A comparative analysis on circulation efficiency of different banana circulation modes in Zhangzhou city based on DEA model

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Abstract

In the paper, the software DEAP was used to evaluate relative efficiency of 8 kinds of banana circulation modes in Zhangzhou City. CCR model and BCC model were employed. The related index included input (unit circulation cost, circulation time, and circulation loss rate) and output (net profit). The result showed that, the comprehensive efficiency, pure technology efficiency, scale efficiency in Mode 1 (farmers-third party logistics–supermarket–consumers) and Mode 8 (farmers-banana sales stalls–consumers) were relatively efficient. Therefore, it was judged that the main factors affecting the circulation efficiency were the compression of circulation level and the ascension of scale and professional level.

Keywords: DEA, circulation mode, circulation efficiency

1 Introduction

Technology efficiency was firstly proposed by the British economist M. J. Farrell of Cambridge University in 1957 based on Debreu's research work. Farrell proposed that technology efficiency refers to the ratio of the actual output and the production boundary of an enterprise under the given inputs; while the ratio of the gap between the production boundary and the actual output and the production boundary is the technology inefficiency. In 1972, S. N. Afriat firstly employed the maximum likelihood approach to establish the frontier production function model with statistical properties, which opened a new phase of the study using econometric model to analyse technology efficiency; however, the result of this approach was greatly affected by the residual distribution form. Different assumptions often lead to different estimation results. In 1974, J. Richmond firstly proposed the re-modified ordinary least squares approach to study the frontier production function.

However, there is a common drawback in the above models: they assumed that frontier production function of each production unit was the same, and the technology efficiency lead to the difference between actual output and boundary output. Actually, that is not the case. In view of this problem, in 1977 D. J. Aigner C. A. Knox Lovell in America and W. Meeusen in Belgian proposed stochastic frontier production function, which made the measuring of technology efficiency possible. At the same time, the famous strategist W. A. Charnes and W. Cooper proposed Data Envelopment Analysis in 1978 (abbreviated as DEA), a new approach for evaluating the efficiency developed based on the concept of relative efficiency.

Based on variable returns to scale (VRS), the technology efficiency was further decomposed into pure technology efficiency and scale efficiency by Banker (1984), so that the application of this technology became more widely. Since then, based on the theory and practice in the use and development of logistics, and it gradually formed a non parametric approach used for economic quantitative analysis, mainly dependent on the linear programming technique. However, the endeavour of famous American strategists A. Charnes and W. W. Cooper (1985) made the non parametric approach popular in the form of data envelopment analysis (DEA) in the early 1980s; therefore, sometimes DEA was called non parameter approach or Farrel efficiency analysis.

On the basis, DEA began to be widely employed by research staff in various fields, for example: analysis on economic situation in cities, efficiency analysis of financial institutions, and management assessment of the public utilities. Besides efficiency evaluation, DEA is also employed for forecasting and early warning in economic system (Sheng Zhaohan et al., 1996; Klimberg et al, 2009). It reveals the unknown information in the system, to provide decision support for managers.

The economic meaning of DEA efficiency is: the output level in the existing system, structure and technology level; if the optimal value of the model is less than 1, it is considered that the economic activity is inefficient, thus the input can be reduced to achieve the current output; conversely, if the optimal value of the

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model is equal to 1, the economic activity is efficient, and the output of the current input is the maximum output.

2 A brief introduction of banana circulation modes in Zhangzhou city

In the paper, price data in each link in each circulation mode in Zhangzhou market from January 1, 2008 to December 30, 2012 were collected, and the average unit circulation cost, average net profit, circulation loss rate, circulation time of each circulation mode in each year were calculated. The banana produced from Tianbao Town, Xiangcheng District, Zhangzhou City in different sales modes were chosen as the object of the study. The reasons were there exist obvious differences in time to market of the same banana from different production places at the same final consumption market, and the actual situation in the research was that the local banana played a great part in Zhangzhou Market. According to the survey, the result showed that there were 8 kinds of banana sales modes in Zhangzhou. They are:

Mode 1: Farmers – third party logistics – supermarket – consumers.

Mode 2: Farmers – assemblers – wholesalers – supermarket – consumers.

Mode 3: Farmers – assemblers – wholesalers – fruit shops – consumers.

Mode 4: Farmers – assemblers – wholesalers – farmers market – consumers.

Mode 5: Farmers – assemblers – wholesalers – fruit shops – mobile stalls – consumers.

Mode 6: Farmers – fruit shop – consumers.

Mode 7: Farmers –farmers market – consumers.

Mode 8: Farmers – banana sales stalls – consumers

3 DEA model

Data envelopment analysis (DEA) is a linear programming model, mainly used for the efficiency evaluation of complex system with multiple inputs and multiple outputs. It does not need dimensionless treatment to the data, so this approach is more reliable. At present, in the academic circle, a relatively complete data envelopment analysis system has been formed and widely used in many fields. DEA has many different models, which represent different economic significance. The CCR model is the most basic model, which contains non-Archimedean infinitesimal, and the size of decision-making unit does not affect the relative efficiency. When the evaluation results show that the decision-making unit is DEA efficient, and the decision-making unit is technically efficient and scale efficient.

CCR model and input and output of its basic variables are shown in Table 1:

TABLE 1 CCR model and input and output of its basic variables

		DMU$_1$	***DMU***$_2$		***DMU***$_n$		
v_1	1	x_{11}	x_{12}	…	x_{1n}		
v_2		x_{21}	x_{22}	…	x_{2n}		
…	…	…	…	…	…		
v_m	m	x_{m1}	x_{m2}	…	x_{m3}		
		y_{11}	y_{12}	…	y_{1n}	1	u_1
		y_{21}	y_{22}	…	y_{2n}	2	u_2
…	…	…	…	…	…		
		y_{s1}	y_{s2}	…	y_{sn}	3	u_n

In the Table 1, x_{ij} indicates the amount of No. i input for No. j DMU. When $x_{ij} > 0$, y_{rj} indicates the amount of No. r input for No. j DMU. When $y_{ij} > 0$, v_i represents a measure of No. i input; while v_r represents a measure of No. r input.

Among them, the input amount of DMU_1 is $X_j = \left(x_{1j}, x_{2j}, ..., x_{mj}\right)^T$, while the output amount is $Y_j = \left(y_{1j}, y_{2j}, ..., y_{sj}\right)^T$, $j = 1,2,…n$. The corresponding weight coefficient is $v_j = \left(v_1, v_2, ..., v_m\right)^T$, $u_j = \left(u_{1,} u_{2,} ...u_s\right)^T$, h_j is called the efficiency evaluation index of DMU_j.

$$h_j = \frac{u^T Y_j}{v^T X_j} = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}}, j = 1, 2, ..., n. \quad (1)$$

Based on the principle that efficiency evaluation index of each decision-making unit should not be more than 1, the efficiency of No. j_0 decision making unit is evaluated. Select the right coefficient u and v to make h_0 highest, which is shown as following:

$$\begin{cases} \max \dfrac{\sum_{r=1}^{s} u_r y_{rj_0}}{\sum_{r=1}^{m} v_i x_{ij_0}} \\ s.t \dfrac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{r=1}^{m} v_i x_{ij}} \le 1 \\ u_r \ge 0 \\ v_i \le 0 \end{cases}, \quad (2)$$

where $j = 1,2,\ldots,n$, $r = 1,2,\ldots,s$, $i = 1,2,\ldots,m$. When Charnes-Cooper is employed, ($t = \frac{1}{v^T x_0}$, $w = tw$, $u = tu$) is changed, slack variables s^-, s^+ are added, and the duality programming and non-Archimedean infinitesimal ε are introduced, the Equation (1) can be converted to:

$$\begin{cases} \min\left[\theta - \varepsilon\left(e_1^T s^- + e_2^T s^+\right)\right] \\ s.t \sum_{j=1}^{n} \lambda_j x_j + s^- = \theta x_0 \\ \sum_{j=1}^{n} \lambda_j y_j - s^+ = y_0 \\ \lambda_j \geq 0, j = 1,2\ldots n \\ s^+ \geq 0, s^- \geq 0 \\ e_1 = (1,1,\ldots 1)^T \in R^m \\ e_2 = (1,1,\ldots 1)^T \in R^M \end{cases} \quad (3)$$

Among them, according to the requirements on the accuracy of calculation model, non-Archimedean infinitesimal ε can select different range (10^{-5} to 10^{-10}). Compared to DMU_0, λ_j is combined ratio of DMU_j in re-constructed effective DMUs. Based on non-Archimedean infinitesimal, the optimal solutions of CCR model λ_0, s_0^+, s_0^-, θ_0 are calculated, through which it can be determined whether the research object is of technology efficiency and scale efficiency. The judgment basis is as following:

a) When $\theta_0 = 1$, $s_0^+ = 0$, $s_0^- = 0$, the decision making unit j_0 is DEA efficient, and economic activity of decision-making unit is of technology efficiency and scale efficiency.

b) When $\theta_0 = 1$, $s_0^+ \neq 0$, $s_0^- \neq 0$, the decision making unit j_0 is weak DEA efficient, and economic activity of decision-making unit is not both at the best of technology efficiency and scale efficiency.

c) When $\theta_0 < 1$, the decision making unit j_0 is not DEA efficient, and economic activity of decision-making unit is neither at the best of technology efficiency nor scale efficiency.

In the CCR model, the research object is the same type of decision making units in a system; it analyses the relatively effective production frontier in a certain input or output level, and compared it with each decision making unit, so as to evaluate their effectiveness.

The BCC model is based on the CCR model. In BBC model, it divided the technology efficiency into pure technology efficiency (PTE) and scale efficiency (SE). After adding constraints on weight λ, it evaluates the relative efficiency of decision making units in the case of variable returns to scale. Among them, the pure technology efficiency (PTE) refers to the ratio of the actual input and the optimal input. If PTE = 1, it indicates that the decision-making unit is of pure technical efficiency; if PTE < 1, the decision-making unit is of pure technical inefficiency. Scale efficiency (SE) refers to the scale efficiency level of each individual decision making unit. If SE = 1, it indicates that the decision making unit is of scale efficiency; if SE < 1, it shows that the decision making unit is scale inefficiency.

4 Indicators construction

According to the requirements of data envelopment model, in the paper, unit net profit is selected as output indicators, and unit circulation cost, circulation time and circulation loss rate are selected as input indicators.

a) Unit net profit. It is the output index to measure the banana circulation efficiency, including sales and profits. In the paper, unit net profit is used to measure the banana circulation efficiency.

b) Unit circulation cost. It refers to the total cost in the banana circulation process, including picking, packing and transportation cost, market cost and management cost.

c) Circulation time. It refers to the time that it takes for the goods to transfer from production to consumption. Because after picking, the banana has to be ripened in the warehouse for about 3-5 days, and the ripening time in each banana circulation mode is the same. To be more accurate calculation, the circulation time deducts its ripening time in the course. That is the time when banana in the course of circulation (not including the ripening time).

d) Circulation loss rate. It refers to the amount of loss in the circulation process or the proportion of loss accounted for the total number.

TABLE 2 Input and output index of each banana circulation mode in Zhangzhou City in 2008 (based on the survey)

	output	**input**		
Circulation Mode	Unit net profits (Yuan/kg)	Unit circulation cost	circulation time (hour)	Circulation loss rate (%)
Mode 1	0.8	0.82	16	13%
Mode 2	0.72	0.9	28	16%
Mode 3	0.58	0.75	24	16%
Mode 4	0.58	0.69	24	17%
Mode 5	0.48	0.65	24	17%
Mode 6	0.63	0.70	12	35%
Mode 7	0.62	0.65	12	38%
Mode 8	0.6	0.53	12	38%

Note: In order to make the data comparable, unit net profit, unit circulation cost in each link are assessed in banana prices. Loss rate is calculated in percentage, and circulation time is calculated in hour.
Data sources: according to the survey data.

TABLE 3 Input and output index of each banana circulation mode in Zhangzhou city in 2009 (based on the survey)

Circulation Mode	output	input		
	Unit net profits (Yuan/kg)	Unit circulation cost	circulation time (hour)	Circulation loss rate (%)
Mode 1	0.83	0.78	16	12%
Mode 2	0.79	0.82	28	16%
Mode 3	0.62	0.76	24	14%
Mode 4	0.51	0.63	24	16%
Mode 5	0.42	0.66	24	16%
Mode 6	0.67	0.71	12	30%
Mode 7	0.52	0.62	12	36%
Mode 8	0.59	0.49	12	36%

Note: In order to make the data comparable, unit net profit, unit circulation cost in each link are assessed in banana prices. Loss rate is calculated in percentage, and circulation time is calculated in hour.
Data sources: according to the survey data.

TABLE 4 Input and output index of each banana circulation mode in Zhangzhou City in 2010 (based on the survey)

Circulation Mode	output	input		
	Unit net profits (Yuan/kg)	Unit circulation cost	circulation time (hour)	Circulation loss rate (%)
Mode 1	0.88	0.75	16	11%
Mode 2	0.79	0.84	28	17%
Mode 3	0.69	0.79	24	14%
Mode 4	0.58	0.65	24	16%
Mode 5	0.54	0.69	24	16%
Mode 6	0.75	0.73	12	30%
Mode 7	0.57	0.66	12	36%
Mode 8	0.73	0.50	12	36%

Note: In order to make the data comparable, unit net profit, unit circulation cost in each link are assessed in banana prices. Loss rate is calculated in percentage, and circulation time is calculated in hour.
Data sources: according to the survey data.

TABLE 5 Input and output index of each banana circulation mode in Zhangzhou City in 2011 (based on the survey)

Circulation Mode	output	input		
	Unit net profits (Yuan/kg)	Unit circulation cost	circulation time (hour)	Circulation loss rate (%)
Mode 1	0.99	0.73	16	10%
Mode 2	0.86	0.86	28	18%
Mode 3	0.67	0.86	24	14%
Mode 4	0.55	0.67	24	16%
Mode 5	0.54	0.70	24	16%
Mode 6	0.79	0.74	12	30%
Mode 7	0.57	0.65	12	36%
Mode 8	0.73	0.51	12	36%

Note: In order to make the data comparable, unit net profit, unit circulation cost in each link are assessed in banana prices. Loss rate is calculated in percentage, and circulation time is calculated in hour.
Data sources: according to the survey data.

TABLE 6 Input and output index of each banana circulation mode in Zhangzhou City in 2012 (based on the survey)

Circulation Mode	output	input		
	Unit net profits (Yuan/kg)	Unit circulation cost	circulation time (hour)	Circulation loss rate (%)
Mode 1	1.01	0.71	16	10%
Mode 2	0.84	0.88	28	18%
Mode 3	0.69	0.81	24	17%
Mode 4	0.57	0.68	24	23%
Mode 5	0.54	0.73	24	25%
Mode 6	0.75	0.75	12	31%
Mode 7	0.56	0.69	12	35%
Mode 8	0.74	0.53	12	35%

Note: In order to make the data comparable, unit net profit, unit circulation cost in each link are assessed in banana prices. Loss rate is calculated in percentage, and circulation time is calculated in hour.
Data sources: according to the survey data.

5 Model evaluation and calculation results

In the paper, the reverse tracking approach was employed, combined with depth interviews and questionnaire survey. A large number of first-hand information was obtained, which provides necessary data support for the empirical analysis. Due to the multiple circulation links in the circulation process, the corresponding index data of each circulation link is added, in order to get the overall index data. Specifically, first of all, the interview records and questionnaires are classified according to the different circulation modes, and then subdivided into different circulation links, and input and output data of each link in each circulation mode are added, to get the input-output data of the whole circulation mode, finally the average of each input and output index in each circulation mode is calculated for the empirical analysis. As Table 1 and Table 5 showed, 8 kinds of circulation modes listed in the Table 8 were considered as 8 decision making units. Combined with the data in the Table 6 and the software DEAP, CCR model and BCC model based on the input-oriented were employed to evaluate efficiency of the circulation mode.

TABLE 7 Efficiency evaluation results of each banana circulation mode in Zhangzhou city

Circulation Mode	Decision-making unit	Comprehensive efficiency	Pure technology efficiency	Scale efficiency	Returns to scale
Mode 1	1	1	1	1	constant returns to scale
Mode 2	2	0.774	0.839	0.923	increasing returns to scale
Mode 3	3	0.682	0.912	0.748	increasing returns to scale
Mode 4	4	0.682	1	0.682	increasing returns to scale
Mode 5	5	0.651	0.948	0.687	increasing returns to scale
Mode 6	6	0.994	1	0.994	increasing returns to scale
Mode 7	7	0.838	1	0.838	increasing returns to scale
Mode 8	8	1	1	1	constant returns to scale
mean		0.828	0.962	0.859	

Note: the comprehensive efficiency is technology efficiency calculated based on the CCR model; pure technology efficiency is technology efficiency calculated based on the BCC model; scale efficiency = comprehensive efficiency / pure technology efficiency.

6 Conclusions

Results were shown in Table 6. According to the evaluation results, it came out the following conclusions:

a) Among the 8 banana circulation modes, 2 modes were efficient, while 6 were inefficient. Namely, most banana circulation modes with retail terminal were in the inefficient state. After the comprehensive efficiency was divided into pure technology efficiency and scale efficiency, it could be seen that pure technology inefficiency and the scale inefficiency resulted in the inefficient state of most banana circulation modes, and scale inefficiency was the main reason.

b) Table 8 shows that the relative efficiency of circulation mode with minimum circulation level were higher than that with more circulation level, that is, the comprehensive efficiency of Mode 1 and Mode 8 were higher than that of Mode 3, Mode 4, Mode 6 and Mode 7. Thus, it could be seen, in the case that the supermarket organized banana supply from the third party logistics, the supplier had played a positive role, or the behaviour of banana farmers who skipped the process of purchase, wholesale promoted the circulation efficiency.

c) The relative efficiency of Mode 5: Farmers – assemblers – wholesalers – fruit shops – mobile stalls – consumers was the lowest, only 0.651.

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