Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2014, 6(3):729-734

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

The measurement and analysis of regional energy efficiency in China

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ABSTRACT

This paper measures regional energy efficiency in China with stochastic frontier analysis (SFA), based on total factor framework. First, it discomposes influential factors for regional energy efficiency based on Cobb-Douglas production function. Based on it, it constructs a stochastic frontier production function model with panel data of 29 provinces during 2000-2009, and measures regional energy efficiency of each region in China. The results of SFA analysis indicates, currently the state of economic growth of each region in China presents increasing returns to scale, and high energy price impedes the economic growth. The principal impetus for high-speed economic growth stems from capital input, and the next are energy and labor. The improvement of regional non-energy factor efficiency depends on, mainly, the enhancement of regional institutional level and secondly on frontier technology progress. The energy efficiencies of provincial regions present steady rising during 2000-2008. In 2009, energy efficiencies of most provinces decline for the influence of world financial crisis.

Key words: Energy Price; Energy Efficiency; Stochastic Frontier Analysis

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INTRODUCTION

The steady economic growth of China requires corresponding continuous secure energy supply. On the background of strong demand for energy, besides the diversification of secure energy supply and developing substitutable green energy, improvement of energy efficiency could offset the high-speed growth of energy demand and alleviate the increasingly tense imbalance between supply and demand for energy, as an effective approach to resolve economic problems stemmed from energy issue. In a long time, as the extensive economy growth mode and the limitation from economic level of China, the energy efficiency of China, compared with developed countries, is low. The average energy consumption for GDP in world is 0.46 kilowatt hour per 2000 dollar, while the same value of GDP in China requires energy consumption for 1.28 kilowatt hour (from CHINA ENERGY STATISTICAL YEARBOOK for 2008). On the other hand, the spatial distribution of energy efficiency of China is unbalanced, which corresponds with the unbalanced regional economic growth, decreasing progressively in a gradient way from east to west. Low energy efficiency generates problems such as high consumption, serious pollution et at. inevitably. Energy efficiency has become an urgent issue. Energy efficiency is defined as, traditionally, single factor productivity index, merely the relationship between energy input and economic output, without any consideration for the impact from other input factor on energy efficiency, neglecting the fact that output is the outcome of substitutable factors such as energy, capital, labor, et al., therefore concentrating merely on energy input is partial and of conspicuous defect. The measurement for regional energy efficiency of this paper is based on total factor framework, using total factor productivity index, avoiding the defects of single factor productivity.

After defining energy efficiency, analyzing the cause for the successive progressive decline of regional energy efficiency of China from east to west and how energy efficiency in each region, under the existence of difference of regional energy efficiency, varies and its influential factors are crucial for study the issue of regional energy efficiency in China.

LITERATURE REVIEW

Considerable researchers study the difference in regional energy efficiencies of China and its cause with various approaches. Gao and Wang[1] divide provinces in China into energy high-efficiency area, middle-efficiency area and low-efficiency area with clustering methodology, and probe the impact of economic development level, industrial structure, investment condition and energy price et al. on energy productivity with panel data of provinces during 1995 to 2003 in a general level. Wei and Shen[2] measure and compare energy utilization efficiency of each region in the method of data envelope approach (DEA) with provincial panel data, and point out that the improvement of industrial structure benefits improving energy efficiency. Shi et al.[3] measure values of influential factors of regional differences in energy efficiencies of China during 1980 to 2005, pointing out the effect of differences in total factor productivity is constantly increasing.

There are considerable factors affecting differences in regional energy efficiency. Different researchers present different primary influential factor based on their studies. Li et al.[4] divide factors affecting regional energy intensity variation into technology advancement effect, structure variation effect and economic scale effect with Generalized Fisher Index (GFI) method, and conduct a factor decomposition analysis on regional energy intensity variation with related data from 30 provinces in China during 1995-2005. The analysis reveals that regional structure is the principal explanatory factor for energy intensity variation, the second is regional technology advancement, while regional economic scale explains the variation comparative weakly. Shi[5] calculates energy productivities in regions and energy-saving potential under the convergence of energy productivity in each region, proposing that the primary factors affect regional energy productivity include industrial structure, per capita GDP, energy consumption structure, degree of opening-up and geographical position.

In conclusion, most studies about energy efficiency of China focus on the investigation of industrial structure and production technology, seeking the potential and methods to enhance energy efficiency from the perspectives of industrial structure upgrade and production technology advancement primarily. Furthermore, most studies assume energy efficiency as single factor productivity index, which is conspicuously defective. It merely depicts the relationship between energy input and output, which cannot measure the impact of other input factor-combination on energy efficiency and cannot depict the connotation of efficiency totally. Although recently some researchers try to measure regional energy efficiency from the perspective of regional difference, based on total factor production framework. While most of them adopt data envelopment analysis (DEA) approach to measure and compare energy efficiency of each region, which could only reflect variation of energy efficiency in each region, however difficult to compare regional energy efficiency levels and analyze its cause.

MODEL DESIGNATION

Stochastic frontier production function model construction

As a total factor productivity index, energy efficiency is affected by considerable factors, especially other factors in production progress. Therefore production function is the natural starting point for the analysis of energy efficiency. Generally there are two empirical models for estimating aggregate production function. One is Cobb-Douglas production function. The other is Translog production function. Most empirical studies indicate the former could depict the reality of economic growth of China comparatively well, therefore this paper adopts a equation of this form as follows.

$$Y_{it} = A_{it} K_{it}^{\alpha} L_{it}^{\beta} E_{it}^{\gamma} \tag{1}$$

Based on existed studies indicating that energy price (such as prices of oil, coal et al.) possesses non-liner impact on macro-economic variables (Hamilton[6]), therefore we can hypothesise,

$$A_{it} = \exp(\ln A_{it}^{'} + \lambda \ln EP_{it}) \tag{2}$$

Substituting equation (2) into equation (1) will get

$$Y_{it} = A_{it}^{'} EP_{it}^{\lambda} K_{it}^{\alpha} L_{it}^{\beta} E_{it}^{\gamma} \tag{3}$$

Where Y_{it} represents output in time t of region i, A_{it} represents generalized technology level, or named as Total Factor Productivity, $A_{it}^{'}$ represents non-energy factor productivity, λ represents efficiency elasticity coefficient of energy price, EP_{it} represents energy price, K_{it} represents capital input, L_{it} represents labor input, E_{it} represents energy input, t is time trend, α, β and γ represent the output elasticity of capital, labor, energy respectively. When α+β+γ is greater than 1, equal to 1 or less than 1, the returns to scale of factor input in economy present progressively increasing, constant or progressively decreasing.

As the estimation of non-energy factor productivity, we assume east, east-north, middle and west regions face different frontier technology levels, while each area inside the four main regions possesses the same frontier technology, the real production technology and frontier technology of which is defined as the technology efficiency.

Therefore we assume the function of non-energy factor productivity as follows,

$$A_{it}^{'} = \exp(A_0 + \varphi_1 td_1 + \varphi_2 td_2 + \varphi_3 td_3 + \varphi_4 td_4 + v_{it} - u_{it}) \quad (4)$$

where A_0 represents original technology level, t is time trend, φ_j represents the velocity of frontier technology advancement, d_j represents regional dummy, which is equal to 1 only when the involved area belong to this region, otherwise equal to 0. j =1, 2, 3, 4 represents east, east-north, middle, and west regions respectively. u_{it} represents technology efficiency index, $\exp(-u_{it})$ represents difference of frontier technology level between each region. It is generally deemed that human capital (Lucas[7]) and institution are the foremost influential factors for regional technology efficiency, which determine the region's capacity to absorb advanced technology, ameliorate resource allocation and input-output structure and enhance productivity. While latest studies indicate human capital possesses little influence on difference in regional technology efficiency (Fu and Wu[8], Shi et al.[3]). Therefore this paper takes institution as the explanatory variable for regional technology efficiency, assuming technology efficiency follows a normal distribution with the mean of m_{it}, the variance of σ_u^2, where $m_{it}=\omega_0+\omega_1 I_{it}$, I_{it} represents regional institution, ω_1 is parameter, representing the influential degree of institution on technology efficiency. v_{it} is observation error and random disturbance, which is assumed to follow the normal distribution with the zero-mean and constant variance, viz., v_{it}~$N(0,\sigma_v^2)$. Constitute equation (4) into equation (3), and take the logarithm, and then we could get follows,

$$\ln Y_{it} = A_0 + \varphi_1 td_1 + \varphi_2 td_2 + \varphi_3 td_3 + \varphi_4 td_4 + \lambda \ln EP_{it} + \alpha \ln K_{it} + \beta \ln L_{it} + \gamma \ln E_{it} - u_{it} + v_{it} \quad (5)$$

The above model is the stochastic frontier production function, a frontier analysis method based on parameter estimation. Compared with data envelopment analysis based on non-parameter method, its highlighted merit is the capacity to provide specific production function relationship and considering the influential variables of technology efficiency.

RESULTS AND DISCUSSION

Data Source and Sample Explanation

The empirical study of this paper involves production of each region, time trend, energy price, physical capital input, labor input, energy input and level of regional institution et al.. The sample involves data of 29 provinces during 2000-2009, totally 290 observations. The index selection and data source and disposition is listed as follows.

Output is represented by gross production of each region, noted as GDP_{it}, adjusting it as the price of 2009 with inflation index, viz., consumer price index, the unit of which is 100 million yuan. The data is stemmed from CEInet statistics database (http://db.cei.gov.cn/). Time trend is represented by annual natural sequence, the initial year is defined as 1.

Given the deficiency of the purchase price index of fuel and power of each province, and this index is not recorded by considerable provinces, we adopt the purchase price index of crude material, fuel and power of each region, recorded as EP_{it}. The base period is 2000=100. This data is stemmed from statistics yearbook of each province and CEInet statistics database. This index of some provinces is recorded for only the recent 2 years, therefore we substitute them with adjacent provinces'. The specification of this process is list as follows. The data of Tianjin is substituted by Beijing's, the data of Shandong is substituted by Jiangsu's, the data of Shanxi is substituted by Henan's. For Hubei and Hunan, the data is substituted by Anhui's. For Shanxi and Xinjiang, the data is substituted by Gansu's. For Sichuan, Chongqing and Yunnan, the data is substituted by Qinghai's.

Physical capital input is represented by index of capital stock, K_{it} (Shan[9]). While in this paper, this data is converted into index in price of 2009. The data during 2007-2009 is supplemented in the calculating method for capital stock. The capital stock per annum is calculated in perpetual inventory method and estimated with the depreciation rate, 10.96%. The source data is stemmed from CHINA STATISTICS YEARBOOK and statistical yearbook of each province. The unit is 100 million yuan.

Labor input is represented by numerical index of labor in the whole society and in the end of year in each region, recorded as L_{it}, the data of which is stemmed from CEInet statistics database with the unit, 10 thousand people. Energy input is represented by the aggregate amount of energy consumption of each region, recorded as E_{it} with the unit of 10 thousand tons of standard coal, the data of which is stemmed from CSMAR Solution (www.gtarsc.com) and statistical yearbook of each province. Level of regional institution is represented by marketization index of each region in China, recorded as I_{it}, the initial year of which is set in 2001, and the data of it is stemmed from *The Marketization Index of China-A Report of Marketization Relative Progress in Each Region for 2009.* The data in 2008 and 2009 is estimated by the average increasing rate in recent two years.

Stochastic Frontier Regional Production Function Model Estimation

We estimate equation (5) with software Frontier 4.1, in the method of 3 step maximum likelihood estimation. The basic idea is substituting the variance σ_v^2 and technology efficiency σ_u^2, with the parameter $\sigma^2=\sigma_u^2+\sigma_v^2$ and the parameter $\theta=\sigma_u^2/\sigma^2$, respectively. According to the maximum likelihood function of the estimated equation, we calculate the best fitted value of σ^2 and θ with numerical method, then get the unbiased and consistent estimation of σ_v^2 and σ_u^2(as well as u). The specific steps is that, first, estimating the production elasticity of capital and labor et al. with ordinary least square method, while the intercept is biased, needing adjustment. Then acquiring the variance ratio, θ, with two-period-lattice seeking method, meanwhile adjusting the production elasticity and other parameters. Last, taking the above estimated value as the initial value, conducting iterative computation with Davidon-Fetcher-Powell quasi-Newton method to square the maximum likelihood estimation of parameters (Battese and Coelli[10]).

With the data of 29 regions during 2000-2009, we estimate equation (5) without limit. The result is listed in table 1.

Table 1 The Estimated Result of Production Function

variable	parameter	coefficient	Standard error	t-statistics
constant	A_0	0.0967	0.5271	0.1834
td_1	φ_1	-0.0105	0.0084	-1.2468
td_2	φ_2	-0.0117*	0.0083	-1.4190
td_3	φ_3	-0.0193***	0.0079	-2.4271
td_4	φ_4	-0.0313***	0.0070	-4.4774
LnEP	λ	-0.0030	0.1096	-0.0272
LnK	α	0.6194***	0.0306	20.2178
LnL	β	0.1851***	0.0202	9.1796
LnE	γ	0.2176***	0.0266	8.1737
Constant	ω_0	1.2811***	0.1738	7.3693
LnI	ω_1	-0.4456***	0.0503	-8.8614
	σ^2	0.0150***	0.0020	7.6777
	θ	0.9976***	0.0189	52.9265
	Log likelihood function	204.91425***		
	LR test of the one-sided error	66.247342***		

*Note, * represents significant at the 10% level, ** represents significant at the 5% level, *** represents significant at the 1% level*

It can be concluded that the t-statistics of parameters indicate most parametric estimation is significant at 1% level, indicating this equation is comparatively robust. LR test of the one-sided error rejects the non-hypothesis that there is no technology efficiency (u_{it}=0) and variance ratio (θ) is close to 1, viz., technology efficiency could almost explain the difference between regional real production efficiency and the optimal efficiency frontier completely. While statistical errors only explain 0.01% of the difference, which indicates the selection of frontier model is rational.

Given the estimated results, parameter estimation indicates the sum of output elasticities of capital, labor and energy is equal to 1.0221, viz., $\alpha+\beta+\gamma=1.0221$, indicating in recent period, the economic growth of each region in China presents the state of returns to scale is progressively increasing. For the structure of model estimation, we can interpret it as follows.

(1) The Analysis for Model Parameter. For non-energy factor productivity, in the sample range from 2000 to 2009, the advancement of frontier technology of the most economically advanced east region contributes little for the improvement of total factor productivity, the coefficient of which is -0.0105, quite small given the fact that because of the estimation error and the short of sample range, the model cannot reflect the contribution of frontier technology completely. Comparatively the difference of advancement of frontier technology between middle and west regions

and east region is being enlarged, leading to the productivity of middle and west regions lags behind east and east-north regions'. In this period, the primary factor working for the improvement of productivity of non-energy factor is the level of regional institution (regional marketization index), the elasticity coefficient of which reaches to -0.4456, viz., 1 percentage of improvement in the level of regional institution will lead to 44.56 percentage of improvement in technology efficiency, demonstrating the high-speed growth of China is benefitted from the reform and opening-up policy and the principle impetus of it is stemmed from the improvement of the level of regional institution. The coefficient of energy price is -0.0030. Given the large fluctuation range, the impact of energy price is comparatively large. High energy price holds negative effect on economic growth. The estimation results of elasticity coefficients of capital, labor and energy are corresponding with most estimation about economic growth of China. Capital holds the principle effect on the contribution for regional economic growth, labor contributes to the growth in a degree above 10%. In the meantime, as an important factor, the effect of energy is increasing, the contribution of which is up to 21.76%.

(2) The Analysis for Model Estimation. From the result of estimation, we can get the energy efficiency of each province of China during 2000-2009. According to the classification for regions, the variation of energy efficiency of each province is listed in figure 1, 2, 3 and 4. From the perspective of time period, the energy efficiency of each province in China is steadily increasing. While the international financial crisis in 2008 imposes some destructive effect on the economy of China. The east and west regions suffer comparatively small effect, which east-north and middle regions suffer greater effect. The east could defend the impact of the crisis based on the better base of economic growth, while the west does not suffer much effect for the small economic gross and the affection from domestic economy. From the perspective of the interior of regions, the differences of energy efficiencies in east region are comparatively large all the time. And the same differences in east-north region are increasing conspicuously. For the middle region, there is significant existence of the convergence of inter-province energy efficiencies, and the energy efficiency improves significantly. For the west region, there is a general convergence of inter-province energy efficiencies, while the internal differentiation is notable. Inner Mongolia, Shanxi and Guangxi cluster into the first echelon, Sichuan, Yunnan, Gansu and Xinjiang are the second echelon and Qinghai, Ningxia and Guizhou is the third echelon. Lastly, the regional energy efficiencies, attained by weighting average method with energy efficiency of each province in the four main regions of China, are listed in figure 5. The energy efficiency of the east exceeds other regions' generally. The energy efficiencies of the east-north, the middle and the west tend to convergence, while lagging behind that of the east as a whole.

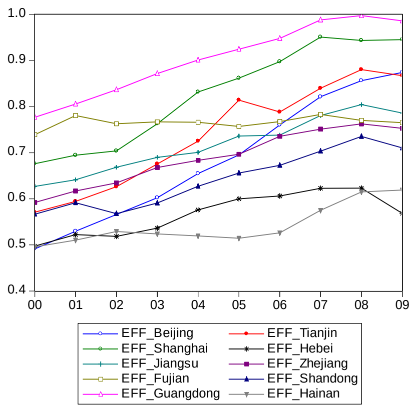


Fig. 1: energy efficiency of the east

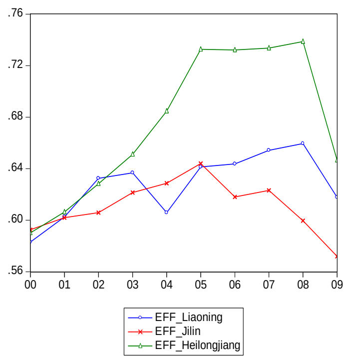


Fig. 2: energy efficiency of the east-north

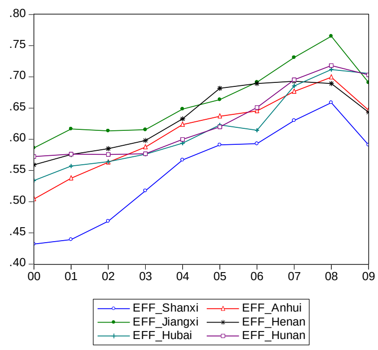
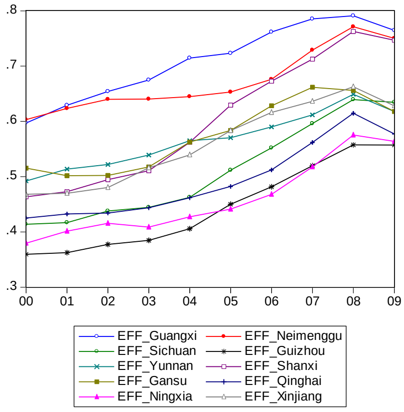


Fig.3: energy efficiency of the middle



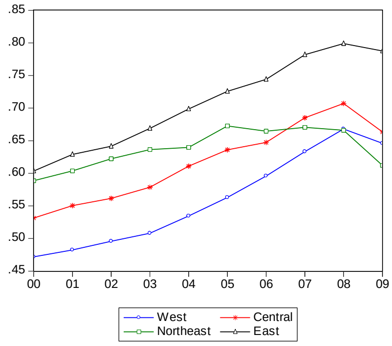


Fig. 4: energy efficiency of the west **Fig. 5: energy efficiency of the four regions**

CONCLUSION

This paper constructs a stochastic frontier production function model with panel data of 29 provinces during 2000-2009, and measures regional energy efficiency of each region in China. The results of SFA analysis indicates, currently the state of economic growth of each region in China presents increasing returns to scale, and high energy price impedes the economic growth. The principal impetus for high-speed economic growth stems from capital input, and the next are energy and labor. The improvement of regional non-energy factor efficiency depends on, mainly, the enhancement of regional institutional level, and secondly on frontier technology progress. The energy efficiencies of provincial regions present steady rising during 2000-2008. In 2009, energy efficiencies of most provinces decline for the influence of world financial crisis.

Acknowledgments
This work is supported by the Key Research Base for Zhejiang Provincial Philosophy and Social Sciences Foundation(12JDLB02YB).
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