



Technical Efficiency of White Leg Shrimp Production Using Data Envelopment Analysis (DEA), Case Study: Jiangsu Province, China

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Authors' contributions

This work was carried out in collaboration between all authors. Author MM designed the study including review of literature. All authors helped in developing the questionnaire. Authors MM, ZZ and AH analyzed the data. All authors discussed the result, read and approved the final manuscript.

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ABSTRACT

Production of white leg shrimp (*Penaeus vannamei*) is a very important economic activity in the overall farming system in China. In spite of the present successes witnessed by white leg shrimp farming, there are many challenges (disease, overfeeding, effluent discharge, lack of technical knowledge, low educational level, inexperienced managers, the high cost of production among others) continuing to set back the growth of this sector in China. The study was conducted in Jiangsu province because is one of the leading producing provinces of White-leg shrimp (*Penaeus vannamei*) in China. The research examines the technical efficiency level of white leg shrimp production in Jiangsu Province, China. Three seasonal crops data in 2016 crop year were collected

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from 52 white leg shrimp farmers in the study area. All data were coded in Excel 2007 spreadsheet package and analysed with SPSS version 20 and DEAP version 2.1 software at 95% confidence level. Descriptive statistical, regression and Data Envelopment Analyses (DEA) were used to analyse the data. Results revealed an average technical efficiency score of 83.1%, under a constant return to scale. Majority of the farmers (62%) were technically inefficient in utilising input resources with technical efficiency score less than 1. Twenty farmers were technically efficient with technical efficiency (TE) score equal to 1. Feed, fingerlings and chemical showed significant negative influence on technical efficiency at 5% level of significance while labor, fixed cost and age exhibited strong negative impact at 1% level of significance.

Keywords: Technical efficiency; *Penaeus vannamei*; DEA; Jiangsu of China.

1. INTRODUCTION

The world aquaculture has experienced the most rapid growth in shrimp production. It has been estimated that aquaculture will soon constitute about half of the world fisheries production and will provide approximately 62% of fish consumption [1]. China contributed about 60% of the world aquaculture production as reported in 2016 [2]. In the year 2030, this sector will contribute a large part of a fish production, which will be manifested by the contribution of shrimp production.

The global shrimp production has quickly expanded as a result of an extraordinary expansion of shrimp farming since 1980, estimated at 13% annual increase, [3]. The world shrimp production has increased from less than 3.2 million metric tons in 2008 to 3.6 million metric tons in 2014 [4]. It has been reported that the expansion in shrimp production is mainly attributed to technological breakthrough of innovation and global market [5,2].

The study showed [6] that there is an increasing concern among organisations to study the level of efficiency of their enterprise performance, that the traditional performance measurement system provides a very unbalanced picture of performance that can lead managers to miss interpret opportunities for improvement, that the most common method of comparison or performance evaluation was regression analysis and stochastic frontier analysis. Adding that these measures are often inadequate due to the multiple inputs and outputs related to different resources, activities and environmental factors. It was concluded that Data Envelopment Analysis (DEA) provides a means of calculating apparent efficiency levels within a group of organisations. In data envelopment analysis, an efficiency of an enterprise is estimated in relation to the best practice of the organisations [6].

The measurement of economic efficiency (technical, allocative and production) has been closely linked to the use of data envelopment analysis especially in aquaculture to determine production and technical efficiencies of shrimp farms. The primary objective of this study is to determine the technical effectiveness of white shrimp (*Penaeid vannamei*) production using Data Envelopment Analysis.

2. REVIEW OF RELATED LITERATURE

2.1 Technical Efficiency Analysis in Aquaculture

[7] employed the case of double bootstrap DEA model to determine the variability in technical efficiency estimation and to correct the bias inherent in the deterministic measurement for the case of shrimp farming in Ninh Thuan, Vietnam. The results showed that the bias-corrected point estimated for technical efficiency was 0.73, and at the 95% confidence interval, it was estimated to be 0.68 at the lower limit and 0.80 at the upper limit. The result suggested that there is considerable room for improvement in technical efficiency in the sample of farms analysed. Moreover, the mean estimates of the technical efficiency of 0.73 using the double bootstrap approach were statistically significantly lower than that of 0.79 for the case of Ninh Thuan's White leg shrimp farming. The study revealed that there is a potential improvement in technical efficiency than that using deterministic DEA, which has been adopted widely in aquaculture [7].

[8] analysed the technical efficiency of Black tiger shrimp (*Penaeus monodon*) farms and white leg shrimp farms in Song Cau district of Phu Yen province, Vietnam. Cross-sectional data of 62 Black tiger shrimp (*Penaeus monodon*) and 88 white shrimp samples were used. Nonparametric Data Envelopment Analysis (DEA) approach was used, and the results revealed that the technical

efficiency for Black tiger shrimp system under the assumption of constant returns to scale, variable returns to scale and scale efficiency was measured to be 0.82, 0.95 and 0.87, respectively. In the white leg shrimp system, the farms achieve a mean efficiency level of 0.88, 0.94 and 0.95 under a condition of constant returns to scale, variable returns to scale and scale efficiency, respectively. Similarly, DEA input-oriented variable return to scale was applied in estimating technical super-efficiency of improved extensive shrimp farming in Ca Mau Province, Vietnam by [9]. Cross-sectional data of 92 samples of black tiger shrimp farms from two districts; Cai Nuoc, Dam Doi, were used. The results showed that the mean constant return to scale (CRS) technical efficiency of the total samples was 0.36. The results further revealed that in Dam Doi district, there was a negative relationship with a technical efficiency which suggested that farms in Cai Nuoc district were high efficiency than farms in Dam Doi district [9].

[10] examined the technical and scale efficiency of tiger shrimp farm in an intensive system in Binh Dai district, Ben Tre Province, Vietnam by applying DEA method. In his analysis, the performance of shrimp farms in Binh Dai district was measured using input-oriented CRS and DEA model. The super efficiency was also estimated to have a better ranking for the farms performance which shows that at the normal production process, the intensive tiger shrimp farms in Binh Dai district are relatively efficient. Pure and scale technical efficiencies levels of the shrimp farms are rather high at an average above 90% which showed that as risk factors are controlled, the intensive shrimp farming technology can be controlled very well.

2.2 Objectives of the Study

The main aim of this study is to analysis the technical efficiency level of White Leg Shrimp (*P. vannamei*) production in Jiangsu Province. In this regard, the study examines how efficient resources are used in shrimp (*P. vannamei*) farming.

2.3 Hypotheses

H₀: High costs of feed and fingerling does not have a significant relationship with technical efficiency.

3. MATERIALS AND METHODS

3.1 Study Location

The study was conducted in Rudong county (Fig. 1) of Nantong city, Jiangsu province, east coast of China. Rudong is a municipal government area with 14 towns and 5 districts in Nantong city with an area of 1,872 Km² and a total population of 1.08 million people. Rudong is located on the bank of the Yellow Sea. As a result, there is a substantial fishing industry and the county was named "the place of seafood in China" by the Chinese Cooking Association in 2007 [11].

Nantong city is located in Jiangsu province on the northern bank of the Yangtze River, near the river mouth. It has an area of 8544 square kilometers with a population of 7,282,835 at the 2010 census, Nantong is a vital river port bordering Yancheng to the north, Taizhou to the west, Suzhou and Shanghai to the south across the river and the East China Sea to the east. Nantong was historically known as an agricultural area. Its principal agriculture products include fish, cotton, rice, wheat, fruit etc [12].

Hubei, Guangdong and Jiangsu provinces were the largest producers of freshwater white leg shrimp production [13]. Annual white leg shrimp (*P. vannamei*) production in Jiangsu province reached a record of 179,750mt in 2015 for freshwater 152,111mt and seawater 27,639mt, representing 84.62% and 15.38% respectively [14]. The author chose Jiangsu among the three largest producers for the study. Nantong city is the largest shrimp producer in Jiangsu province of which Rudong county stands out as the largest contributor [12].

3.2 Data Collection and Sampling Method

The primary data used for carrying out this study was a cross-sectional data for three crop seasons in 2016 production year. Each of the crop seasons is made up of three months hence the three cop seasons total 9 months. Data collection commenced in October 2017, and with the final field work completed in November 2017. Information and data were collected from 52 white leg shrimp farmers in the study areas using structured questionnaires of both English and Chinese versions through the assistance of FFRC students who were Chinese native speakers. The questionnaires were first tested

among 10 white leg shrimp farmers in Rudong County before it was finally administered. To facilitate the data collection, questionnaires were completed by the farmers at the study site. The questionnaire was designed into three major parts as follow:

- ❖ General/household characteristics: age, education, experience, household size farm size, the main occupation of household, the number of ponds and training attended.
- ❖ Production characteristic: production system, number of labor, and stocking density etc.
- ❖ Cost; fixed costs and variable costs in crop year 2016. The amount and unit price of outputs (White leg shrimp).

3.3 Data Analysis

The primary data was the main information used for this analysis. All the data collected were coded and entered into a statistical package for technical efficiency analysis. Technical efficiency at farm level was measured using a data envelopment analysis (DEA) approach. SPSS version 20, DEAP version 2.1 software and

Microsoft Excel 2007 spreadsheets were used. Simple descriptive statistical analysis (mean, standard deviation, maximum, minimum, percentage) was employed also for some main inputs and output variables to estimate efficiency level. Regression analysis was used to determine the factors influencing technical efficiency. Specific factors (seed, chemical, feed, fuel, labor, fixed cost, age and farm size) were investigated to ascertain the main factors affecting the technical efficiency of white leg shrimp production.

3.4 Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) deals with the use of linear programming methodology to measure the relative performance of organization units and efficiency of multiple decision-making units (DMU) when the production procedure provides a multiple of inputs and outputs that make comparisons difficult. [13] who built up the efficient frontier term known as Data Envelopment Analysis (DEA). Since then, there has been several studies that have used the DEA method. [13] suggested a model that could provide input orientation and estimate the constant return to scale (CRS).



Fig. 1. Study area
Source: [11]

3.5 Model Specification of Technical Efficiency

3.5.1 DEA model

[15] were the first to introduce DEA in technical efficiency analysis. Since then, DEA has been used to estimate efficiency in many different areas, ranging from the public sector to natural resource sectors such as the fishing industry. The DEA uses practical outputs and inputs. The technical efficiency is derived using the linear programming technique whose objective is to maximise the objective function that is, the ratio of outputs over inputs subject to the constraint that this ratio is equal to and less than one. The most important way to introduce DEA is by the ratio form. Assume the ratio of all output overall input to be $u'y_i/v'x_i$. The DEA mathematical model is a fractional programming objective function and is known as the CCR model. Consider the case of n DMUs (DMU $_j$: $j = 1, 2, \dots, n$), which produces outputs y_{rj} ($r = 1, 2, \dots, s$) by using m different inputs, x_{ij} ($i = 1, 2, \dots, m$). The original Charnes-Cooper-Rhodes model measure efficiency of DMU $_o$ where index 'o' is the DMU evaluated as follows (technical efficiency).

$$Max_{u,v} w_0 = \sum_r u_r y_{ro} \quad (1)$$

Subject to

$$\sum_i v_i x_{io} = 1 \quad (2)$$

$$\sum_r u_r y_{rj} - \sum_i v_i x_{ij} \leq 0 \quad (3)$$

$$u_r \geq \varepsilon, \text{ and } v_i \geq \varepsilon$$

Where

y_{rj} = quantity of output produced j

V_i = weight for input i

X_{ij} = quantity of input used by firm j

ε = small positive number

u_r = weight for output r

w_0 is obtained using superior inputs and outputs of DMU $_o$ by maximizing the objective function in equation 2 with respect to the weight variables. Using the first two constraints in Eqn 1. Adding ω to $(\sum_{r=1}^s u_r y_{ro} + w)$ and constraint in Eqn. 3 relaxes the CRS restriction and envelopes the data more closely than the CRS technology. Technical efficiency is a relative measure of efficiency under a less restrictive variable for returns to scale technology by the addition of

variable w [16] In general, a DMU is said to be efficient if it finds a scores of 1 and a score less than 1 meaning, it is inefficiency.

3.6 Variables

To estimate the farm technical efficiency, eight inputs and one out were used. The output is the white leg shrimp production while the inputs used to calculate the technical efficiency were farm size [7] cost of feed [17], cost of fingerlings, fuel cost, labor cost, cost of chemical, fixed cost. In addition, age (a socio-economic variable) affects TE [18].

3.7 Ordinary Least-Squares (OLS) Regression Model

This model deals with the analysis of a relationship between one or more explanatory variables and a continuous or at least interval outcome variable that minimises the sum of square errors, where an error is a difference between the actual and the predicted value of the outcome variable. According to [19], the most common analytical method that utilises OLS models is linear regression (with a single or multiple prediction variable). DEA estimates technical efficiency scores but it does not account for the error measurement and statistical noise that may influence the shape and position of the frontier. To identify factors affecting technical efficiency scores which were estimated in the DEA stage, OLS regression model was used. The DEA regressed the first stage index on some discretionary and non-discretionary factors. Because of the upper limit on the efficiency index from the DEA stage is 1, OLS regression can produce biased estimates, and this stage requires a priori specification of functional form, though for simplicity these were not measured in this analysis. In the linear regression analysis, measures of farm technical efficiency calculated from the previous stage were used to estimate the relationship between the efficiency and costs of inputs variables such as; seed/fingerling, chemical, feed, fuel/electricity, labor, farm size, fixed cost and socioeconomic characteristics such as; age.

$$TE = \alpha SEED^{\beta1} CHEM^{\beta2} FEED^{\beta3} FUL^{\beta4} LAB^{\beta5} FSZ^{\beta6} FC^{\beta7} AGE^{\beta8}$$

Where

TE = Technical Efficiency

FEED= Feed

FSZ = Farm size

SEED = Fingerlings used
 FUL = Fuel
 FC = Fixed cost
 CHEM = Chemical used
 LAB = Labor
 AGE = Age of farmers

$$TE = L\alpha + \beta_1 FEED + \beta_2 CHEM + \beta_3 FEED + \beta_4 FUL + \beta_5 LAB + \beta_6 FSZ + \beta_7 FC + \beta_8 AGE$$

4. RESULTS

4.1 Descriptive Statistical Analysis of Inputs and Output Variables per Hectare

The parameters used to estimate the technical efficiency include the total fixed cost and total variables cost of shrimp production. Table 1 summarizes the inputs and output variables per hectare for 52 Decision Making Unit (DMU) of White leg shrimp farms. Regarding output production of white leg shrimp, the average production output per kilogram, per hectare of all farms was 21,283 kg/ha, with a range from CNY14,618 to CNY34,858 kg/ha. For the input variables, the results showed that the average cost of fuel is CNY69098 while that of labour is CNY57038. In addition, the average cost of chemicals and feed are CNY24,798 and 187,174 respectively.

Average managers' salary and seed cost are CNY45,673 and 71,408 respectively. Fixed cost ranges from CNY24,567/ha to CNY98,767/ha with an average cost of CNY54,160/ha.

4.2 Efficiency Scores of White Leg Shrimp Farms

The result revealed that 32 out of 52 farms had technical efficiency score (TE < 1), representing 61.5 percent. It means that resources were not well utilized during the production process in these farms. The remaining 20 farms had

technical efficiency score (TE = 1), accounting for 38.5 percent of the farms. Which revealed efficiency in these farms.

4.3 Average Technical Efficiency Scores

Fig. 2 gives an idea on technical efficiency scores of 52 sampled farmers which indicate that an average score of TE of about 83% of the DMUs to Constant Return to Scale (CRS) is 0.831. The remaining 17% indicate that farms have the ability to achieve maximum output quantity of shrimp production using the same inputs and technology applied. The mean Variable Return to Scale Technical Efficiency (VRSTE) and Scale Efficiency (SE) were 0.969 and 0.855 representing 96.9% and 85.5% respectively.

4.4 Percentage Distribution on Return to Scale Efficiency

Fig. 3 shows that the number of technically efficient farms operating on production frontier were 60% Increasing return to scale, about 38% Constant return to scale and 2% Decreasing return to scale.

4.5 Factors Affecting the Technical Efficiency of White Leg Shrimp Farms

The results presented in Table 4 reveals that 53.8% of the variables in technical efficiency can be explained by the variation in the cost of inputs and age as socio-economic variables. The analysis discovered that all inputs variables and age showed negative signs of coefficient on the technical efficiency but exhibited different statistical percentages of significant levels. Seed, chemical, and feed, exhibited 5% level of significance while labor, fixed cost and age showed very strong level of significance at 1% of each on technical efficiency.

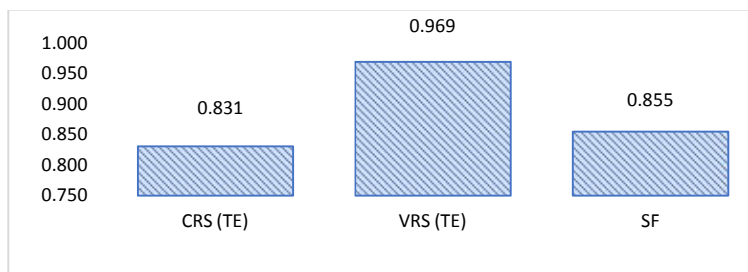


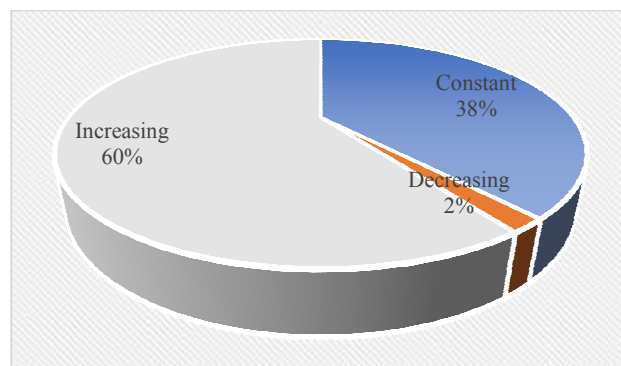
Fig. 2. Average technical efficiency scores

Source: Field survey (2017)

Table 1. Descriptive statistic distribution of cost of inputs and output for technical efficiency analysis

Variables	Minimum	Maximum	Mean	Std. deviation
Output (Y)	14,618	34,858	21,83	3,641
Fuel/electricity (X ₁)	44,978	112,444	69,098	19,178
Labor (X ₂)	58,47	202,399	57,038	30,067
Chemical (X ₃)	44,98	53,973	24,798	11,595
Feed (X ₄)	20,240	260,870	187,174	60,498
Manager salary (X ₅)	36,000	80,000	45,673	11,789
Seed (X ₆)	17,994	105,794	71,408	17,781
Other (X ₇)	14,993	749,663	32,147	11,720
Fixed cost (X ₈)	24,567	98,767	54,160	14,961

Source: Field survey (2017)

**Fig. 3. Return to scale (RTS) (%)**

Source: Field survey

Table 4. Estimated values of the factor affecting technical efficiency of shrimp farms

Variables	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. error	Beta		
(Constant)	1.885	.180		10.489	.000***
Seed/fingerling	-.006	.000	-.262	-2.375	.022**
Chemical	-.006	.000	-.231	-1.999	.052**
Feed	-.007	.000	-.235	-1.923	.061**
Fuel/electricity	-.006	.000	-.124	-1.075	.288
Labor	-.006	.000	-.285	-2.550	.014***
Farm size	.000	.000	-.181	-1.476	.147
Fixed cost	-.006	.000	-.275	-2.481	.017***
Age of farmers	-.006	.002	-.289	-2.628	.012***
F-Statistics	0.258				.000***
R ² Adjusted	0.452				
R ²	0.538				

Dependent Variable: Technical Efficiency, Note: *** signify 1%, ** signify 5%. Data source: Field survey.

4.6 Test for Hypothesis

H₀: High costs of feed and fingerling does not have significant relationship with technical efficiency.

Based on the results showed in Table 4, it can be seen that the costs of feed and fingerling

exhibited strong negative statistical significant level at 5% on technical efficiency. It means that these variables affected technical efficiency level. Based on the finding above, the null hypothesis is rejected in favour of the alternative hypothesis that states that there is a significant relationship between cost of feed and fingerlings on technical efficiency.

5. DISCUSSION

5.1 Technical Efficiency Scores of White Leg Shrimp Farms

A farm is said to be efficient if its technical efficiency score is equal to 1 and inefficiency when its score less than 1. Hence that farm could reduce its input level in order to produce reasonable level of output. The constant return to scale occurs when the output and input-orientated measures would not only produce equivalent measures of technical efficiency but can also be unequal when increasing or decreasing return to scale. The results of study revealed that 32 (62%) out of 52 farms were technically inefficient with a technical efficiency score less than 1. It means that, substantial inefficiencies occurred in shrimp farming in the study area. However, these inefficient farms could improve their efficiency by decreasing their input resources costs in order to produce reasonable level of output. The 20 remaining farms had technical efficiency equal to 1 implying that input resources were well utilized in these farms.

The average technical efficiency scores recorded for CRS, VRS and SE were 0.831, 0.969 and 0.855 respectively. The finding is in line with the results obtained by [8] who analyzed the technical efficiency of white leg shrimp farms using DEA approach in Song Cau district, Phu Yen province, Vietnam and concluded that the technical efficiency for white leg shrimp system under assumption of constant returns to scale, variable returns to scale and scale efficiency were 0.88, 0.94 and 0.95 respectively

The result for technical efficiency scores under CRS implies farms were producing shrimp at approximately 83.1% of the potential frontier production levels at the current status of technological input levels. It also revealed that these operatives could reduce inputs resources (e.g. cost) by 16.9% and still have the ability to achieve the same output quantity of shrimp production using the same inputs and technology applied. Under assumption of VRS, it was discovered that the average technical efficiency score for DMUs was 96.9%, which means that on average, the farms or DMUs could have used 3.1% fewer resources to produce the same amount of output. For the scale efficiency (SE), the means score was 85.5% which implies that the actual scale of production has deviated from the most production scale size by 14.5%.

5.2 Technical Efficiency Determinants

The results of the analysis using OLS function in the regression indicated that 53.8% of the variables in the technical efficiency were as a result of in inputs cost, age and farm size on the technical proficiency. Regarding the factors that influenced the technical efficiency of white leg shrimp farms, the coefficients of all the variables showed negative signs. It means that a unit increase in the independent variable will lead a correspondent decrease in technical efficiency level. Some farmers were not efficient in input utilisation due to lack of technical management. Feeds, fingerlings, chemicals showed a strong negative significant relationship with technical efficiency at 5% level of significance respectively. It means that increase in the cost of these inputs will decrease the production hence decrease in efficiency level. Fixed cost and age of farmers had a negative impact on technical efficiency at 1% significant level. This shows that in terms of age, the older White leg shrimp farmers become, the less technically efficient they may become due to the neglect of new technology. Sometimes, spending many years in shrimp farming does not guarantee high-efficiency level and to the adoption of new technology. This is in agreement with the findings by [18] that old age farmers may find it difficult to invest in new and improved technology.

6. CONCLUSION

The empirical results revealed that the estimated average CRS, VRS and ES are 0.831, 0.969 and 0.855 respectively. Results further showed that in terms of efficiency scale, 61.5% of farmers were operating below the frontier. The degree of technical efficiency of some farmers is low as a result of poor technical management. Farmers were operating at 16.9% Constant Return to Scale (SRC) technical inefficiency. On the other hand, it implies that the priority of producers should focus on increasing their abilities in employing their own or low-cost inputs rather than depending on the high cost of inputs to achieve the potential output. In conclusion, most farmers were fairly efficient. However, there is room for improvement provided if farmers adapt good technical management practices of the most current state of a technological application to achieve maximum efficiency level.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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