrial structure at present. And that might be the reasons why efficiency can't increase over time.

Electricity consumers have only insufficient knowledge or information on how to use electricity efficiently could be another reason of lower efficiency. Like Kempton and Layne (1994) suggested, most electricity consumers of electricity could be weak in data electricity collection and analyses distort market decisions.

Section 4 Conclusion

The contributions of this study, from an empirical perspective, have provided a framework to investigate the situation of relative efficiency of electricity use and the growth rate of electricity's productivity. This information is significant for evaluating electricity or environmental related economics policy. In this paper we have found out the relative efficiency score of different regions from 2004 to 2008. Besides the efficiency score and change rate, we have also found that there is serious inequality problem on efficiency between regions and the electricity's productivity hasn't changed at all between 2004 and 2008. Based on our results, we have suggested some potential reasons of it in the previous section. If the reasons are not wrong, some solutions we propose in below could be related.

1. Government should promote the R&D sector and take an efficient use of expenditure in R&D sector. In order to avoid the "inverse subsidy effect", Chinese government should make the supervision mechanism to ensure the money be used in the right position.

2. Government should try to change the industrial structure from the energy intensive to technology intensive industries. At the same time, the government should support the development of high-tech industries and eliminate those high-pollution and high-energy consumption enterprises.

3. Government could also find more ways to educate citizens on how to use electricity more efficiently. For example, holding some talk on teaching citizens switch off electric home appliances when they don't need it.

4. Electricity company in China could provide daily feedback on whole house electricity consumption as guidance for more efficient electricity use (Kempton and Layne, 1994).

The above reasons and solutions we have proposed is just some hypothesis. Further serious studies about them are needed in order to increase efficiency of electricity use and electricity productivity in China. And once the efficiency of electricity use and electricity productivity in China could be increased then we believe that many pollution and economic problem will be then solved automatically.

References

Caves, D. W., Christensen, L. R., & Diewert, W. E. (1982). The economic theory of index numbers and the measurement of input, output, and productivity. *Econometrica: Journal of the Econometric Society*, 1393-1414.

Coelli, T. (1996) A guide to DEEP Version 2. 1. CEPA, Working Paper, 96/08.

Dong-lin, X. U. (2004) .An Empirical Analysis of China's Industrial Structure Change and Economic Growth .*Journal of Zhongnan University of Finance and Economics*, 2 :009.

Fare, R., Grosskopf, S., & Lovell, C. A. (1985). *The measurement of efficiency of production*. Boston: Kluwer-Nijhoff Pub.

Fare, R., Grosskopf, S., Norris, M., & Zhang, Z. (1994). Productivity growth, technical progress, and efficiency change in industrialized countries. *The American economic review*, 66-83.

Kempton, W., & Layne, L. L. (1994). The consumer's energy analysis environment. *Energy Policy*, *22*(10), 857-866.

Li, L. B., & Hu, J. L. (2012). Ecological total-factor energy efficiency of regions in China. *Energy Policy*, *46*, 216-224.

McElroy, M. B., Lu, X., Nielsen, C. P., & Wang, Y. (2009). Potential for wind-generated electricity in China. *science*, *325*(5946), 1378-1380.

Patterson, M. G. (1996, 12). What is energy efficiency? *Energy Policy*, 24(5), 377-390. doi: 10.1016/0301-4215(96)00017-1

Sul, S. K. (2011). *Control of electric machine drive systems* (Vol. 88). John Wiley & Sons.

You, C. F., & Xu, X. C. (2010). Coal combustion and its pollution control in China. *Energy*, *35*(11), 4467-4472.