Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2014, 6(4):128-135

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

China's thermal power industry total factor energy efficiency and its convergence

Liu Shuliang and Wang Juanli*

North China Electric Power University of China, China

ABSTRACT

Resources and environmental pressures which China's sustained economic growth would face have become the focus of attention of the government and the community. It is more prominent in the thermal power industry, with high energy consumption and high pollution. Based on the DEA-Malm quist productivity index, considered environmental impact during 2000~2008, this paper has surveyed 30 provinces' total factor energy efficiency, the technology progress, and the technology efficiency index. The results demonstrate that TFP of overall China grew slowly and the impact of its economic level and resource conditions in each region was obvious. Furthermore, the paper analyzes the TFP trend and the main reason of it. Through the convergence analysis of overall China and three major areas, there is no σ *convergence, but absolute* β *and conditional* β *convergence in the whole country, while in each area, there is only* β *convergence.*

Key words: Thermal power industry; total factor energy efficiency; environmental impact; DEA-Malmquist index, convergence

---

INTRODUCTION

Coal is China's main energy, accounting for more than 70% of primary energy, while the use of coal for power generation accounts for more than half of the consumption of raw coal; China's power generation is main thermal power, and coal accounts for more than 95% of the energy of thermal power [1]. For example, coal for power generation in 2005 is about 1.156 billion tons, accounting for 52.8 percent of total coal consumption, accounting for the proportion of primary energy consumption about 38%, and accounting for the proportion of total final energy consumption of the basic about 18%. Therefore promoting the energy efficiency of China's power industry, especially thermal power industry, will be undoubtedly significant to promoting the country's energy efficiency and energy saving. Thus, the research on thermal power industry's total factor energy efficiency can not only help to identify the reasons for low energy efficiency of China's thermal power generation, but also is of great practical significance to improve the situation of environmental resources and achieve our targets of energy saving and emission reduction.

Fisher had analyzed China's industrial enterprises data from 1997 to 1999, counted that the level of China's energy use and energy intensity of the absolute decline was primarily due to energy price increases, which increased R & D investment and enterprise ownership reform in 1996 [2-4]. Lam had used data envelopment analysis (DEA) method to have a more comprehensive study on total factor productivity of Chinese thermal power industry changes in from 1995 to 2000, and analysis the factors that affecting the technical efficiency, but had not took environmental factors into account. Sun Licheng, Zhou Dequn and Li Qun had applied DEA-Malmquist method into forecast energy efficiency and changes in indies in 12 countries from 1997 to 2006, the results showed that the drop of the growth rate of the energy use and technological progress is the main reason for Chinese energy use efficiency. Bai Xuejie and Song Ying have used three-stage DEA model to exclude environment variables and make statistical noise to analysis the thermal power industry in 30 provinces in China in 2004, the results showed that the efficiency of thermal power industry in many provinces was influenced by the level of regional economic development, resource endowments, other environmental variables and the impact of good or bad luck. The problem of high scale efficiency in the homogeneous business environment is more prominent [5-9].

At present, literature that takes environmental impact into total factor energy efficiency framework is still relative. Yuan Xiaoling, Zhang Baoshan, selecting based on input-oriented constant returns to scale super-efficiency DEA model, estimated the inter-provincial total factor energy efficiency including environmental pollution of China's 28 provinces and autonomous regions in 1995-2006. And they considered that the industrial structure, ownership structure, energy consumption structure and resource endowments had a significant negative impact on total factor energy efficiency and that the energy price factor showed a weak positive correlation with the total factor energy efficiency.Wang Keliang, Yang Baochen measured China's provincial total factor energy efficiency over the period 2000 to 2007 considering environmental constraint and compared the efficiency of each province, the whole country and three major areas, and Tobit model was used to test the influence factors of China's total factor energy efficiency, The empirical results show the low level of China's total factor efficiency and relatively significant differences in energy utilization among all areas and three major regions. It is clear that optimizing economic structure and energy consumption structure, as well as technical progress have remarkable facilitation for improving energy efficiency. Wang Shanshan, Qu Xiao'e selected the panel data of 28 manufacturing industries between 2003 and 2008 as samples, adopted non-parametric data envelopment analysis DEA-Malmquist exponential method, calculated the total factor energy efficiency indexes of China manufacturing industry on considering the environmental effects, and also studied the influence factors on the total factor energy efficiency by adopting Tobit model [10-12].

EXPERIMENTAL SECTION

METHODOLOGIES

(1) Environmental Technology

In order to integrate environmental factors into the framework of total factor energy efficiency, we need to construct a production possibility set firstly, which contained both desirable output and undesirable output.

Assume that each province or region uses N kinds of inputs $x = (x_1, x_2, \ldots, x_N) \in R_+^N$ to produce M kinds of desirable outputs $y = (y_1, y_2, \ldots, y_M) \in R_+^M$ and I kinds of undesirable outputs $b = (b_1, b_2, \ldots, b_I) \in R_+^I$.

The relationship between input and output is represented by the following output set:

$$P(x) = \{(y,b); x can produce (y,b)\}, x \in R_+^N \tag{1}$$

If the output set represents environmental technology, the output set will have the following four properties.

A. $$(y,b) \in P(x);\ \ b = 0 \Rightarrow y = 0 \tag{2}$$

It means if there is no undesirable output, there is no desirable output. Or if there is desirable output, there must be undesirable output.

B. $$(y,b) \in P(x), 0 \le \theta \le 1, \theta(y,b) \in P(x) \tag{3}$$

This implies that the reduction in undesirable output is always along with the reduction in desirable output.

C. $$(y,b) \in P(x),\ \ y^0 \le y,\ \ (y^0, b) \in P(x) \tag{4}$$

This implies that desirable output can also be reduced without reducing the undesirable one. The amount of desirable output shows the level of technical efficiency under environmental constraint.

D. If $x^0 \ge x$, then $P(x^0) \supseteq P(x)$ (5)

Assume period t=1,2,…,T, and J decision making unit(DMU), j=1,2,…,J, input-output vector is $\left(x_{(J\times N)}^t, y_{(J\times M)}^t, b_{(J\times I)}^t\right)$. Using data of inputs, outputs and pollution, the DEA models for measuring the environmental technology model, meeting those above characteristics, it can be represented by the following model:

$$P^t\left(x^t\right)=\left\{\begin{matrix}\sum_{j=1}^{J} y_{j,m}^t,\lambda_j \geq y_{j,m}^t, m=1,\mathrm{L},M;\sum_{j=1}^{J} b_{j,i}^t\lambda_j=b_{j,i}^t, i=1,\mathrm{L},I; \\ \sum_{j=1}^{J} x_{j,n}^t\lambda_j \leq x_{j,n}^t, n=1,\mathrm{L},N;\lambda_j\geq 0,\ j=1,\mathrm{L},J\end{matrix}\right\} \tag{6}$$

(2) Directional distance function
Environmental technology gives the frontier of production possibility under environmental constraints, which is the set maximum output and minimum pollution under a given input. But the environmental output set that meet the above properties can not be calculated by the traditional Shephard distance function. According to Luenberger's shortage function, we build a directional environment distance function:

$$D(x,y,b,g)=\sup\{\beta:(y,b)+\beta g\in p(x)\} \tag{7}$$

$g=\left(g_y,g_b\right)$ is the direction vector of the expansion of desirable output and contraction of undesirable output. β implies that for a given input x, when output y and b expand or contract by the same proportion, the maxim-um in desirable output y and undesirable output b possible reduces. Therefore, the directional distance function measures the level of producer's inefficiency relative to the level of environmental technology. The firm, which operates on the frontier, has technical efficiency, when the value of directional distance function, β is zero. We can use the following mathematical linear programming to calculate β, the value of directional distance function.

$$\begin{cases} Max\beta \\ s.t. \\ \sum_{j=1}^{J}\lambda_j^t y_{jm}^t \geq (1+\beta)y_{jm}^t, m=1,L,M \\ \sum_{j=1}^{J}\lambda_j^t b_{ji}^t=(1-\beta)b_{ji}^t, i=1,\mathrm{L},I \\ \sum_{j=1}^{J}\lambda_j^t x_{jn}^t \leq x_{jn}^t, n=1,\mathrm{L}\,N \\ \sum_{j}^{J}\lambda_j=1;\lambda_j\geq 0;\ j=1,\mathrm{L},J \end{cases} \tag{8}$$

(3) Malmquist-Luenberger Index
According to Chung, the output-oriented Malmquist-Luenberger index (ML) between t period and the period t+1 is represented as follows:

$$ML_t^{t+1}=\left\{\frac{\left[1+D_0^t(x^t,\vec{y^t},b^t;g^t)\right]}{\left[\left[1+D_0^t\left(x^{t+1},\vec{y^{t+1}},b^{t+!};g^{t+!}\right)\right]\right.}\times\frac{\left[1+D_0^{t+1}\left(x^t,\vec{y^t},b^t;g^t\right)\right]}{\left.\left[1+\vec{D_0^t}\left(x^{t+1},y^{t+1},b^{t+1};g^{t+1}\right)\right]\right]}\right\} \tag{9}$$

ML index can be decomposed into Technology Efficiency (TE) and Technological Progress (TP):

$$ML=TE\times TP \tag{10}$$

$$TE_t^{t+1}=\frac{1+\vec{D_0^t}\left(x^t,y^t,b^t;g^t\right)}{1+\vec{D_0^{t+1}}\left(x^{t+1},y^{t+1},b^{t+1};g^{t+1}\right)} \tag{11}$$

$$TP_t^{t+1} = \left\{ \frac{1+\vec{D}_0^{t+1}\left(x^t, y^t, b^t; g^t\right)}{1+\vec{D}_0^{t}\left(x^t, y^t, b^t; g^t\right)} \times \frac{\left[1+\vec{D}_0^{t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+!}\right)\right]}{\left[1+\vec{D}_0^{t}\left(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1}\right)\right]} \right\} \quad (12)$$

Future more, TE also can be decomposed into Pure Technology Efficiency (PTE) and Scale Efficiency (SE). Likewise,

$$TE = PTE \times SE$$

If the value of ML, TE and TP is greater than 1, it indicates that productivity growth, efficiency improvements and technology progress. While the value is less than 1, it indicates that productivity decline, efficiency deterioration and technology regress. If the value is equal to 1, it indicates that the productivity, efficiency and technology have no change[13-18].

THE TOTAL FACTOR ENERGY EFFICIENCY AND ITS DECOMPOSITION

Based on Malmquist-Luenberger Index, according to non-parametric DEA model, with the software of DEAP2.1, considered the environmental impact during the year 2000~2008, this paper surveys 30 provinces' total factor energy efficiency's average change and its decomposition results of China's thermal power generation. In order to study the regional differences of energy efficiency, the paper divided 30 provinces into 3 regions in the traditional way. The results are in Table 1 to Table 4.

Table 1 Total Factor Energy Efficiency and Its Decomposition in the Eastern Region

Province	**TFP**	TE	TP	PTE	SE
Beijing	1.014	1.000	1.014	1.000	1.000
Tianjin	1.008	0.999	1.010	1.000	0.999
Hebei	1.004	1.000	1.004	1.000	1.000
Liaoning	1.010	1.009	1.001	1.005	1.004
Shanghai	1.021	0.998	1.023	0.999	0.999
Jiangsu	1.061	1.000	1.061	1.000	1.000
Zhejiang	1.022	1.005	1.017	1.003	1.002
Fujian	1.012	1.002	1.011	1.002	1.000
Shandong	1.010	0.999	1.011	1.000	0.999
Guangdong	1.014	1.003	1.011	0.999	1.004
Hainan	1.022	1.006	1.016	1.000	1.006
Eastern Mean	1.018	1.002	1.016	1.001	1.001

Table 2 Total Factor Energy Efficiency and Its Decomposition in the Middle Region

Province	TFP	TE	TP	PTE	SE
Shanxi	1.038	1.010	1.027	1.006	1.004
Anhui	1.013	1.001	1.011	1.000	1.001
Jiangxi	1.006	1.005	1.001	1.005	1.000
Henan	1.019	1.011	1.009	1.011	1.000
Hubei	1.009	0.997	1.012	0.999	0.998
Hunan	1.006	0.994	1.012	0.996	0.998
Jilin	1.010	1.007	1.002	1.007	1.000
Heilongjiang	1.008	1.000	1.008	1.002	0.998
Middle Mean	1.014	1.003	1.010	1.003	1.000

Table 3 Total Factor Energy Efficiency and Its Decomposition in the Western Region

Province	TFP	TE	TP	PTE	SE
Inner Mongolia	1.050	1.009	1.041	1.007	1.002
Guangxi	0.956	1.000	0.956	1.000	1.000
Chongqing	0.958	1.000	0.958	1.000	1.000
Sichuan	0.993	0.998	0.995	1.000	0.998
Guizhou	0.973	1.000	0.973	1.000	1.000
Yunnan	1.008	1.002	1.006	1.000	1.002
Shaanxi	1.002	1.002	1.000	1.002	1.000
Gansu	1.028	1.041	0.988	1.000	1.041
Qinghai	0.998	1.000	0.998	1.000	1.000
Ningxia	1.026	1.034	0.992	1.034	1.000
Xinjiang	1.007	1.004	1.003	1.003	1.001
Western Mean	1.000	1.001	0.992	1.004	1.004

Table 4 Total Factor Energy Efficiency and Its Decomposition of the Nation

	TFP	TE	TP	PTE	SE
Nation	1.010	1.004	1.005	1.003	1.002

Future more, according to equal (10), we can calculate the Contribution Rate of TE and TP. The results are as shown in Table 5.

Table 5 The Contribution Rate of TE and TP

	TFP	TE	TP	CR of TE	CR of TR
Nation	1.010	1.004	1.005	44.35%	55.65%
Eastern	1.003	1.002	1.001	66.7%	33.3%
Middle	1.001	1.001	1.000	100%	0%
Western	1.004	1.006	0.998	150%	-50%

According to Table 4, the annual average growth of total factor energy efficiency of China's thermal power industry is 1%, with technical efficiency increasing by 0.4%, technological progress increasing by 0.5%. And according to Table 5, the Contribution Rate of TR is 55.65%. It demonstrates that the growth of thermal power industry's total factor energy efficiency of the nation is mainly due to TP.

According to Table 1, the annual average growth of the total factor energy efficiency in Eastern Region is 1.8%, greater than the Nation. And the growth is mainly due to the increase of TE, the Contribution Rate is 66.7%, which is shown in Table 5.

The Middle Region has the same character of the Eastern Region, and the annual average growth of the total factor energy efficiency is 1.4%. But, the Contribution Rate of TE is 100%, according to Table 5. It means the growth of TFP is due to TE only.

The annual average growth of the total factor energy efficiency in each province of Eastern Region and Middle Region is also greater than the Nation. The highest is Jiangsu province (6.1%).

In the Western Region, the TFP of some provinces is negative, such as Guangxi province(-4.4%). But the TFP of Inner Mongolia, with abundant coal resources, is 5.0%.

From the above analysis we can conclude that the provinces with higher growth rate of total factor energy efficiency are all either developed coastal provinces(Jiangsu, Zhejiang, etc) or coal-rich provinces (Shanxi, Inner Mongolia, etc.). The provinces with negative growth are developing areas, and the reason of causing its negative growth is mainly due to technical regress, while the efficiency of these provinces almost has no changes.

THE TREND OF TOTAL FACTOR ENERGY EFFICIENCY

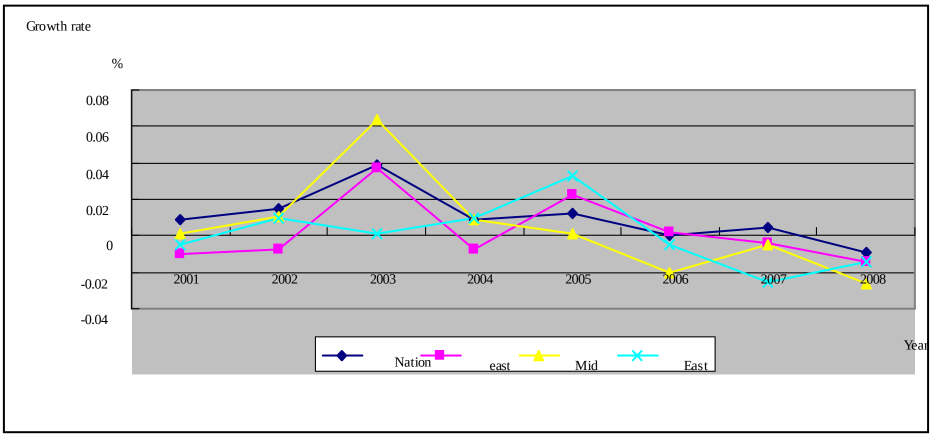

Fig. 1: Growth trend of ML index from 2001 to 2008

(1) From 2001 to 2003, the National Thermal Power Industry's total factor energy efficiency presents a rising trend, to the maximum in 2003. This Phenomenon is due to rapid growth of electricity consumption which caused by economic recovery and rapid development after Southeast Asian financial crisis in1998.

(2) In 2003, a national electricity shortage appear in China, the shortage of power improves the efficiency of thermal power units in each region, and thereby promotes the growth rate of total factor energy efficiency. The total factor

energy efficiency begins to decline after 2003, and shows a modest rebound in 2005, afterwards, presents a downward trend, tending to zero, even being negative growth in 2008.

In this period, many new thermal power plants are built and thermal power units are operated, because of power shortage caused by a new round of economic growth, making the total factor energy efficiency under environmental constraint decline. In Eleventh Five-Year period, more stringent pollution control requirements was adopted, which claim to phase out small thermal power units, strict examine the thermal power plants new built, and resolutely put an end to the building of small thermal power generation units, thus preventing technical progress in a short period, with the emergence of negative growth. Thus the growth rate of total factor energy efficiency in this period begins to decline. Viewing from the sub-regional perspective, the western region is the region which the total factor energy efficiency grows fastest, volatility is largest, and decline is fastest. Central region is the region that grows slowest. And the growth trend of eastern region is most similar to the national average one.

CONVERGENCE ANALYSIS

The growth trend of total factor energy efficiency of thermal power generation in three regions has great difference. To test the difference, we need do convergence analysis of the growth of total factor energy efficiency of each region.

Convergence analysis of used in the economic literature commonly include: σ convergence, absolute β convergence and β conditional convergence. For the total factor energy efficiency, the σ convergence determine convergence by analyzing the standard deviation distribution of total factor energy efficiency's level, that is, if the standard deviation tends to decrease over time, there is convergence, otherwise no convergence. Absolute β convergence refers that as time goes on, the total factor energy efficiency of economies trends to a same growth level and a same growth rate. This indicates that the total factor energy efficiency of developing economies grows faster than the one of developed economies in the process tending to steady-state, the factors behind the economy-wide energy efficient than the developed economies, growth in total factor energy efficiency faster. Conditional β convergence refers that, according to different properties of these economies, each economy is close to itself steady-state level by different speeds, and the speed is proportional to the distance being relative to its steady-state level. That is to say, the lower is initial level, the faster is growth rate. σ convergence and absolute β convergence are both belong to the concept of absolute convergence.

(1) σ Convergence Test

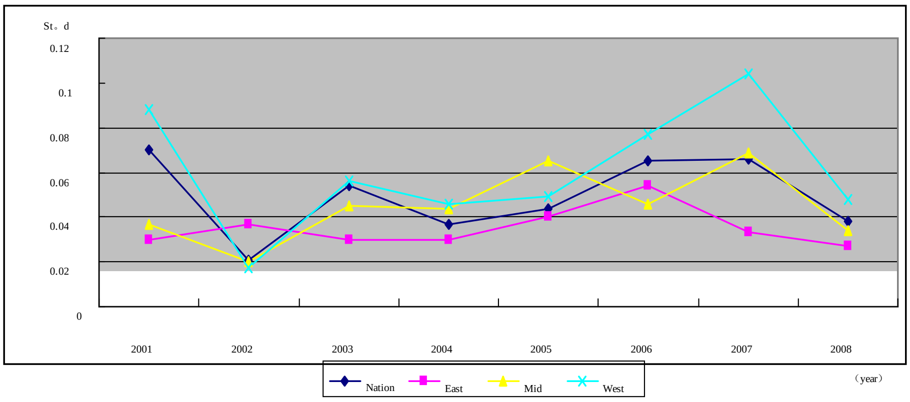

Fig. 2: The standard deviation of TFP

As can be seen from Fig.2, in the term of whole country, from 2001 to 2002, total factor energy efficiency of thermal power generation is σ convergence.

Since 2002, it appears divergent trends and continued to until 2006. In 2007, it appears σ convergence. In term of region, the eastern region has been showing a slight divergence from 2001 to 2006, afterwards, σ convergence occurs. The trend of total factor standard deviation of western region thermal power generation is similar to the national one, with σ convergence also occurring in 2007. The standard deviation's fluctuation of total factor energy efficiency of thermal power generation in central region is more frequent and doesn't show obvious convergence or divergence phenomenon. From the horizontal comparisons between three regions, the standard deviation of total factor energy efficiency of thermal power generation in western region is the largest and the one of eastern region is the smallest. That shows, relative to the eastern and central provinces, the total factor energy efficiency's growth gap among western provinces is still larger.

(2) The Absolute β Convergence Test

$$g_{i,t} = \frac{LnTFP_{i,T} - LnTFP_{i,0}}{T} = \alpha + \beta LnTFP_{i,0} + \varepsilon \tag{13}$$

$$\begin{aligned} g_{i,t} &= LnTFP_{i,t} - LnTFP_{i,t-1} \\ &= \alpha + \beta LnTFP_{i,t-1} + \sum_{j=1}^{n} r_j x_{i,t}^{j} + \varepsilon \end{aligned} \tag{14}$$

In the formula, α is constant term, $g_{i,t}$ is the average annual total factor energy efficiency's growth rate of thermal power generation of economies from base period to T, $\mathrm{LnTFP}_{i,0}$ is the base period Logarithmic value of total factor energy efficiency of thermal power generation of economies and β is its coefficient values. ε is residual term. $x_{i,t}^{j}$ is the increased control variable of j and γ_j is its coefficient. If β is negative, then there is absolute convergent.

Table 6 Absolute β Convergence Test (OLS regression)

	Nation	Eastern Region	Middle Region	Western Region
Constant Term	-0.0005	-0.0001	-0.0011	-0.0067
	(0.0020)	(0.0013)	(0.0036)	(0.0043)
Coefficient of $\mathrm{LnTFP}_{i,0}$	-0.193**	-0.174	-0.168	-0.067
	(0.0729)	(0.0655)	(0.1349)	(0.1345)
Adjust R2	0.174	0.027	0.074	-0.081
The F Statistic	7.071**	1.267	1.556	0.247

*** represents that it is significant at the level of 5%*

As can be seen in Table 6, regression equation coefficients of the nation and three region are negative, but only the coefficient of the nation is significant, while the three regions although have no sign of divergence, but the coefficient is not significant, so there is absolute β convergence only in nation.

(3) Conditional β convergence test

Panel Data Fixed effects test is testing a new method of conditional convergence text, which is different from traditional testing methods, Panel Data's fixed effects corresponds with different steady-state conditions of economies, so it does not need to add control variables. At the same time Panel data fixed effects test can use the least data to do conditional convergence test.

Making use of the software of Eviews 6.0, the estimation results of PLS is represented in Table 7. The model estimation results of nation and three regions are significant at 1% level. As the estimates value of β is significantly negative, it indicates that there is exist conditions convergence in China's thermal power generation and the total factor energy efficiency of each province and regional thermal power generation all moves towards to their equilibrium state.

Table 7 Conditional β Convergence Test

	Nation	Eastern Region	Middle Region	Western Region
Constant Term	0.0112*	0.0048	0.0014	0.0047
	(0.0035)	(0.0042)	(0.0063)	(0.0074)
Coefficient of $\mathrm{LnTFP}_{i,0}$	-1.085*	-1.102*	-0.982*	-1.019*
	(0.0696)	(0.1253)	(0.1484)	(0.1170)
Adjust R2	0.511	0.470	0.398	0.464
The F Statistic	8.278*	7.121*	5.543*	6.976*

** represents that it is significant at the level of 10%*

CONCLUSION

Traditional measure methods of total factor energy efficiency often ignore the undesirable output and only consider the desirable output. Therefore, the value of total factor energy efficiency measured has a lager deviation from actual one. After taking environmental constraint into account, the paper using Malmquist-Luenberger productivity index measures the growth of total factor energy efficiency of 30 provinces'thermal power generation of China over 2000 to 2008, and test its convergence, the results show that:

(1) The total factor energy efficiency of thermal power generation considering environmental constraint is significantly lower than the one that doesn't. This is mainly because, after considering environmental constraint, technical efficiency is almost changes. It indicates environmental constraint seriously reduce the growth of technical progress so as to the growth of total factor energy efficiency.

(2) From a national perspective, the growth rate of total factor energy efficiency in developed or coal-rich provinces is generally higher than other provinces; from the sub-regional perspective, the growth of total factor energy efficiency of thermal power generation in western region is fastest, followed by the eastern region, central region slowest, this is mainly because of the most abundant coal resources in the western region, the most developed economies in eastern region, while central region does not possess these advantages above. This indicates that resource endowment and the level of economic development have a great impact on the growth of total factor energy efficiency of the thermal power generation.

(3) From the national calculation results, the growth of total factor energy efficiency of national thermal power generation is the result of the common effect of technological progress and efficiency improvement; from the sub-region measured results, the one of eastern region is also the result of the common effect of technological progress and efficiency improvement, while the one of central and western region is mainly caused by efficiency improvement, and technical progress play little role. This shows that by increasing the technical progress, the total factor energy efficiency of thermal power generation in China's central and western region is still much potential to promote. In future development, we should pay more attention to the improvement of technological progress.

(4) In the convergence analysis test of the total factor energy efficiency of China's thermal power generation, as far as the whole country is concerned, there is only β absolute convergence and β conditional convergence but no σ convergence. It indicates that total factor energy efficiency of China's thermal power generation moves towards a common steady-state level. From the sub-region, in China's eastern, central and western region there is no absolute convergence; β convergence exists only conditions that the regional thermal power generation total factor energy efficiency are moving closer to their steady state.

REFERENCES

[1] Chambers P.G, Chung Y, Fare R: *Journal of Economic Theory*, v.70, pp.407-419, **1996**.
[2] Zhengge Tu, Geng Xiao: *Economic Research Journal*, pp.4-15, **2005**.
[3] Wang Bing, Pengfei Yan: *Economic Research Journal*, v.5, **2007**.
[4] Zhengge Tu: *Journal of Finance and Economics*, v.33, pp. 90-102, **2007**.
[5] Liu Wei, Guangrong Tong: *Journal of Chin a University of Geoscience*, v.10, **2010**.
[6] Wang Bing, Yanrui Wu, Pengfe Yan: *Economic Research Journal*, v.5, pp.110-115, **2008**.
[7] Xuejie Bai, Song Ying: *China Industrial Economics*, v.8, **2009**.
[8] Wang Jue, Wenfei Song, Xianfeng Han: *Economic Review*, v.5, **2010**.
[9] Wang Bing, Jinyong Lu, Chen Ru: *Economic Review*, v.4, **2010**.
[10] Guohu Peng: The Disparity of Income TFP and the Convergence Hypothesis in Chinese Provinces. *Economic Research Journal*, v.9, **2005**.
[11] Farrell M.J.The measurement of productivity efficiency. In Journal of the Royal Statistical Society 120, **1957**.
[12] Shi Dan: *Economic Research Journal*, v.9, pp.49-56, **2002**.
[13] Chung Y.H., R. Fare, S.Grosskopf: Productivity and Undesirable Outputs: A Directional Distance Function Approach. *Journal of Environmental Management*, v.51, **1997**.
[14] Fare, R.S. Grosskopf, J. Logan: *Journal of Public Economics*, v.26, pp.89-106, **1985**.
[15] Fare, R.S. Grosskopf: *Ecological Economics*, v.18, pp.161-175, **1996**.
[16] Fare, R.S. Grosskopf: *Journal of Productivity Analysis*, v.13, pp.93-103, **2000**.
[17] Fare, R.S. Grosskopf: *Journal of Operational Research*, European, v.157, pp.242-245, **2004**.
[18] Fare, R.S. Grosskopf, A.P.J.Carl: William Weber. Substitutability among Undesirable Outputs. *Working Paper*, **2007**.