Changes in Total Factor Productivity, Technological Progress and Efficiency of Banana Industry in China

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Abstract Based on the DEA-based Malmquist index method, the total factor productivity was calculated for 5 major banana production areas in 2003-2004, and it was further divided into technological progress and technical efficiency. The results show that the total factor productivity of banana industry in China was 1.3% in the sample period, mainly due to technological progress, the average growth rate was 2.6%, while the pure technical efficiency and scale efficiency was -0.1% and -1.2% respectively. The improvement of total factor productivity in banana industry in China relied mainly on technological progress, cultivation of new banana varieties, management of high quality cultivation, popularization and application of water conservation and fertilizer saving technology, and injury-free picking technologies. The pure technical efficiency and scale efficiency of banana production were negative, indicating that the management level of banana was not high. The effect of scale economy of this industry through agglomeration and consolidation is still to be practiced. Banana growers should promote the improvement of large scale and management level of the banana industry at the same time of promoting the technological progress.

Key words Banana industry, Total factor productivity, Technological progress, Technical efficiency

1 Introduction
Banana is one of the important pillar industries in hot zone of China, and it is also an important source of increasing farmers’ income. On the whole, China’s banana planting area, yield, and output value showed a fluctuating trend. According to the national banana industry technology system research, the total banana planting area in 2015 was 357000 ha and the total yield was 12.11 million t. However, the banana industry in China relied largely on the extensive development of factor inputs and the conversion rate of scientific and technological achievements was low. Therefore, it is of great significance to study the total factor productivity of banana industry, so as to promote its sustainable development. Xia Yongkai et al. [1] used DEA’s SBM super-efficiency model to calculate the annual growth rate of technical efficiency of China’s banana production from 1995 to 2009 was 0.6%. In the selection and use of banana technologies, using the Logistic model, Luo Guangfan et al. [2] and Xia Yongkai et al. [3] analyzed the field survey data of 164 banana households in Guangdong and 125 banana households in Guangxi, and summarized the demands for new varieties, irrigation and fertilization, banana fruit management, pest control technologies. Based on the field survey data of 257 households of banana growers in 12 counties (districts) of Guangxi, Zhang Jia et al. [4], using a binary Logistic model, analyzed the influencing factors of their demands for these technologies. Guo Jianchun et al. [5] analyzed the current situation and the technical effect evaluation of the banana growers in Guangxi, and explored the diffusion pattern of banana production technologies.

With the aid of the C-D production function model, ia Yongkai et al. [6] calculated the contribution rate of scientific and technological progress of banana production in China during 1995-2013 (the result was 23.5%). Huang Mengsi and Sun Jian [7], using DEA’s Malmquist index analysis method, made an empirical analysis on the growth and structure of cotton TFP in China during 2004-2013. Zhang Jing [8], using DEA-based Malmquist index method, decomposed and calculated the total factor productivity of manufacturing industry in Shanxi Province. According to studies of Yin Lei and Shen Yi [9], rural financial development exerts a positive effect on agricultural total factor productivity, rural financial development promotes the growth of total factor productivity, which is mainly the effect of agricultural technological progress. Huang Yong [10] studied the changes in agricultural productivity growth, technological progress and efficiency in Hubei Province, and stated that the important task of agricultural development in Hubei Province is to improve the agricultural technical efficiency. Liu Yanni et al. [11] calculated the increase in the total factor productivity of agriculture in China during 1978-2009, and the results show that technological progress plays a key role. Zheng Xungang [12], based on the panel data during 2000-2007, made an empirical analysis on total factor productivity growth of the western agricultural production, and found that technological progress is the main driving force of productivity growth. According to empirical analysis on China’s agricultural total factor productivity growth by Quan Jiongzheng [13], the productivity growth is mainly due to technological progress. Through overview of the existing literature, it is found that the studies about total factor productivity are mainly concentrated on the calculation of total factor productivity in a country, region or industry [7-19], but there are great difference in the total factor productivity and its driving factors between different industries, and there are few literatures on the...
study of total factor productivity in China’s banana industry. In view of this situation, using DEA-based Malmquist index method, we calculated the total factor productivity of 5 major banana production areas (Guangdong, Hainan, Guangxi, Yunnan and Fujian) in China during 2003 – 2014, further divided it into technological progress and technical efficiency, and found major factors influencing the total factor productivity, in the hope of providing certain reference for decision making for technological progress and structural adjustment of China’s banana industry.

2 Model and variable selection

Total factor productivity (TFP) is a commonly used and effective method for calculating the productivity. It is a production frontier method based on the production non-efficiency assumption. The specific evaluation methods include parameter estimation, semi-parameter estimation and non-parameter estimation with data envelopment analysis (DEA) as representative. The results of the parametric method based SFA and nonparametric method based DEA are generally similar and the difference will be not big.

According to the data acquisition and data analysis model, we mainly adopted DEA-Malmquist index method to calculate and analyze the TFP of banana production in China, and further decomposed it into technological progress and technical efficiency.

2.1 Data envelopment analysis (DEA) method

DEA method was proposed by the famous American operation scientist Charnes and Copper in 1978. It is used to empirically measure productive efficiency of decision making units (or DMUs). Although DEA has a strong link to production theory in economics, the tool is also used for benchmarking in operations management, where a set of measures is selected to benchmark the performance of manufacturing and service operations. Suppose the input vector of a DMU in a production activity is \( X = (X_1, X_2, \Lambda, X_j) \), and the output vector is \( y = (y_1, y_2, \Lambda, y_j)^T \). Suppose there is \( n \) DMU \( j \) (1 \( \leq j \leq n \)), the input and output vector corresponding \( DMU_j \) is respectively:

\[
X_j = (x_{1j}, X_2j, \Lambda, X_{nj})^T > 0, \ j = 1, 2, \Lambda, n
\]

\[
y_j = (y_{1j}, y_{2j}, \Lambda, y_{nj})^T > 0, \ j = 1, 2, \Lambda, n
\]

And \( X_j > 0, y_j > 0, \ i = 1, 2, \Lambda, s \). In other words, each DMU has \( m \) type of input and \( s \) type of output; \( X_{nj} \) denotes the input quantity of the \( j \)-th DMU to the \( i \)-th type input, and \( y_{nj} \) is the output quantity of the \( j \)-th DMU to the \( r \)-th type output. In the production process, the status and function of each input and output are different, thus it is necessary to evaluate the DMU and integrate the inputs and outputs, namely, take them as the production process with only one overall input and one overall output, then it is necessary to assign each input and output with appropriate weight. To avoid the weight vector being influenced by subjective intention, it is generally necessary to take them as variable vector. \( v = (v_1, v_2, \Lambda, v_n)^T \), \( u = (u_1, u_2, \Lambda, u_n)^T \), \( v_i \) is a measure (weight) of \( i \)-th type output, while \( u_i \) is a measure (weight) of \( r \)-th type output. Each \( DMU_j \) has corresponding efficiency evaluation index:

\[
h_j = \frac{\sum u_i y_i}{\sum v_i X_i} (j = 1, 2, \Lambda, n)
\]

Then, properly select the weight coefficient \( v \) and \( u \), and make them satisfy \( h_j \leq 1 \), \( j = 1, 2, \Lambda, n \). Make the effect evaluation on the \( j_0 \) DMU, \( 1 \leq j_0 \leq n \), take weight coefficient \( v \) and \( u \) as variable, take the efficiency indicator of the \( j \)-th DMU as the target, and take the efficiency index of all DMUs \( h_j \leq 1 \), \( (j = 1, 2, \Lambda, n) \) as the constraint, to establish the following optimal model:

\[
\begin{align*}
\text{Max} & \quad \frac{\sum u_i y_i}{\sum v_i X_i} \\
\text{s.t.} & \quad \frac{\sum u_i y_i}{\sum v_i X_i} \leq 1 \\
& \quad v, u \geq 0 \\
& \quad j = 1, 2, \Lambda, n
\end{align*}
\]

When evaluating the relative efficiency of the \( j \)-th DMU, there is the following optimal model:

\[
\begin{align*}
\text{Max} & \quad \frac{u_i y_i}{\sum v_i X_i} \\
\text{s.t.} & \quad \frac{u_i y_i}{\sum v_i X_i} \leq 1 \\
& \quad v, u \geq 0 \\
& \quad j = 1, 2, \Lambda, n
\end{align*}
\]

where \( h_0 \) is \( h_0 \) (the other type is the same), i.e. the efficiency evaluation index of the \( j \)-th DMU. Using Charnes-Cooper transformation, we can convert the above formula into an equivalent linear program:

\[
\begin{align*}
\text{Max} & \quad y_0 \\
\text{s.t.} & \quad \omega^T X - \mu^T y \geq 0 \\
& \quad \omega^T X_0 = 1 \\
& \quad \omega, \mu \geq 0
\end{align*}
\]

If the optimal solution to the linear program (P) satisfies \( \omega^T > 0, \mu^T > 0 \), and the target value \( \omega^T y_0 = 1 \), the DMU is deemed as DEA efficient. Therefore, when using DEA to measure the efficiency, if the evaluation indicator of DMU is 1, it is efficient; otherwise, it is inefficient.

2.2 DEA-Malmquist index method

In 1953, the Swedish economist and statistician Malmquist proposed a quantity index (later it was named Malmquist index) for use in consumption analysis for the first time. Malmquist index can be further decomposed into changes in relative technical efficiency and technological progress. Technological progress (Tch) is used to reflect the degree of change in production technology, while technical efficiency (Ech) is a measure of whether there is a waste of inputs and whether the allocation of resources is optimal, and technical efficiency can be further decomposed into pure technical efficiency index (Tch) and scale efficiency index (S乙ch) under the assumption of constant return to scale. Each household of banana grower is a production decision-making unit. Using the DEA method modified by Fare etal,
we built the best practice frontier for each year of banana production. In order to obtain the total factor productivity in $t+1$ period based on $t$, with the reference to ideas of Fare, Grosskopf, and Norris, we calculated changes in the productivity using the geometric mean of two Malmquist productivity indices.

$$M_t(x^{t+1}, y^{t+1}; x', y') = \left[ \frac{D'_t(x', y')}{D'_t(x', y')} \left\{ \frac{D^{t+1}_t(x', y')}{D^{t+1}_t(x', y')} \right\} \right]^{1/2}$$

$$= \left[ \frac{D'_t(x', y')} {D'_t(x', y')} \left\{ \frac{D^{t+1}_t(x', y')} {D^{t+1}_t(x', y')} \right\} \right]^{1/2}$$

$$= E(x^{t+1}, y^{t+1}; x', y') TP(x^{t+1}, y^{t+1}; x', y')$$

where $E$ is the relative efficiency change index under the condition that the return to scale is constant and the element is discretionary, it is the measure of the distance of each observation object to the best practice boundary in the period of $t$ to $t+1$. This efficiency change index can be decomposed into the scale efficiency change index $SC(x^{t+1}, y^{t+1}; x', y')$, element discretionary change index $CNC(x^{t+1}, y^{t+1}; x', y')$, and pure technical efficiency change index $PC(x^{t+1}, y^{t+1}; x', y')$. TP is the technological progress index, and it measures the movement of the technical boundaries in the period of $t$ to $t+1$. Therefore, productivity index can be decomposed into;

$$M_t(x^{t+1}, y^{t+1}; x', y') = PC(x^{t+1}, y^{t+1}; x', y') \times SC(x^{t+1}, y^{t+1}; x', y') \times CNC(x^{t+1}, y^{t+1}; x', y') \times TP(x^{t+1}, y^{t+1}; x', y')$$

The technological progress index is decomposed into the neutral technological progress (NTP), output non-neutral technological progress (OBTP) and input non-neutral technological progress (IBTP):

$$TP(x^{t+1}, y^{t+1}; x', y') = \left[ \frac{D'_t(x', y')} {D'_t(x', y')} \left\{ \frac{D^{t+1}_t(x', y')} {D^{t+1}_t(x', y')} \right\} \right]^{1/2}$$

$$= \left[ \frac{D'_t(x', y')} {D'_t(x', y')} \left\{ \frac{D^{t+1}_t(x', y')} {D^{t+1}_t(x', y')} \right\} \right]^{1/2} = NT(x^{t+1}, y^{t+1}; x', y') \cdot OBTC(x^{t+1}, y^{t+1}; x', y') \cdot IBTC(x^{t+1}, y^{t+1}; x', y')$$

In equation (5) and equation (7), the construction of the Malmquist productivity index requires the calculation of four mixed distance functions; $D'_t(x', y')$, $D^{t+1}_t(x', y')$, $D'_t(x', y')$, and $D^{t+1}_t(x', y')$. Besides, it is necessary to calculate a mixed index $D'_t(x^{t+1}, y^{t+1} | C, S)$ with the smallest changes of input $x^{t+1}$ for given output $y^{t+1}$ under the technology in period $t$. Similarly, it is necessary to determine the mixed distance function $D^{t+1}_t(x^{t+1}, y^{t+1} | C, S)$ of the K-th banana grower can be calculated using the linear program of equation (8), and other mixed distance functions can be obtained in the same way.

$$\left\{ \begin{array}{l} \min \theta^t \\ s.t. \ y_{t+1}^{*, t+1} \leq \sum_{i=1}^{m} Z_i^t x_{i,n}^t, m \\ \sum_{i=1}^{m} x_{i,n}^t, n \leq \theta^t x_{i,n}^t \\ Z_i^t \geq 0 \\ \end{array} \right.$$
3.2 Structure of production cost According to Table 2, in terms of the total input cost of the whole country, the material and service inputs accounted for 58.77% of total production costs, while the labor cost and land cost accounted for 25.97% and 19.26% of total production costs. There was little difference in the cost structure between 5 major banana production areas. Therefore, it is necessary to further study the production efficiency of the cost inputs to observe their underinvestment or redundancy.

Table 2 Structure of average banana production cost in whole China and major production areas in 2003 – 2014 (yuan/667m²)

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</tr>
</thead>
<tbody>
<tr>
<td>Material and service</td>
<td>2131.35 60.20 2144.42 59.24 1942.41</td>
<td>59.73</td>
<td>1947.06 57.84 1879.85 56.71 2009.02</td>
<td>58.77</td>
<td>887.81 25.97 547.43 16.52 521.84</td>
<td>15.26</td>
<td>3148.65 83.85 30.76 2014.06</td>
<td>30.76</td>
<td>1386.07 113.7%</td>
<td>113.7%</td>
<td>3418.67 195.91</td>
<td>195.91</td>
</tr>
<tr>
<td>Labor cost</td>
<td>938.46 25.51 959.32 25.49 829.66</td>
<td>25.51</td>
<td>824.25 24.49 887.36 26.77 887.81</td>
<td>25.97</td>
<td>887.81 25.97 887.81 25.97 547.43</td>
<td>16.52</td>
<td>3148.65 83.85 30.76 2014.06</td>
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<td>1386.07 113.7%</td>
<td>113.7%</td>
<td>3418.67 195.91</td>
<td>195.91</td>
</tr>
<tr>
<td>Land cost</td>
<td>470.71 13.29 516.15 14.26 479.91</td>
<td>14.76</td>
<td>594.98 17.67 547.43 16.52 521.84</td>
<td>15.26</td>
<td>3148.65 83.85 30.76 2014.06</td>
<td>30.76</td>
<td>1386.07 113.7%</td>
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<td>3418.67 195.91</td>
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</table>

3.3 Production income According to Table 3, in 2003 – 2014, the annual income of Hainan and Fujian was higher than that of other production areas. Yunnan had the lowest income; the growth rate of annual income was highest in Guangxi, up to 115.91%, mainly contributed to growth of income (68.61 yuan) in 2007 and 1172.2 yuan in 2008, which could not indicate the stable income growth of banana planting in Guangxi. Actually, the growth rate of annual income of Hainan and Fujian was higher than that of other production areas, Yunnan had the lowest income; the growth rate of annual income was highest in Guangxi, up to 115.91%, mainly contributed to growth of income (68.61 yuan) in 2007 and 1172.2 yuan in 2008, which could not indicate the stable income growth of banana planting in Guangxi. Actually, the income fluctuation trend of Guangxi was similar to other major production areas; overall decline in 2003 – 2011, and gradual increasing after 2012. The income of banana industry fluctuated greatly, especially during 2007 – 2012, it experienced the natural and market risk, the production costs constantly increased, and the sales income suffered a negative growth, which seriously dampened the enthusiasm of banana growers for planting banana.

Table 3 Production income of banana in whole China and major production areas in 2003 – 2014 (yuan/667m²)

<table>
<thead>
<tr>
<th>Major production area</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hainan</td>
<td>1911.0</td>
<td>1552.1</td>
<td>1929.2</td>
<td>1494.5</td>
<td>875.3</td>
<td>2900.4</td>
</tr>
<tr>
<td>Guangdong</td>
<td>1494.6</td>
<td>2356.6</td>
<td>2316.0</td>
<td>1619.6</td>
<td>646.7</td>
<td>-456.2</td>
</tr>
<tr>
<td>Guangxi</td>
<td>902.6</td>
<td>1439.1</td>
<td>1108.5</td>
<td>1245.1</td>
<td>68.6</td>
<td>1172.2</td>
</tr>
<tr>
<td>Yunnan</td>
<td>543.4</td>
<td>778.9</td>
<td>576.5</td>
<td>1096.3</td>
<td>465.5</td>
<td>-1581.5</td>
</tr>
<tr>
<td>Fujian</td>
<td>1671.9</td>
<td>2900.6</td>
<td>2255.8</td>
<td>2901.6</td>
<td>860.0</td>
<td>1605.6</td>
</tr>
<tr>
<td>Whole China</td>
<td>1336.8</td>
<td>1810.0</td>
<td>1670.9</td>
<td>1493.7</td>
<td>513.7</td>
<td>238.1</td>
</tr>
</tbody>
</table>

4 Model estimation results and analysis

4.1 Total factor productivity of China’s banana industry According to Table 4, from the perspective of time, the total factor productivity showed an overall rising trend, but the fluctuation was large, and the trend was not obvious, the average annual growth rate of productivity was 1.3%, mainly contributed to technological progress (average growth of 2.6%), while the growth rate of pure technical efficiency and scale efficiency was -0.1% and -1.2%, respectively. Neither technological progress and pure technical efficiency, nor scale efficiency achieved steady growth, but it still could be found in recent years, technological innovation ability of the banana industry was constantly improving, technological progress has become the main driving force for total factor productivity growth. However, the level of industrial agglomeration was not high, both the management efficiency and technology accumulation were uneven, and the effect of pure technical efficiency and scale efficiency was not obvious. The production efficiency reached the highest 1.266 and 2.303 in 2008 and 2013 respectively. In 2008 and 2013, the growth rate of technological progress was 60.3% and 113.7% respectively, indicating that technological progress was the main driving force for the growth of production efficiency. In the sample period, the total factor productivity reached efficient only in five years (2004, 2008, 2009, 2013 and 2014), and it was inefficient in the remaining years, largely because of low efficiency or inefficiency of the integrated technology. For the pure technical efficiency and scale efficiency, the annual growth rate was -0.1% and -1.2% respectively, the lowest year was in 2008, and the highest year was in 2011. The pure technical efficiency reached efficient in 2005, 2007, 2009, 2010, 2011, and 2014, and the return to scale gradually increased in 2006, 2010, 2011, and 2013. Therefore, in 2004, 2007, 2009, and 2014, there was no excessive input or lack of output in banana production. In addition, in 2004 – 2014, the overall efficiency was inefficient for 7 years, indicating that the scale was inconsistent with the input and output.

4.2 Total factor productivity of 5 major banana production areas From Table 5, the total factor productivity (TFPch) of 5 major banana production areas was ranked as follows: Guangxi > Hainan > Yunnan > Guangdong > Fujian, and average annual growth of 1.3% of total factor productivity was mainly due to the average annual growth rate of technological progress of 2.6%. In the overall technical efficiency, Guangxi and Hainan were efficient production units, while Fujian and Yunnan had declining return to scale. The annual growth rate pure technical efficiency of Guangdong was -0.3%, showing the necessity for exploring the technical potential in production and bringing into play a higher technical production efficiency. In production efficiency, except Fujian, other four provinces (regions) were efficient units. The total factor productivity of Fujian Province was 0.956, and the average annual growth rate was -4.4%, indicating that banana production of Fu-
sian Province badly needed technological innovation and improvement of the production management conditions. For the pure technical efficiency and scale efficiency, Guangxi and Hainan were efficient production units, with moderate output and input. Due to the low degree of industrialization of planting and management, Fujian and Yunnan suffered declining return to scale, which restricted the growth of technical efficiency. Also, the pure technical efficiency index of Guangdong Province was 0.997, the growth rate was −0.3%, indicating that at the same time of introducing advanced technology in Guangdong Province needed paying attention to banana garden management and turning technology into the productivity through management practice.

### 5 Conclusions and recommendations

#### 5.1 Conclusions

The total factor productivity of banana industry in China was 1.3% in 2003–2014, mainly due to technological progress, the average growth rate was 2.6%, while the pure technical efficiency and scale efficiency was −0.1% and −1.2% respectively. It indicated that the improvement of total factor productivity in banana industry in China relied mainly on technological progress, cultivation of new banana varieties, management of high quality cultivation, popularization and application of water conservation and fertilizer saving technology, and injury-free picking technologies. The pure technical efficiency and scale efficiency of banana production were negative, indicating that the management level of banana was not high. The effect of scale economy of this industry through agglomeration and consolidation is still to be practiced. Banana growers should promote the improvement of large scale and management level of the banana industry at the same time of promoting the technological progress.

#### 5.2 Recommendations

(i) It is recommended to vigorously promote large-scale and specialized banana production and standardized management, so as to promote the sustainable development of banana industry in China. (ii) It is recommended to transform the development of banana industry, and change the extensive development of element input mode into intensive development relying on total factor productivity and technological progress. (iii) It is recommended to strengthen the practical research and development of banana production and establish and improve a sound technical system. (iv) It is recommended to accelerate the breeding of new varieties and the construction of excellent breeding system, to strengthen the researches about banana pest control technology and banana fertilization management technology. (v) It is recommended to improve the quality of banana growers, and actively cultivate professionals of banana production technology, to provide powerful intellectual support for scientific development of banana production. (vi) It is recommended to strengthen financial and policy support for banana growers in planting conditions and method improvement, and accelerate the use of lightly simplified machinery and equipment facilities in banana cultivation, harvesting and post-harvest treatment.

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4 Significance of rural investigation by the CPC

(i) Developing rural social investigation is a concrete manifestation of the basic principles of historical materialism. There is no right to speak without investigation. Since the reform and opening up, China has established the guiding ideology of seeking truth from facts, and adhering to the Marxist historical materialism is the basic precondition and necessary basis for ensuring scientific practice. (ii) Rural investigation is an important basis for the Chinese Communist Party to formulate scientific decisions and promote rural social development. Since the reform and opening up, there have been enormous changes in rural areas of China. The investigation of new situation of rural social development is a basic precondition for formulating rural policies and solving three rural issues. The establishment of the household contract responsibility system has greatly promoted the development of rural social productive forces and summoned the enthusiasm of farmers. Practice has proved that strengthening investigation is a fundamental way for formulating policies for promoting rural economy and social coordinated development.

(iii) Carrying out rural social investigation is an important engine for promoting the development of rural sociological theory. Since the introduction of rural sociology in China in the 1920s, the development of its theory has undergone a long process of development. A lot of practice has proved that rural social investigation is the source of rural sociology theory and the only way for testing the theory of rural sociology, and also provides an important theoretical support for other disciplines.

References


(From page 23)