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Efficiency Analysis of Pond Fish Culture System in Negeri Kedah and Pulau Pinang: Data Envelopment Analysis Approach

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Abstract

Aquaculture is the solution to the issue of over-exploited for capture fisheries and demand of fish that growing faster. In addition, the available resources keep decreasing and there is a need to fully utilize the resource efficiently in order to achieve sustainable development of aquaculture. Thus, this study estimates the technical efficiency of pond fish culture system in Malaysia. This study employs Data Envelopment Analysis (DEA) approach to analyze the technical efficiency of 121 aquaculture farmer in the states of Kedah and Pulau Pinang and also investigates the determinants affecting the technical efficiency by employing Tobit regression model. The estimated result reveals a mean of technical efficiency was 0.76, which implies that the farmer's efficiency could be further to the extent of 24% in term of output level. The estimated Tobit regression model reveals that the level of education, farm size and species cultured were the factors that significantly affect the level of technical efficiency. Thus, for the development of aquaculture, technical efficiency aspect should be emphasized.

Keywords: aquaculture; data envelopment analysis; pond culture system; technical efficiency.

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1. Introduction

Issue of limited stocks of marine fisheries and fishing beyond the sustainable reproductive capacity is a worldwide issue. This food security issue is now even drawing more concerns due to the increasing demand for fish that caused by the growing world population and increasing household income. In dealing with this issue, the government of Malaysia identified aquaculture as a strategic sector to produce fish for both local consumption and export [1].

Aquaculture is the production of various species of fish, shrimp, shellfish, seaweed and ornamental fish that carried out under controlled conditions in three types of environment which is freshwater, brackishwater, and marine [2]. Aquaculture can be carried out in several culture system which are pond (freshwater and brackishwater), ex-mining pool (freshwater), cage (freshwater, brackishwater, and marine), cement tank (freshwater and brackishwater), canvas tank (freshwater), pen (freshwater and brackishwater), stakes, ropes, and rafts for cockles, mussels, oysters, and seaweeds (marine). In Malaysia, pond culture system is a second biggest contributor to aquaculture production after seaweed. According to [3], seaweed had contributed 50.82 percent of the total aquaculture production while pond culture system had contributed 27.34 percent of the total aquaculture production in 2013.

The total aquaculture production from pond culture system showed positive growth with an average annual increasing of 19 percent for the period of 2003 until 2010. However, since 2011 the total aquaculture production from pond culture system shows a declining trend. The total production of pond culture system declined by about 26 percent from 196,776.66 tons (2010) to 144,966.11 tons (2013). According to [4], the declining of production of pond culture system was due to the scarcity of land that had converted to residential and industrial purpose.

Due the increasing scarcity of resources nowadays, enhancement of productivity through efficient utilizing of existing resources or inputs is very crucial [5]. According to [6], efficient producers are able to produce maximum output by using a given input. In addition, efficient producer will be always ready in dealing with any challenges occur in supply chain management in the future [7]. Therefore, it is very important to measure efficiency of the production and identify the factors that have significant effects on efficiency. The result of this can be provided to policymakers for productivity improvement of aquaculture sector in order to deal with food security issue and for sustainable development of pond culture system.

Thus, this study was carried out to (i) estimate the level of technical efficiency of pond culture system and (ii) determines the factor affecting the level of technical efficiency of pond culture system in states of Kedah and Pulau Pinang. Based on the results of this study, some recommendations are suggested to be used as a reference to policymaker for productivity enhancement via improving technical efficiency level.

2. Materials and Methods

2.1. Data Collection

This study is based on farm-level cross sectional data collected through field survey in 2014. Data collection was conducted in two major pond culture producing states in northern part of Peninsular Malaysia namely, the states of Kedah and Pulau Pinang. The states of Kedah and Pulau Pinang were chosen to represent northern part of Peninsular Malaysia because production from pond culture system in these two states was the highest. Aquaculture farmers of pond culture system were selected purposively because pond culture systems are the main contributor to the total aquaculture production in Malaysia as compared to other culture systems which are cage, ex-mining, tank, pen, and canvas.

The present study uses a stratified random sampling design. According to Department of Fisheries, the total number of aquaculture farmers for pond culture system in Kedah and Pulau Pinang were 804 and 104 farmers respectively. The total numbers of aquaculture farmers are divided according the districts of each state and the top three districts of each state in terms of availability of active pond culture farmers are selected. In Kedah, the selected districts were Kubang Pasu (61 farmers), Kota Setar (25 farmers), and Kuala Muda / Yan (51 farmers). In Pulau Pinang, districts of Barat Daya (17 farmers), Seberang Perai Utara (15 famers), Seberang Perai Tengah (11 farmers) and Seberang Perai Selatan (36 farmers) were selected.

Therefore, the total population of aquaculture farmers that are believed to represent Kedah and Pulau Pinang were 137 and 79 farmers respectively (total of 216 for both states). Based on that, the sample of farmers from each district mentioned above was then randomly selected. Subsequently, a total of 121 aquaculture farmers were successfully interviewed which involved 79 farmers from Kedah and 42 farmers from Pulau Pinang. Only 121 respondents were successfully interviewed due to lack of cooperation from farmers. A structured questionnaire was used to collect information on socio-demographic characteristics, farm-specific information, output produced in a single production season as well as inputs used.

2.2. Analytical Framework

Technical efficiency is based on production function frontier where it show whether the producer is able to obtain the maximum output from a given input [8]. According to [9], technical efficiency is related to the optimum output that can be produce with a given input (output orientation) or minimum input required to produce a given output (input orientation). In other word, technically efficient producer can produce the same output with fewer inputs or can use the same inputs to produce more output.

Most of the previous study used input oriented DEA in estimation of technical efficiency score of aquaculture farms [10-13]. According to [14, 15], this is because aquaculture farms have more control over inputs than output levels. Thus, this study also used the input oriented DEA under CRS specification. According to [16], input oriented measure will be the inverse of the output oriented measure if under CRS specification. Furthermore, TE score obtained from both input and output oriented were same [17, 18].

2.2.1. Data Envelopment Analysis (DEA)

DEA is the non-parametric mathematical programming approach to frontier estimation and was introduced by Charnes, Cooper, and Rhodes in 1978. According to [19], DEA is a linear programming techniques based on the measurement of relative performance of Decision Making Units (DMUs). Efficiency was measured by the ratio of weighted sum of output to weighted sum of input and must be done for each DMU. According to [9], the ratio is from 0 to 1 and if the ratio equal to 1, it will said as best practice unit while if the ratio less than 1 it will categorized as inefficient. According to [20], DEA has the advantage which is it more flexible in handling multiple output and input because there is no parametric specification of the underlying technology was required.

Given Constant Returns to Scale (CRS) assumption, technical efficiency of DMUs can be estimates by solve the envelopment form below:

$$\min_{\theta, \lambda} \quad \theta,$$

$$\text{st} \qquad -y_i + Y\lambda \geq 0, \qquad (1)$$

$$\theta x_i - X\lambda \geq 0,$$

$$\lambda \geq 0,$$

Where θ is a scalar and λ is Nx1 vector of constant. This linear programming required to solve the problem N times, once for each DMU in the sample. The value of θ obtained is the efficiency score for the i^{th} DMU. According to [21], the envelopment form as shown above is referred to as “Farell Efficiency” in recognition of M. J. Farell (1957).

2.2.2. Tobit Regression Analysis

Tobit regression model was first proposed by James Tobin in 1958 and also known as censored regression model. General Tobit regression model can be defined as follows:

$$y_i^* = \beta x_i + u_i, \sim N(0, \sigma^2) \qquad (2)$$

Where y_i* is latent dependent variable for ith firm. x_i is the explanatory variable. β is unknown coefficient to be estimated. u_i are normally distributed with mean, 0 and variance, σ^2. In Tobit regression, this state will occur:

If $y_i^* \leq 0$, the efficiency score (observed dependent variable), $y_i = 0$,

If $y_i^* \geq 1$, the efficiency score (observed dependent variable), $y_i = 1$,

And if $0 < y_i^* < 1$, the efficiency score (observed dependent variable), $y_i = y_i^*$

Therefore, Tobit regression model assumed y_i are the censored value of y_i * with censoring value below 0 and value above 1.

As discussed above, the efficiency score obtained from DEA lies between 1 and 0. Therefore, the efficiency score will become dependent variable in Tobit regression model in order to relate the efficiency score with factors that influence the efficiency. According to [22], when the dependent variable is ranged between 0 and 1 which is the observations on the dependent variable are censored or limited then Tobit regression model is an appropriate estimator.

2.3. Empirical Model Estimation

In DEA, the model used was based on Constant Return to Scale (CRS). The CRS specification was chosen with regard to all companies operating at an optimal scale. Economies of scale for the agricultural sector such as aquaculture are difficult to change in proportion to its size and it has a perfectly competitive market structure. Technical efficiency measure for the ith DMU under assumptions of CRS can be formulated as follow:

Min $\theta, \lambda \quad \theta$,

$$\text{st} \qquad -y_i + (Y_1\lambda_1 + Y_2\lambda_2 + \dots\dots\dots\dots) \geq 0,$$

$$\theta x_{1i} - (X_{11}\lambda_1 + X_{12}\lambda_2 + \dots\dots\dots\dots) \geq 0,$$

$$\theta x_{2i} - (X_{21}\lambda_1 + X_{22}\lambda_2 + \dots\dots\dots\dots) \geq 0, \qquad (3)$$

$$\theta x_{3i} - (X_{31}\lambda_1 + X_{32}\lambda_2 + \dots\dots\dots\dots) \geq 0,$$

$$\theta x_{4i} - (X_{41}\lambda_1 + X_{42}\lambda_2 + \dots\dots\dots\dots) \geq 0,$$

$$\theta x_{5i} - (X_{51}\lambda_1 + X_{52}\lambda_2 + \dots\dots\dots\dots) \geq 0,$$

$$\lambda \geq 0,$$

$$(\lambda = i = 1, 2 \dots)$$

Where i is for the ith DMU or respondent. Y is the output while X_1, X_2, X_3, X_4, and X_5 are inputs which are farm size, seed, feed, labour, and other inputs respectively. Computer programme, DEAP Version 2.1 was used to estimates the technical efficiency score.

Table 1 shows the description of the variable involved in DEA that consist of one output and five inputs. Output (Y) and all input except for farm size (X_1) were measured in monetary term (Ringgit Malaysia). Output (Y) refers to value of aquaculture production produced by farmers for one hectare in single cycle, measure in Ringgit. Input of farm size (X_1) represents total size of aquaculture farm, measured in hectare.

Seed (X_2) is measured as the quantity of the juvenile of cultured species stocked for one hectare in single cycle. Feed (X_3) is measured as the quantity of feed used for one hectare in single cycle. The labour (X_4) variable represented the expenses on wage for one hectare in single cycle. Other inputs (X_5) included the sum of costs of maintenance, electricity, fuel, transportation, fertilizer, lime, medicine, and other related such as negligible fixed costs.

Table 1: Description of variables in DEA

Variable name in the model	Description	Measurement unit
Dependent variable		
Output (Y)	Total value of aquaculture production per hectare per cycle	Ringgit Malaysia
Independent variable		
Farm size (X_1)	Size of aquaculture farm	Hectare
Seed (X_2)	Total seed stocked in aquaculture farm per hectare per cycle	Ringgit Malaysia
Feed (X_3)	Total feed utilized per hectare per cycle	Ringgit Malaysia
Labour (X_4)	Total wage spend per hectare per cycle	Ringgit Malaysia
Other inputs (X_5)	Total other input involved per hectare per cycle	Ringgit Malaysia

In the second stage of the analysis, the Tobit regression model can be expressed as follows:

$$y_i = \beta_0 + \beta_1 Z_1 + \beta_2 Z_2 + \beta_3 Z_3 + \beta_4 Z_4 + \beta_5 Z_5 + \beta_6 Z_6 + \beta_7 Z_7 + \beta_8 Z_8 + u_i,\ u_i \sim N(0,\sigma^2) \quad (4)$$

Where y_i is technical efficiency score for ith DMU or firm or respondent. Z_1 is age. Z_2 is education. Z_3 is experience. Z_4 is knowledge. Z_5 is farm size. Z_6 is farm ownership. Z_7 is capital source. Z_8 is for species. u_i represent normal distributed error term. The Tobit regression was done through Maximum Likelihood (ML) method. The definitions and measurements for variable Z_1 to Z_8 are presented in Table 2.

Age of farmers are expected may have both positive and negative effect on technical efficiency. First, older farmers may be more efficient when relate to have more experience over time. However, older farmer may become less efficient due to unwilling to adopt new technology introduced. Basically, education are expected to have positive impact on technical efficiency. On other hand, the high educational farmers may be less efficient because have less time to manage farm operation due to employment opportunity off farm. Knowledge related to aquaculture activity are expected to have positive impact on technical efficiency.

Several farm-specific factors are regressed to access their impact on technical efficiency. The farm area are intended for examine the effect of farm size on technical efficiency. The status ownership of aquaculture farm is indicates whether the farmer owns or rents the farm. Farmers that own the farm are expected to be more efficient. The capital also is a dummy variable, whether the farmers self-financing or make a loan in order to perform farm operation. Self-financing farmer may be more efficient. Farmers that culture high value species are expected to be more efficient.

Table 2: Description of variables in Tobit.

Variable name in the model	Description	Measurement unit
Socio-demographic variables		
Age (Z_1)	Age of aquaculture farmers	Years
Education (Z_2)	Level of education of aquaculture farmers	Level
Experience (Z_3)	Years the farmers involved in aquaculture production	Years
Knowledge (Z_4)	Level of knowledge that related to aquaculture production activity	Level
Farm-specific variables		
Farm size (Z_5)	Size of aquaculture farm	Hectare
Farm ownership (Z_6)	Ownership status of aquaculture farm (1 = owner, and 0 = otherwise)	Dummy
Capital source (Z_7)	Source of capital to perform aquaculture operation (1 = owner, and 0 = otherwise)	Dummy
Species (Z_8)	Represent the species cultured (1 = Catfish, 2 = Tilapia, 3 = Sea bass, 4 = White shrimp, 5 = Tiger prawn)	Rank

3. Results and Discussions

3.1. Sample Characteristic

Table 3 shows the descriptive statistic of the data collected. The average value of output produced for pond culture system is about RM195, 283 per hectare. The mean costs of seed, feed, labor, and other input are RM31,433, RM59,838, RM8,978, and RM13,436 respectively. Based on that, the costs of seed and feed found as two major costs in aquaculture production. Both seed and feed constitutes 28 percent and more than 50 percent of production costs respectively. Labor costs is the lowest costs due to mostly fish farmers perform the farm operation themselves with help from their family members and just start hiring workers when the needs arise [23]. Other inputs costs are on maintenance, electricity, fuel, transportation, fertilizer, lime, medicine, and other related such as negligible fixed costs.

Table 3 also shows that the farmers aged less than 50 years old. The farmers also found attained the highest educational level at secondary school and this show that the illiteracy among aquaculture farmers is decreasing. In term of experience, average time for farmers spent in aquaculture activity is 10 years. Furthermore, also found that aquaculture farmer had a good level of aquaculture knowledge where most of the farmers have level of aquaculture knowledge at 60 -74 percent. Aquaculture knowledge is measure based on knowledge that related to aquaculture operation such as water management, and food management. The mean of farm size are about 2.54 hectare and range from a minimum of 0.02 hectare to a maximum of 17.50 hectares. Most of the farmers rent the farm and self-financed to perform farm operation. There are five species cultured which are catfish, tilapia, sea bass, white shrimp and tiger prawn.

Table 3: Summary of descriptive statistic for variable

Variable name	Mean	Standard deviation	Minimum	Maximum
Output				
Production (RM/ha)	195, 283	198, 766	4, 500	1, 050, 000
Input				
Seed (RM/ha)	31, 433	47, 244	750	400, 000
Feed (RM/ha)	59, 838	71, 515	331	330, 240
Labour (RM/ha)	8, 978	15, 770	0	108, 000
Other input (RM/ha)	13, 436	22, 067	222	160, 667
Socio-demographic characteristics				
Age (years)	45	10.86	23	70
Educational level	2.98	0.612	1	4
Experience (years)	10	6.63	1	30
Knowledge level (%)	67.11	12.36	40	100
Farm-specific information				
Farm size (ha)	2.54	3.47	0.02	17.50
Farm ownership	0.54	0.50	0	1
Capital source	0.79	0.41	0	1
Species	2.38	1.26	1	5

Note: Average exchange rate in 2016: US$1=RM3.99

3.2. Technical Efficiency Estimates

The result reveals that the estimated technical efficiency (TE) score of pond culture farmers under CRS in the study area was range from 0.20 to 1.00, with a mean of 0.76. This implies that, on average, the farmers can reduce input-use to the extent of 24 percent without compromising on the level of output (input orientation) or the farmers can increase their output level to the extent of 24 percent without reducing the level of input (output orientation). Figure 1 depicts the frequency distribution of the estimated TE score. The distribution shows that 42.1 percent of the pond culture farmers were identified as fully technically efficient. Majority (71.9%) of the pond culture farmers were found to have TE scores above 0.5. These results showed that majority of pond culture farmers in study area were performed relatively well in their farm operation.

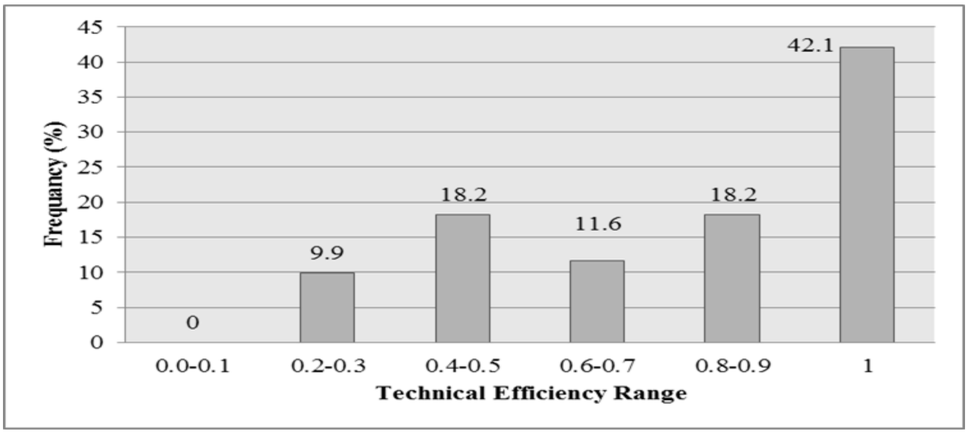

Figure 1: Frequency distribution of technical efficiency score for pond culture system

3.3. Determinant of Technical Efficiency

Table 4 showed the results of Tobit regression model. Goodness of fit test for this Tobit regression model were found significant at 1% level with pseudo R^2 value equal to 0.2054.

Table 4: Determinants of technical efficiency of pond culture system

	Technical Efficiency			
Variables	Coefficients	Robust standard error	t-value	*p*-value
Age	0.015	0.030	0.49	0.623
Age^2	-0.0001	0.0003	-0.49	0.623
1/**Education**	0.924	0.369	2.50	0.014**
1/**Experience**	0.247	0.200	1.24	0.218
Knowledge	0.009	0.026	0.35	0.729
Knowledge^2	-0.0001	0.0002	-0.30	0.763
1/Farm size	0.054	0.015	3.55	0.001*
Farm ownership	0.032	0.076	0.42	0.675
Capital source	-0.058	0.086	-0.68	0.500
Species	0.140	0.316	4.42	0.000*
Constant	-0.611	1.238	-0.49	0.623
Log pseudo likelihood	-59.878			

Notes: * significant at 1% level, ** significant at 5% level, *** significant at 10% level.

Results showed that education, farm size and species were the key determinants in affecting technical efficiency of pond culture system in study area. Level education was estimated to have significant negative effect on technical efficiency. This showed that as the level of education increase by 1 percent, the technical efficiency is decreased by 0.924 units. This is similar with the result obtained by [19] that identify the determinant of inefficiency of earthen pond and concrete pond in Nigeria.

For farm-specific variables, size of farm and species cultured were found to have significant effect on technical efficiency of pond culture system. Farm size was estimated to have negative effect on technical efficiency at 1 percent significant level. This result implies that the small farms are technically more efficient than larger one. This confirms to the results obtained from work by [24- 27, 1]. This is perhaps due to small farms are more easy to manage especially in term of managing the input resources compare to larger farms that are difficult to monitor.

The species variable, reflecting the value of cultured species based on market price, has a significant positive effect on technical efficiency at 1 percent significant level. Species ranked from low market value to high market value which is starts with catfish, red tilapia, sea bass, white shrimp, and tiger prawn. The result reveals that as the value of species cultured increase technical efficiency also increased. Thus, the selection of species to be cultured also need to be consider in order to achieved efficiency in production.

Other variable such as age, experience, knowledge, farm ownership, and capital source were found insignificant effect to technical efficiency. In the model, variable age and age^2 are maintained even found insignificant. This is due to omitting of age and age^2 will create omitted variable bias [28]. Thus, to avoid the bias, the age and age^2 are keeping in the model. Same goes to variable knowledge and knowledge^2.

4. Limitations of the study

This study is limited to the production of pond culture system only. Others culture systems such as cage and tank is not included in the study. Thus, the results from this study may not be representative the aquaculture sector in general. Furthermore, the study only involved two states in the north part of Peninsular Malaysia namely the states of Kedah and Pulau Pinang. So, this study cannot be generalized to represent pond culture system in Malaysia.

5. Conclusion and Recommendations

In the present study, the level of technical efficiency of pond culture system in states of Kedah and Pulau Pinang and its determinant were estimated by using DEA and Tobit regression model. The findings revealed that the mean technical efficiency of sampled pond culture system is at 76 percent. This implies that the production from pond culture system have chance of 24 percent to increase through improving the level of technical efficiency. It is only 42.1 percent of the pond culture farmers were identified as fully technically efficient. This suggests that there is a need for the government, in particularly the Department of Fisheries to take drastic measures to increase the technical efficiency level among pond culture farmers, thus can increase the aquaculture productivity of pond culture system.

The results from Tobit regression model indicate that level of education, size of farm, and value of species cultured were the factors significantly influencing the level of technical efficiency of pond culture system in Kedah and Pulau Pinang. Farmers may need policy support and government cooperation especially in term of pricing since result reveals high market price species such as tiger prawn leads to high technical efficiency. Therefore, the recommendation is that government may increase the market price of species culture thus can give high return to farmers. In addition, the extension agency need take an action to promote high value species to be cultured among farmers. Furthermore, policies leading to the improvement of investment through private and public partnerships also would be favorable for improving the technical efficiency especially for instant capital source and promotes commercialization of aquaculture.

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