Efficiency analysis of wood processing industry in China during 2006-2015

Kun Zhang¹, Baolong Yuan*, Yanxuan Li²

¹School of Business, Central South of University of Forestry and Technology, Changsha 410004, China
²Bank of Beijing Co., Ltd. Changsha Branch

*Corresponding author: Baolong Yuan, Lecturer, Central South of University of Forestry and Technology, Address to No. 498, Shaoshan Rd., Tianxin Dist., Changsha City 410004, China. E-mail: 502797867@qq.com

Abstract: The wood processing industry is an important industry which affects the national economy and social development. The data envelopment analysis model (DEA) is a quantitative evaluation method for studying industrial efficiency. In this paper, the wood processing industry of 8 provinces in southern China is taken as the study object, and the efficiency of each province in 2006 to 2015 was measured and calculated with the DEA method, and the efficiency changes, technological changes and Malmquist index were analyzed dynamically. The empirical results show that there is a widening gap in the efficiency of wood processing industry of the 8 provinces, and the technological progress has shown a lag in the promotion of wood processing industry. According to the research conclusion, along with the situation of domestic and foreign wood processing industry development, the government must introduce relevant policies to strengthen the construction of the wood processing industry technology innovation policy system and the industrial coordinated development system.

1 Introduction
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 wood processing industry has made rapid development, and it has become one of the important industries in China's production and construction. The efficiency of the wood processing industry is vital to the improvement of farmers' income and the development of regional forestry economy (Wada,
Seike, & Tsurumi, 2015). The development of wood processing industry has an irreplaceable role in the development of low-carbon economy and the promotion of environment-friendly society. However, the weak foundation and the shortage of wood resources in China's wood processing industry have seriously restricted the development of this industry. The Chinese government has always been committed to increasing the supply of wood resources and trying to increase the sustainable supply of resources by adding the reserves of forest resources, the forest cover has increased from 8.6% to 21.63% during 2006 to 2017, but there is still a big gap compared with the international level of 31%. Meanwhile, China's wood processing industry enterprises are of small scale, not forming industrial clusters. Due to lack of technological innovation, besides, it is still in the low-end position of the industrial chain according to the international industrial division, compared to the developed countries. Therefore, how to improve the efficiency of input and output of wood processing industry, 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 wood processing industry 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 wood processing industry. Meanwhile, according to the availability of data, we selected the wood processing industry of the 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 wood processing industry in that region and provided some feasible recommendations for the decision-making of relevant sectors.

2. Literature Review

In terms of the analysis on the field of wood processing industry, Rhodes (1986) first applied the data envelopment analysis (DEA) to the forestry industry. Currently, there are still a very small number of literatures on the efficiency of wood processing industry, and the focus of existing studies is measuring the efficiency of private wood processing enterprises and measuring industrial management efficiency. Nyrud and Bergseng (2002) measured the production efficiency of 200 wood processing enterprises in Norway using the data envelopment analysis. Hseu and Shang (2005) studied the pulp and paper industry using the DEA model. Carter and Siry (2003) analyzed the wood production efficiency with the DEA and SFA methods. Huang Dunliang et al. (2015) measured the total factor productivity of the wood processing industry in 13 countries using the DEA-Malmquist index. Some scholars analyzed the industrial competitiveness of wood processing industry, which involved the factors affecting the efficiency of wood processing industry, and conducted the comparative analysis on the total factor productivity development changes of wood processing industry in developed countries and developing countries. Ntabe et al. (2010) analyzed the efficiency of wood processing industry with raw material supply, process technology, product type and quality, market, human condition, forest industry environment and waste disposal mechanism as the study indicators.

In the study on the efficiency of wood processing industry in China, some scholars have studied the influence of national policy, industry and enterprise competition on the development
of wood processing industry by taking specific provinces as the research object (Yang & She, 2007; Liu, Gao & Wang, 2013; Guo & Feng, 2014). Lai (2014) analyzed the dynamic development process and influencing factors of the enterprise productivity using stochastic frontier model based on the micro-data about China’s wood processing and products from 2000 to 2007. And Hou (2012) also studied the efficiency of China’s wood processing enterprises with the DEA method.

The existing literatures play a certain reference role for the evaluation of regional ecological efficiency and the analysis of influencing factors, but there are still following problems to be improved: ① Most of the literatures have calculated the efficiency values using the traditional DEA model. These models cannot distinguish the decision units with the effective efficiency. Even the study results adopting the Malmquist index were also obtained by analyzing the problem from the macro state level or the micro enterprise level. ② There are few studies on the efficiency of wood processing industry at home and abroad, and most of the existing literatures conducted analysis with the cross-sectional data as the samples, without using the panel data to reflect the influence of various factors on the efficiency of wood processing industry.

3. Research Method

3.1 SE-DEA Model

In this paper, the super-efficiency DEA model (SE-DEA) was used to evaluate the efficiency of forestry processing industry of the 8 provinces in southern China from 2006 to 2015. The range of efficiency values calculated based on this 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.

\[
\min r_{se} = 1 + \frac{\rho}{\frac{\hat{a}}{m} \sum_{i=1}^{m} s_i^x} \frac{1}{x_{k_l}}
\]

s.t. \( \hat{a} \sum_{j=1}^{n} x_{q_j} - \frac{1}{x_{k_l}} \)

\( \hat{a} \sum_{j=1}^{n} y_{p_j} = \frac{s^y}{y_{k_l}} \)

\( l, s^x, s^y \geq 0 \)

\( t = 1, 2, ..., m; r = 1, 2, ..., q; j = 1, 2, ..., n(f-k) \) (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 \( \rho \) is the efficiency value. \( x_{q_j} \) refers to the \( t^{th} \) input of the \( f^{th} \) decision-making unit, \( y_{p_j} \) refer to \( r^{th} \) output of the \( f^{th} \) decision-making unit, \( s^x \) is the slack variable of the input, and \( s^y \) is the slack variable of the output.
3.2 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 \( DMU_k \) and the leading \( DMU \); the other is technological change (TC), which mainly reflects the change in the frontier of the whole industry.

Suppose \( x^t_\prime, y^t_\prime \) and \( x^{t+1}_\prime, y^{t+1}_\prime \) 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):

\[
MI(x^{t+1}_\prime, y^{t+1}_\prime, x_\prime, y_\prime) = \sqrt{\frac{E'(x^{t+1}_\prime, y^{t+1}_\prime) E''(x^{t+1}_\prime, y^{t+1}_\prime)}{E'(x_\prime, y_\prime) E''(x_\prime, y_\prime)}}
\]  

(2)

Where, \( E'(x_\prime, y_\prime) \) and \( E''(x^{t+1}_\prime, y^{t+1}_\prime) \) 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):

\[
EC = \frac{E''(x^{t+1}_\prime, y^{t+1}_\prime)}{E'(x_\prime, y_\prime)}
\]  

(3)

\[
TC = \sqrt{\frac{E'(x_\prime, y_\prime) E'(x^{t+1}_\prime, y^{t+1}_\prime)}{E''(x_\prime, y_\prime) E''(x^{t+1}_\prime, y^{t+1}_\prime)}}
\]  

(4)

Malmquist index can be decomposed into TC and EC:

\[
MI = \sqrt{\frac{E'(x^{t+1}_\prime, y^{t+1}_\prime) E''(x^{t+1}_\prime, y^{t+1}_\prime)}{E'(x_\prime, y_\prime) E''(x_\prime, y_\prime)}} = \frac{E''(x^{t+1}_\prime, y^{t+1}_\prime)}{E'(x_\prime, y_\prime)} \sqrt{\frac{E'(x_\prime, y_\prime) E'(x^{t+1}_\prime, y^{t+1}_\prime)}{E''(x_\prime, y_\prime) E''(x^{t+1}_\prime, y^{t+1}_\prime)}} = EC \cdot TC
\]  

(5)
3.3 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. According to the availability of data, and combined with the studies of Yang, Shi et al. (2008), Huang and Li(2014), the measurement indicators of this paper were determined (see Table 1).

| 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 wood processing industry 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 wood processing industry. Therefore, the total industrial output value of the wood processing industry was taken as the output indicator in this study. The input in the wood processing industry mainly includes labor input and capital input. The wood processing industry 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 wood processing industry reflects the input scale and structure of the fixed assets of China's wood processing industry to a certain extent, which reflects the capital input situation of the wood processing industry in some degree. Therefore, the original value of fixed assets of wood processing industry was selected as a capital input indicator.

The input-output data of this study is from the relevant annual China Forestry Statistical Yearbook of the 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.

4 Analysis of Empirical Results

4.1 Static Analysis

In this paper, the efficiency of wood processing industry of the 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 wood processing industry 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 wood processing industry of the 8 provinces in southern China were obtained through calculation with EMSI.3 software, and the results are as shown in Table 2.
Table 2. Efficiency Values of Wood Processing Industry of the 8 Provinces in Southern China from 2006 to 2015

| 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  | 2.551| 0.098| 0.049| 0.053| 0.381| 0.463         | 2      |
| 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| 0.027| 0.100| 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  | 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 wood processing industry of the 8 provinces in the 2006-to-2015 period was significant for a specific province. The efficiencies of wood processing industry of the 8 provinces were all relatively low (efficiency average of all provinces <1). Only the efficiencies of wood processing industry 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 wood processing industry is very slow, which is very consistent with the conclusions of previous studies. The main reason is: China’s wood processing industry is features as small-scale enterprises and low concentration, so the industrial development tends more to be achieved through external large-scale economy.

4.2 Dynamic Analysis

In order to analyze the change trend of wood processing industry in the 8 provinces, the panel data of wood processing industry of the 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 3).
### Table 3. Annual Malmquist Index of the Forestry Industry of the 8 Provinces in Southern China from 2006 to 2015 and Its Decomposition

| Province | EC Annual Growth Rate | TC Annual Growth Rate | Malmquist Index Annual Growth Rate |
|----------|-----------------------|-----------------------|-----------------------------------|
| Anhui    | 1.035                 | 0.035                 | 1.131                             |
| Fujian   | 1.545                 | 0.545                 | 1.359                             |
| Guangxi  | 1.872                 | 0.872                 | 1.447                             |
| Hubei    | 0.89                  | -0.11                 | 0.935                             |
| Hunan    | 1.01                  | 0.01                  | 1.187                             |
| Hunan    | 1.426                 | 0.426                 | 2.211                             |
| Sichuan  | 2.248                 | 1.248                 | 1.329                             |
| Yunnan   | 1.011                 | 0.011                 | 0.879                             |
| Average value | 1.38                | 0.38                  | 1.31                              |

In general, the annual growth rate of the Malmquist index of wood processing industry of the 8 provinces was 31% during 2006 to 2015. The Malmquist index of wood processing industry in Anhui, Fujian, Guangxi, Hunan, Jiangxi and Sichuan provinces were all greater than 1, of which the Malmquist index of wood processing industry in Jiangxi province reached 2.211, indicating that the level of wood processing industry 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 wood processing industry 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 wood processing industry of the 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 wood processing industry is basically the same as the growth rate.

### Table 4. Annual Average Malmquist Indexes of Wood Processing Industry of the 8 Provinces in Southern China from 2006 to 2015 and Its Decomposition

| Year       | EC Annual Growth Rate | TC Annual Growth Rate | Malmquist Index Annual Growth Rate |
|------------|-----------------------|-----------------------|-----------------------------------|
| 2006-2007  | 0.945                 | 1.19                  | 1.155                             |
| 2007-2008  | 0.786                 | 1.862                 | 1.444                             |
| 2008-2009  | 1.223                 | 1.402                 | 1.675                             |
| 2009-2010  | 1.489                 | 0.964                 | 0.036                             |
| 2010-2011  | 0.654                 | 2.958                 | 1.696                             |
| 2011-2012  | 0.876                 | 1.954                 | 1.05                              |
| 2012-2013  | 2.709                 | 0.42                  | 1.022                             |
| 2013-2014  | 0.974                 | 1.864                 | 1.759                             |
| 2014-2015  | 2.761                 | 0.48                  | 0.874                             |
| Average value | 1.38                | 1.455                 | 1.31                              |
The cross-sectional data analysis shows (see Table 4) that the average change in dynamic efficiency of wood processing industry of the 8 provinces was 1.380 from 2006 to 2015, and the annual $EC$ was significant. The year with the minimum $EC$ was 2010 to 2011, and the efficiency value was 0.654. The year with the maximum $EC$ was 2014 to 2015, and the efficiency value was 2.761. There was also a big difference in the annual $TC$ of wood processing industry of the 8 provinces between different years. The year with the minimum $EC$ was 2012 to 2013, and the efficiency value was 0.042. The year with the maximum $EC$ was 2010 to 2011, and the efficiency value was 2.958. The years with the maximum Malmquist Index were 2013 to 2014, and the value was 1.759. The year with minimum Malmquist index was 2012 to 2013, and the value was -0.580. The above results show the imbalance of the 8 provinces in southern China in terms of the development of wood processing industry. There are two main reasons for this: (1) Limited by geographical conditions, the supply capabilities of wood processing raw material of the provinces are different; and (2) Limited by the economic development situations, the technical level of wood processing industry of the provinces are different as well.

Except for the 2014-2015 year, the average annual growth rates of the Malmquist index of wood processing industry in the 8 provinces of southern China were all greater than 1. The growth rates fluctuated in sinusoidal state. The year with the maximum growth rate was 2013-2014, and the value was 0.759. The year with the minimum growth rate was in 2014-2015, and the value was -0.126. The annual average $EC$, $TC$ and Malmquist exponential growth change of wood processing industry in each year fluctuated as shown in Fig.1. Besides, the efficiency growth change of wood processing industry showed an obvious lag relative to the technological growth change and the Malmquist index growth change, which indicates that the technology has a lagging effect on the $EC$ of wood processing industry. In the 2014-2015 year, the efficiency of the wood processing industry of the 8 provinces was the largest while the $TC$ showed negative growth. The reason was from the lagging effect of technology on the industry development on the one hand, and from the effect of China’s wood-related policies. In 2014, China’s government implemented the stop-felling policies for the commercial forests in the northern region, mainly the northeastern state-owned forests. Besides, the strict control policy on the foreign wood export and the continuous shortage of wood supply in the domestic market, have seriously hindered the development of northern wood processing industry. However, the wood processing industry in southern provinces where the fast-growing wood like bamboo and cirrus are used as the raw material has been developed, which ultimately prompted an improvement in the overall efficiency of the southern wood processing industry in 2014-2015.
5. Conclusion and Revelation

Based on the panel data of wood processing industry of the 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:

(1) The overall efficiency of wood processing industry of the 8 representative provinces in southern China studied in this paper is relatively low. Furthermore, there is a big gap in the efficiency of wood processing industry of the 8 provinces, which shows that the regional resource endowment is the basis of restricting and determining the development of the industry. The wood resource situation of the 8 provinces in southern China has affected the development efficiency of the wood processing industry. In the coming period, China should develop the wood processing industry based on regional wood resource endowment and improve the production efficiency to avoid the occurrence of "resource curse" phenomenon.

(2) 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. While the decline of industrial efficiency is mainly affected by the decline of technological efficiency. Under the background that the systematic innovation support system of wood processing industry of all the countries across the world is not perfect (Rametsteiner & Weiss, 2006), and that China has completely implemented the stop-felling policies for the natural commercial forests, to improve the efficiency of China's timber processing industry, the government should focus on the establishment of technical innovation support policy system. It is required that all the provinces strengthen the technological input in the wood processing industry, improve the growth rate of the efficiency of wood processing industry, broaden the sources of funding for research and encourage the relevant enterprises and institutions to increase the R&D investment, to promote the wood processing industry technology is converted into productivity.

(3) 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. The existing study results (Chen, Yang, Lin, 2016) show that the integration of the wood processing industry in Southern China is not high and the scale effect is not formed yet. Therefore, to improve the growth rate of the efficiency of wood processing industry, we must
rationally configure the relevant resources, optimize the industrial structure of wood processing industry, promote the full-chain cluster development of wood processing industry and improve the scale efficiency.

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