Application of Industrial Efficiency Evaluation Method: an Application of DEA

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***Abstract*-Data envelopment analysis (DEA) method is an effective quantitative evaluation method to industry analysis. Industry analysis was introduced in this paper one of the most commonly used method of DEA. This paper introduces the industry analysis of one of the most commonly used DEA method. Taking efficiency analysis of wood processing industry as an example, the efficiency of the industry was measured and calculated with the DEA method, and the efficiency changes, technological changes and Malmquist index were analyzed dynamically.**

***Index Term*- Data Envelopment Analysis, Efficiency Analysis, Industry**

I . INTRODUCTION

The great number and variety of applications of DEA (Data Envelopment Analysis) in recent years has been accompanied by important new developments in concepts and methodology. The original applications were to U.S. institutions, but this is no longer true and centers of research are now located in many different parts of the world which have been the source of many new ideas as well as new applications.

As a mathematical programming approach, Data envelopment analysis (DEA) evaluates the relative efficiency of peer decision making units (DMUs) with respect to multiple inputs and outputs (Charnes et al., 1978; Cooper et al., 2004). Since its genesis until today, several models of data envelopment analysis have been developed, based on the orientation (input-or output-oriented), the existence of constant or variable returns to scale (and in the latter case, whether they are increasing or decreasing), and whether or not the inputs can be controlled, among others.

Following on from Cooper et al., it is based on the traditional definition of efficiency, the ratio of outputs to inputs, and the idea is to find weightings such that through linear programming this ratio can be maximized. Thus, to calculate the efficiency of units. In this paper, we want to introduce the specific application of DEA model, and this article will use the relevant data of China's forest products processing industry as a foundation for analysis.

The paper is organized as follows: Section 2 discusses the DEA; Section 3 discusses the sample, efficiency analysis of *wood product industry* (*WPInd*); Section concludes the paper.

II DEA MODEL INTRODUCED

A. DEA Model

The range of efficiency values calculated based on DEA model is no longer limited to [0, 1], and all the decision-making units can be ordered. Moreover, the super-efficiency DEA model does not have the problem of truncation in efficiency value, and it is not necessary to use the Tobit regression model special for processing truncated data to analyze the factors that affect ecological efficiency.

$$
\begin{aligned}
&\min \rho_{SE} = 1 + \frac{1}{m}\sum_{i=1}^{m} s_i^- / x_{ik} \\
&s.t.\ \sum_{j=1, j\neq k}^{n} x_{ij}\lambda_j - s_i^- \leq x_{ik} \\
&\sum_{j=1, j\neq k}^{n} y_{rj}\lambda_j \geq y_{rk} \\
&\lambda, s^-, s^+ \geq 0 \\
&i = 1,2,\ldots,m;\ r = 1,2,\ldots,q;\ j = 1,2,\ldots,n\ (j \neq k)
\end{aligned} \tag{1}
$$

Where, m denotes the input type of each DMU, q is the output type of each DMU, and n is the number of $DMUs$ and ρ is the efficiency value. x_{ij} refers to the ith input of the jth decision-making unit, y_{rj} refer to rth output of the j^{th} decision-making unit, s^- is the slack variable of the input, and s^+ is the slack variable of the output.

B. Malmquist Index Model

The Malmquist productivity index was proposed by Sten Malmquist in the analysis of consumption changes in 1953, and he used his idea in the production analysis along with Fare, Grosskop, Lindgren and Ross. It divides the change of productivity into *TC* and technological efficiency change: the technological change is the movement of the production frontier; and the technological efficiency change is the efficiency of production technology, which is the change in the distance between the production frontier and the actual output. Both can be obtained through the calculation of distance function. The change in productivity is to calculate the input-output change relationship from the base period *t* to period *t + 1* using the distance function ratio. Färe (1992) initially calculated the Malmquist index with the DEA method, and decomposed the Malmquist index into two aspects: one is efficiency change (*EC*), which mainly reflects the change of the input-output ratio by comparing the primarily-evaluated *DMU* and the leading *DMU*; the other is technological change (*TC*), which mainly reflects the change in the frontier of the whole industry.

Suppose x^t, y^t and x^{t+1}, y^{t+1} denote the values of the evaluated DMU_k in period *t* and period *t+1* respectively, and the Malmquist index from period *t* to period *t + 1* is expressed as Formula (2):

$$MI(x^{t+1},y^{t+1},x^t,y^t)=\sqrt{\frac{E^t(x^{t+1},y^{t+1})}{E^t(x^t,y^t)}\frac{E^{t+1}(x^{t+1},y^{t+1})}{E^{t+1}(x^t,y^t)}} \quad (2)$$

Where, $E^t(x^t,y^t)$ and $E^{t+1}(x^{t+1},y^{t+1})$ are respectively the efficiency values of DMU_k in the two periods, then the change of the efficiency is as shown in Formula (3) and the *TC* is as shown in Formula (4):

$$EC=\frac{E^{t+1}(x^{t+1},y^{t+1})}{E^t(x^t,y^t)} \quad (3)$$

$$TC=\sqrt{\frac{E^t(x^t,y^t)}{E^{t+1}(x^t,y^t)}\frac{E^t(x^{t+1},y^{t+1})}{E^{t+1}(x^{t+1},y^{t+1})}} \quad (4)$$

Malmquist index can be decomposed into *TC* and *EC*:

$$\begin{aligned}MI&=\sqrt{\frac{E^t(x^{t+1},y^{t+1})}{E^t(x^t,y^t)}\frac{E^{t+1}(x^{t+1},y^{t+1})}{E^{t+1}(x^t,y^t)}}\\&=\frac{E^{t+1}(x^{t+1},y^{t+1})}{E^t(x^t,y^t)}?\sqrt{\frac{E^t(x^t,y^t)}{E^{t+1}(x^t,y^t)}\frac{E^t(x^{t+1},y^{t+1})}{E^{t+1}(x^{t+1},y^{t+1})}}\\&=EC?TC\end{aligned} \quad (5)$$

III. EFFICIENCY ANALYSIS OF WPIND

As one of the three major building materials (steel, cement and wood), wood also has a direct impact on the efficiency of the national economy. At present, the *WPInd* has made rapid development, and it has become one of the important industries in China's production and construction. The efficiency of the *WPInd* is vital to the improvement of farmers' income and the development of regional forestry economy (Wada, Seike, & Tsurumi, 2015). The development of *WPInd* has an irreplaceable role in the development of low-carbon economy and the promotion of environment-friendly society. How to improve the efficiency of input and output of *WPInd*, improve the level of technological innovation of wood processing enterprises, and promote the large-scale development of the whole industry are the problems of China's *WPInd* to be solved in the future.

The geographical restrictions on the reserves of wood resources lead to a significant difference in the supply of wood processing raw materials between northern and southern China. Though, it is not applicable to combine the situations of northern and southern China for analysis on the specific problems of the *WPInd*. Meanwhile, according to the availability of data, we selected the *WPInd* 8 provinces in southern China as the study object in this study, evaluated their input and output efficiencies in the past 10 years, analyzed the development status of the *WPInd* in that region and provided some feasible recommendations for the decision-making of relevant sectors.

A. Selection of Study Indicators and Data

In this study, a total of 10 years from 2006 to 2015 was selected as the decision-making unit. The sum of input and output indicators is 3, and the number of samples is more than three times the sum of the input and output. The efficiency of the *DEA* model can be calculated theoretically. The measurement indicators of this paper were determined (see Table I).

TABLE I
INDICATORS OF INDUSTRIAL EFFICIENCY EVALUATION

Type	Variable	Variable Description	Unit
Input	Capital input	Average annual balance of net value of fixed assets	Billion Yuan RMB
	Labor input	Average annual number of employees in the industry	Man
Output	Total industrial output value	Total industrial output value	Million Yuan RMB

The total industrial output value of *WPInd* is an important indicator to measure the economic benefits of the industry. It is the value of wood processing products produced by wood processing enterprises in a certain period and is the basic indicator reflecting the total amount of products in the *WPInd*. Therefore, the total industrial output value of the *WPInd* was taken as the output indicator in this study. The input in the *WPInd* mainly includes labor input and capital input. The *WPInd* is a labor-intensive industry, so the labor has a great impact on the industry. In this study, the average annual number of employees in the industry was selected as the labor input indicator. The original value of the fixed assets of the *WPInd* reflects the input scale and structure of the fixed assets of China's *WPInd* to a certain extent, which reflects the capital input situation of the *WPInd* in some degree. Therefore, the original value of fixed assets of *WPInd* was selected as a capital input indicator.

The input-output data of this study is from the relevant annual *China Forestry Statistical Yearbook* 8 provinces in southern China, including Anhui, Fujian, Guangxi, Hubei, Hunan, Jiangxi, Sichuan and Yunnan. In addition, partial missing data was supplemented by the method of multiple imputations.

B. Analysis of Empirical Results

In this paper, the efficiency of *WPInd* 8 provinces in southern China was analyzed by *DEAP2.1* software. The results showed that the efficiency of some provinces in some provinces was 1. As a result, these provinces cannot be effectively sorted, and the *EC* of *WPInd* in the same effective frontier could not be compared. Therefore, in order to further analyze the regions with the above-mentioned efficiency value of 1, the input-oriented super-efficiency *DEA* model was used to re-study the provinces. The super efficiency values of *WPInd* 8 provinces in southern China were obtained through calculation with *EMS1.3* software, and the results are as shown in Table II.

TABLE II.
EFFICIENCY VALUES OF WPIND

Province	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average value	Rating
Anhui	0.15	0.219	0.297	0.388	0.46	1.767	0.613	0.445	0.381	0.282	0.500	1
Fujian	0.151	0.136	0.138	0.154	0.2	0.28	2.551	0.098	0.049	0.053	0.381	3
Jiangxi	0.133	0.096	0.155	0.289	0.242	0.254	0.098	0.127	3.147	0.085	0.463	2
Hubei	0.216	0.148	0.087	0.081	0.039	0.037	0.022	0.024	0.013	0.013	0.068	6
Hunan	0.42	0.1	0.085	0.112	0.071	0.083	0.056	0.029	0.02	0.027	0.100	4
Guangxi	0.091	0.045	0.019	0.017	0.026	0.035	0.03	0.029	0.021	0.016	0.033	7
Sichuan	0.019	0.015	0.006	0.006	0.008	0.01	0.007	0.016	0.02	0.018	0.013	8
Yunnan	0.232	0.116	0.137	0.141	0.028	0.029	0.029	0.034	0.042	0.036	0.082	5
Average value	0.177	0.109	0.116	0.145	0.134	0.312	0.426	0.100	0.462	0.067	--	--

According to the analysis on the time series data, the difference in the efficiency of the *WPInd* 8 provinces in the 2006-to-2015 period was significant for a specific province. The efficiencies of *WPInd* 8 provinces were all relatively low (efficiency average of all provinces <1). Only the efficiencies of *WPInd* in Jiangxi Province （3.147>1） Fujian Province (2.551> 1) and Anhui Province (1.767> 1) were in the relatively high state. The reason is that China is a country with scarce forest resources and a country with an underdeveloped wood industry, even in the provinces where the wood resources are relatively abundant, the development of the *WPInd* is very slow, which is very consistent with the conclusions of previous studies. The main reason is: China's *WPInd* is features as small-scale enterprises and low concentration, so the industrial development tends more to be achieved through external large-scale economy.

In order to analyze the change trend of *WPInd* in the 8 provinces, the panel data of *WPInd* 8 provinces from 2006 to 2015 were used in this paper. The *EC* value was calculated with the Malmquist index model. As the panel data of each province is long, this paper first analyzes the Malmquist index and its decomposition of the annual industrial efficiency of each province (see Table III).

TABLE III.
ANNUAL MALMQUIST INDEX OF WPIND AND ITS DECOMPOSITION

Province	EC	Annual Growth Rate	TC	Annual Growth Rate	Malmquist Index	Annual Growth Rate
Anhui	1.035	0.035	1.089	0.089	1.131	0.131
Fujian	1.545	0.545	1.274	0.274	1.359	0.359
Guangxi	1.872	0.872	2.159	1.159	1.447	0.447
Hubei	0.89	-0.11	1.411	0.411	0.935	-0.065
Hunan	1.01	0.01	1.306	0.306	1.187	0.187
Jiangxi	1.426	0.426	1.508	0.508	2.211	1.211
Sichuan	2.248	1.248	1.882	0.882	1.329	0.329
Yunnan	1.011	0.011	1.009	0.009	0.879	-0.121
Average value	1.38	0.38	1.455	0.455	1.31	0.31

In general, the annual growth rate of the Malmquist index of *WPInd* 8 provinces was 31% during 2006 to 2015. The Malmquist index of *WPInd* in *Anhui*, *Fujian*, *Guangxi*, *Hunan*, *Jiangxi* and *Sichuan* provinces were all greater than 1, of which the Malmquist index of *WPInd* in *Jiangxi* province reached 2.211, indicating that the level of *WPInd* in those provinces has been exactly improved. However, the Malmquist indexes of *Hubei* and *Yunnan* provinces was less than 1, and that of *Yunnan* province was 0.879, indicating that the level of *WPInd* was low.

From the decomposition of Malmquist index, the average annual growth rate of *TC* was 45.5% and the average annual growth rate of *EC* was 38%, indicating that the efficiency improvement of *WPInd* 8 provinces mainly depends mainly on technological progress. The Malmquist indexes of *Jiangxi* and *Guangxi* provinces were greater than the industry average, and their Malmquist index average annual growth rate were respectively 121.1% and 44.7%. The efficiency of *WPInd* is basically the same as the growth rate.

IV. Conclusions

Based on the panel data of *WPInd* 8 provinces in southern China from 2000 to 2015, and according to the analysis with the DEA model and Malmquist productivity index in this paper, the following conclusions can be drawn:

A. DEA model and Malmquist productivity index is useful to analysis the efficient of a certain industry. It is based on a set of input - output observations to estimate production frontier surface effectively. DEA can be seen as a kind of valid method for statistical analysis. Analyzed efficiency of the *WPInd* 8 provinces has good effect with DEA.

B. The overall efficiency of *WPInd* of the 8 representative provinces in southern China studied in this paper is relatively low. The decomposition of the average Malmquist index of 8 provinces shows that the technological progress change has a big lagging effect on the change of efficiency index. From the factors affecting the technological efficiency change index, the technical efficiency change is mainly from the pure technical efficiency, but the influence of scale *EC* should not be ignored. The scale *EC* has a greater effect on the technical efficiency index change.

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