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Malaysian white shrimp *(P. vannamei)* aquaculture: an application of stochastic frontier analysis on technical efficiency

[1*]Ghee-Thean, L., [2]Islam, G.M.N. and [3]Ismail, M.M.

[1]*Section of Economics, School of Social Sciences, Universiti Sains Malaysia, 11800 Pulau Pinang, Malaysia*

[2]*School of Economics, Finance and Banking, College of Business, Universiti Utara Malaysia, 06010 Sintok, Kedah, Malaysia*

[3]*Institute of Agricultural and Food Policy Studies, Universiti Putra Malaysia, Putra Infoport, Jalan Kajang Puchong, 43400, Serdang, Selangor, Malaysia*

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Abstract

Shrimp aquaculture is playing a vital role in Malaysian agriculture, especially its increasing contribution to economic growth. White shrimp aquaculture is not only the key player in brackish water shrimp aquaculture but also the largest contributor to Malaysian shrimp aquaculture. This study estimates technical efficiency and investigates factors affecting technical inefficiency of Malaysian white shrimp aquaculture. Stochastic frontier analysis with trans-log production model is applied in this study. Malaysian white shrimp aquaculture farmers have achieved an estimated average technical efficiency of 81.2 percent. Land ownership, shrimp seed size and seminar are the factors having significant impacts on technical inefficiency and thereby playing important roles in improving technical efficiency of this industry. This study suggests that seminar should be conducted by shrimp farming extension agents to enhance knowledge of shrimp farmers. Malaysian government should allocate lands and, provide technical and financial supports to develop this industry. Subsidy on shrimp seed should be also given to encourage shrimp farmers to embrace and adopt quality shrimp seed for their farms.

Introduction

Malaysia, a country with around 28 million people in 2013, fish food is always the necessary source of animal protein to their community. Fisheries sector is responsible in providing food security to the growing population. Malaysia, surrounded by South China Sea and the Strait of Malacca, coupled with development of aquaculture industry, this country is rich in fish resource.

Today, global and domestic increasing demand of shrimp product has due to the changes of tastes and preferences of consumers. Report showed that people are more likely to consume white meat (shrimp and fish product) rather than red meat (ruminant products). Outbreaks of mad cow disease and hand, foot and mouth disease (HFMD) is believed causing the switching (Amri and Kanna, 2011; Ismail and Abdullah, 2013).

Commercial shrimp aquaculture in many countries, including Malaysia has been prompted due to increasing demand of international market and decreasing volume of shrimp catch (Ismail and Abdullah, 2013). Therefore, brackish water shrimp culture industry is playing increasingly important role in Malaysian aquaculture. In the Third National Agricultural Policy (NAP3), Malaysian government has promoted brackish water shrimp culture under taking a number of initiatives (Ministry of Agriculture Malaysia, 2003). Targeted shrimp production in 2010 was set at 180,000 metric tons or RM 4.3 billion (Islam *et al*., 2011). However, the targeted volume of supply was not materialized.

Malaysian brackish water white shrimp aquaculture industry performed a sustainable growth of production from 2002 to 2010 (although slightly decline 4.84 percent in 2003) (Annual Fisheries Statistics, 2002-2012) (Table 1). However, productions of this industry declined 12.68 percent and 18.78 percent in 2011 and 2012, respectively. Additionally, the productivity has also showed in a declining trend after 2010. Productivity of shrimp aquaculture is measured in total yield (metric tons) per total size of shrimp ponds (hectare). According to Amri and Kanna (2011), the stock density of Malaysian white shrimp aquaculture is 80 post larvae per meter square, and the shrimp pond is equipped with water pumps for exchange water purpose and aeration. This implies that Malaysian white shrimp aquaculture is applying intensive white shrimp culture

*Corresponding author.
Email: *limgheethean@usm.my*

Table 1. Annual Malaysian white shrimp production

Year	White shrimp (metric tons)	Pond size (ha)	Productivity (metric tons/ha/year)	Productivity (metric tons/ha/crop)
2002	844.46	246.89	3.420	1.710
2003	803.59	192.21	4.181	2.091
2004	5117.49	1201.59	4.259	2.130
2005	11497.80	2391.37	4.808	2.404
2006	18600.59	2733.71	6.804	3.402
2007	23737.40	4808.63	4.936	2.468
2008	37544.31	4691.23	8.003	4.002
2009	52926.42	4823.63	10.972	5.486
2010	69084.10	5132.85	13.459	6.730
2011	60322.01	5828.71	10.349	5.175
2012	48991.81	5349.17	9.159	4.580

Source: Annual Fisheries Statistics, 2002 – 2012

system. According to FAO (Food and Agriculture Organization of United Nations) (2014), productivity of intensive white shrimp culture system is around 7 to 20 metric tons/ha/crop and the productivity could be rose up to a maximum of 30 to 35 metric tons/ha/crop. Productivity of Malaysian white shrimp aquaculture is around 1.71 to 6.73 tons/ha/crop (or 3.42 to 13.459 metric tons/ha/year). It seems that productivity of Malaysian white shrimp aquaculture not even achieved the minimum productivity of intensive white shrimp culture system that stated by FAO. Furthermore, productivity of Malaysian white shrimp farmers was found unable to compete with productivities of other ASEAN countries. According to Taw's study (as cited in Nur, 2007), productivities of Indonesia is around 10 to 15 metric tons/ha/year. Vietnam and Thailand brackish water white shrimp aquaculture are around 10 to 20 metric tons/ha/crop and 24 metric tons/ha/crop, respectively (Wyban, 2007; Hung and Quy, 2013). Additionally, Hashim (2008) showed that productivity of Malaysian white shrimp aquaculture could reach 8 to 12 metric tons/ ha/ crop. The relationship of productivity and technical efficiency is positive. Hence, the low productivity of Malaysian white shrimp aquaculture implies that this industry is facing inefficiency of white shrimp production. The objective of this study is to estimate technical efficiency and to investigate factors affecting technical inefficiency of Malaysian white shrimp farms. This study also measured input elasticity and return to scale of shrimp farm operation.

Materials and Methods

This study employs information collected from survey interview. Total number of shrimp farmers in Malaysia is around 740 persons. Thus, a proportionate random sample of 100 respondents (13.5 percent of the total shrimp farmers) engaged in Malaysian shrimp aquaculture were randomly selected for the survey. Survey area comprised several states of East and West Malaysia. States surveyed in West Malaysia are Penang, Perak, Selangor, Pahang and Johor. In East Malaysia, states surveyed are Sabah and Sarawak. Although the survey interview has covered seven states of white shrimp farms, however, analyses on examining technical efficiency level by states are unable to be conducted. It is because population and sample size of white shrimp farms located in some of the surveyed states (Pahang and Sarawak) are too small. Besides, Malaysian brackish water white shrimp farms apply an identical shrimp aquaculture operating system (Amri and Kanna, 2011). Hence, the information collected through survey interview is considered as homogenous data across states in Malaysia.

Some calculations on inputs used in analysis are discussed briefly. All the inputs (labour, feed and seed) are completely managed by shrimp farmers. This study measure all the inputs used in a cycle in the form of quantity per total size of shrimp ponds. Labour is measured in number of labour employed multiply number of farming days, and then divided by size of shrimp pond (ha). Feed is measured in kilogram of shrimp pellet divided by size of shrimp pond (ha). Seed is measured in number of stocked shrimp seed divided by size of shrimp pond (ha).

This study employs Frontier 4.1d developed by Coelli (1996) for input oriented technical efficiency analysis. This tool has been applied in global agricultural economic studies extensively. In technical efficiency analysis, generalized likelihood ratio test has to be conducted prior to stochastic frontier analysis (Coelli *et al.*, 1998). Two hypotheses are tested in this study. The first null hypothesis is the statement of "Cobb Douglas production model is preferred". This hypothesis is conducted to justify the type of production model for measuring technical efficiency. Eventually, this study has chosen trans-log production model for stochastic frontier analysis. The second null hypothesis is the statement of "no inefficiency effect". This hypothesis is conducted to check the validity of inefficiency effect. Model of trans-log production function is specified as follows,

$$\ln Y_j = \beta_0 + \beta_A \ln A_j + \beta_B \ln B_j + \beta_C \ln C_j + 0.5\beta_{AA} (\ln A_j)^2 + 0.5\beta_{BB} (\ln B_j)^2 + 0.5\beta_{CC} (\ln A_j \ln B_j) + \beta_{AC} (\ln A_j \ln C_j) + \beta_{BC} (\ln B_j \ln C_j) + v_j - u_j$$

where Y_j denotes yield of jth farm per hectare (pond size) in a cycle, A denotes labour, B denotes feed and C denotes shrimp seed. Besides, v_j denotes error term and uj denotes a non-negative inefficiency effect with both v_j and u_j are assumed to be independent and identically normal distributed.

This study not only measures technical efficiency level, but also determines factors affecting technical inefficiency. Understanding technical efficiency level and factors affecting technical inefficiency are essential for purpose to improve efficiency performance of Malaysian white shrimp aquaculture. Analysis on factors affecting technical inefficiency is also conducted by frontier 4.1d. A technical inefficiency model has been formed to determine the factors affecting technical inefficiency. Technical inefficiency model that proposed by Battese and Coelli (1995) is applied, which can be addressed as follows,

$$uj = \delta_0 + \delta_1 F_j + \delta_2 G_j + \delta_3 H_j + \delta_4 I_j + \delta_5 J_j + \delta_6 K_j + W_j$$

where u_j denotes technical inefficiency of jth farm, F_j denotes fulltime dummy, G_j denotes experience, Hj denotes seminar dummy, I_j denotes land ownership dummy, J_j denotes average age of pond, K_j denotes size of shrimp seed and finally W_j denotes a normally distributed error term.

Besides measuring technical efficiency level and factor affecting technical inefficiency, input elasticity and return to scale of Malaysian shrimp industry production are also highlighted in this study. Elasticity measures the impact of quantity of input change in affecting quantity of output responsiveness change. Despite elasticity is not likely to be interpreted directly from coefficients of trans-log production function, as Cobb-Douglas production function (Sharma and Leung, 1999), the elasticity of trans-log production function can easily be estimated as follows,

$$\ln Yj = \beta_0 + \beta_A \ln A_j + \beta_B \ln B_j + \beta_C \ln C_j + 0.5\,\beta_{AA} (\ln A_j)^2 + 0.5\,\beta_{BB} (\ln B_j)^2 + 0.5\,\beta_{CC} (\ln C_j)^2 + \beta_{AB} (\ln A_j \ln B_j) + \beta_{AC} (\ln A_j \ln C_j) + \beta_{BC} (\ln B_j \ln C_j) + v_j - u_j$$

$$\text{Elasticity of input A, eA} = \frac{\partial \ln Y}{\partial \ln A}$$

$$= \beta_A + \beta_{AA} \ln A + \beta_{AB} \ln B + \beta_{AC} \ln C$$

where elasticity of input A, eA can be interpreted as responsiveness of changes in yield due to changes of input A. For instance, if eA equal to 0.69 suggesting that one percent increase of quantity of input A will lead to 0.69 percent increase of the yield. In addition, return to scale of a production can be defined as the sensitivity of changes in output as a result of changes in all inputs applied. For instance, if return to scale of shrimp aquaculture industry is estimated 1.069, indicating that when all the inputs applied are increased by one percent, it will lead to 1.069 percent increase in shrimp yield. This phenomenon can be identified as increasing return to scale because the value is larger than 1. Return to scale can be measured by summing all input elasticity of inputs.

Results and Discussion

In this study, among 100 shrimp farms from five states of Malaysia, these shrimp farms have been operated at least 2 years (Table 2). Some of them have even been operated more than 20 years. Malaysian brackish water white shrimp farms have applied an identical operating system. However, the practices of inputs applied in Malaysian shrimp farms are found slightly different according to their own conditions. There is a brief descriptive analysis of these Malaysian white shrimp farms in Table 2.

Result of generalized likelihood ratio test shows that the first null hypothesis was rejected in favour of trans-log production model (Table 3). After ensuring the type of production model, trans-log production model was applied to run the next generalized likelihood ratio test on the second hypothesis, which is the statement of “no inefficiency effect”. The hypothesis which is conducted to highlight the validity of inefficiency effect in technical efficiency analysis and this second null hypothesis was also rejected.

By using trans-log production model, stochastic frontier analysis was conducted to measure technical efficiency. Result shows that an estimated average of technical efficiency of Malaysian shrimp farmers is 81.2 percent (Table 4). The lowest technical efficiency achieved by Malaysian shrimp farmers is found as low as 26.8 percent. On the other hand, the highest technical efficiency of Malaysian shrimp farmer is recorded 94.7 percent. Therefore, result of analysis shows that technical efficiency level of Malaysian surveyed white shrimps farmers ranged from 0.268 to 0.947. Majority of surveyed shrimp farmers (52 percent) are found achieved 0.801 – 0.9 technical efficiency level.

Besides obtaining the apparent result of

Table 2. Descriptive statistics of Malaysia shrimp aquaculture industry

Variables	Mean/ Quantity*	Maximum	Min
Yield (kg/ha)	8,256	30,000	506
Labour (days/ha)	141	10,000	6
Feed (kg/ha)	10,696	82,962	225
Seed (qty./ha)	840,466	6,000,000	17,538
Pond size (ha)	8.62	100	0.5
[a] Fulltime (persons)	82*	-	-
Experience (years)	11	30	1
[b] Seminar (persons)	39*	-	-
[c] Land ownership (persons)	25*	-	-
Age of pond (years)	9.67	28	2
Shrimp seed size (cm)	1	3	0.5

Note: a Number of respondents who work in their farms in full time.
b Number of respondents who have ever attended seminar training.
c Number of respondents who own their farm lands.

Table 3. Generalized likelihood ratio test of hypothesis for stochastic production model

Test of null hypothesis	Log likelihood of H_o	Log likelihood of H_1	Test statistic, λ	DF	Critical value at 10 percent	Decision
Cobb Douglas is preferred	-64.009	-48.877	30.264	6	10.645	Reject H_o
No inefficiency effect	-57.524	-48.877	17.295	8	12.737*	Reject H_o

Note: * represents critical value that referred in Table 1 of Kodde and Palm (1986).

Malaysian white shrimp aquaculture, this study attempts to discover more information on efficiency performance of technical efficiency by states. This study reveals that Pahang shrimp farmers have obtained the best technical efficiency performance by having an estimated average technical efficiency of 91.3 percent, followed by Sarawak and Johor (Table 4). However, result shows that an estimated average technical efficiency of Perak shrimp farmers is only 49.6 percent, which is the lowest record.

In this study, number of surveyed shrimp farmers in every state is not equal, thus, a more detailed result has been discussed. 26 percent of surveyed shrimp farmers achieve not more than 80 percent technical efficiency (Table 4). However, there is only 3 percent of surveyed shrimp farmers achieve not more than 40 percent technical efficiency. 22 percent of surveyed shrimp farmers achieve more than 90 percent technical efficiency.

This study further discusses the result of stochastic frontier analysis using trans-log production model. Trans-log production model was estimated by maximum likelihood, implies response of the best practiced white shrimp farms units against their outputs. There are five estimated coefficients show positive signs, suggesting that Malaysia shrimp yield is probably increasing function of variable inputs (Serin *et al.,* 2008) (Table 5). Besides, by using trans-log production function, this results obtained not only insignificance and unexpected signs of coefficient estimates, but also the presence of undesirable statistical properties (like multi collinearity and heteroskedasticity). On the other hand, scholars opined that the coefficient estimates of production function are not of great concern in technical efficiency analysis, the objective of technical efficiency analysis is to measure efficiency performance (Hallam and Machado, 1996; Serin *et al.*, 2008). Gamma value with 0.668 indicates that technical inefficiency is found 66.8 percent affected by this set of factors.

This study reveals that all factors affecting technical inefficiency are found having expected effects (showing negative signs) to technical inefficiency (Table5), consistent with findings of previous research (Binuomote *et al.*, 2008; Ekunwe *et al.,* 2008; Islam *et al.*, 2014) (Table 5). However, three factors (seminar, land ownership and shrimp seed size) are found significantly affecting technical inefficiency. Seminar is found to have negative effect on technical inefficiency, suggesting that a shrimp farmer who has ever attended seminar on shrimp aquaculture is more technically efficient than those who have never attend any seminar before. Seminar would improve knowledge and skill of shrimp farmers through training given (Hussain *et al.*, 1994).

Table 4. Frequency distribution of technical efficiency by state

Efficiency	Penang	Perak	Selangor	Pahang	Johor	Sabah	Sarawak	TOTAL
0.001 - 0.1	0	0	0	0	0	0	0	0
0.101 - 0.2	0	0	0	0	0	0	0	0
0.201 - 0.3	1	0	0	0	0	0	0	1
0.301 - 0.4	0	0	1	0	0	1	0	2
0.401 - 0.5	0	3	1	0	0	0	0	4
0.501 - 0.6	0	1	0	0	0	0	0	1
0.601 - 0.7	0	3	1	0	1	1	0	6
0.701 - 0.8	1	4	4	0	3	0	0	12
0.801 - 0.9	4	15	15	1	8	6	3	52
0.901 - 1	3	4	4	2	4	3	2	22
Total	9	30	26	3	16	11	5	100
Mean	0.791	0.790	0.805	0.913	0.843	0.808	0.870	0.812
Max	0.940	0.943	0.935	0.937	0.927	0.947	0.913	0.947
Min	0.268	0.475	0.355	0.892	0.621	0.313	0.824	0.268
Standard Deviation	0.203	0.136	0.137	0.023	0.081	0.185	0.040	0.137

Development of human resources (knowledge, and skills of management and organizing) through seminar, extension and training activity could enhance growth of productivity and thereby improve technical change or innovation of the industry (Hassanpour *et al.* 2010; Hassanpour, 2011). In Malaysia, shrimp farming seminar is usually organized by department of fisheries, shrimp pellet manufacturer and shrimp seed nursery. In addition, during the survey interview a number of respondents mentioned that they had attended some seminars in Thailand to learn the latest shrimp farming technology and farming skills. With the knowledge they earned, they applied the practice in their shrimp farms. The finding of this study is in full agreement with the previous findings (Singh *et al.*, 2009; Ghee-Thean *et al.*, 2012; Ghee-Thean and Ismail, 2013; Ismail *et al.*, 2013).

Land ownership is found to have negative effect on technical inefficiency, suggesting that a shrimp farmer who possesses a land by himself tends to perform more technically efficient than those who rent a land for shrimp aquaculture operation (Table5). Shrimp farmers who operate their farms on their own lands might have greater advantage than those who don't own the lands of their shrimp farms. Although owning a piece of land involves great cost and financial commitment. However in the long run, they would benefit from the land once their financial commitments have been cleared. Conversely, those who rent the land of shrimp farm, they have to pay land rental. Land lord has the right to increase the rental from time to time and to suspend the tenancy agreement. Unfortunately, this finding is found contrast with finding of Iinuma *et al*. (1999).

Shrimp seed size is found to have significant negative impact on technical inefficiency (Table5), suggesting that the larger size of shrimp seed farmers apply then the more technical efficient they are. There are many nurseries provide shrimp seed for Malaysian shrimp farms and price of shrimp seed goes up according to its size. Larger shrimp seed costs more, but it is also more resistant to disease and illness. Therefore, larger shrimp seed could reduce death rate of shrimp. This finding is found consistent with finding of Alam (2011), implying that the larger of shrimp seed size, could reduce technical inefficiency. Further research is recommended by this study on the issue of using larger size of shrimp seed to enhance yield of shrimp farm.

Beside the analysis of technical efficiency level and factor affecting technical inefficiency, input elasticity of labour has been investigated and it has showed a negative value, suggesting that increase in labour (labour-days) would only cause the decrease in shrimp yield (Table5). This finding is consistent with previous findings (Bamiro *et al.*, 2006; Serin *et al.*, 2008; Ghee-Thean *et al.*, 2012; Piya *et al.*, 2012). This finding could be interpreted as outcome of excess labour employment (Ghee-Thean *et al.*, 2012). This incident would be caused by employing labours that lack of experience or unskilled labours. Although the labours ask for lower pay than experienced and skilled labours, but they are inefficient and spending more time that lead to the shrimp farms have to employ more labours. Besides, the joining of unskilled or inexperience family members in shrimp farm operation, also contributes to the finding (Ghee-Thean *et al.*, 2012). Excess of labour employment not only burdens the expenses of shrimp farm operation, but also pulls down the technical efficiency level of a farm.

Input elasticity of feed is a positive value

Table 5. Estimated translog production and inefficiency model

Variable	Coefficient	Standard Error	T Ratio
Constant	-15.592	1.297	-12.018***
Labour	1.965	0.993	1.978**
Feed	-0.1760	0.635	-0.277
Seed	2.400	0.358	6.695***
(Labour)2	-0.334	0.096	-3.487***
(Feed)2	0.072	0.063	1.143
(Seed)2	0.061	0.047	1.285
(Labour)(Feed)	0.339	0.098	3.450***
(Labour)(Seed)	-0.257	0.099	-2.589***
(Feed)(Seed)	-0.149	0.044	-3.352***
Inefficiency model			
Constant	2.247	0.889	2.527**
Fulltime	-0.250	0.499	-0.502
Experience	-0.006	0.036	-0.160
Seminar	-0.888	0.475	-1.868*
Land ownership	-1.315	0.696	-1.889*
Age of pond	-0.074	0.046	-1.608
Shrimp seed size	-3.730	1.600	-2.331**
Sigma-squared	0.337	0.121	2.784***
Gamma	0.668	0.145	4.614***
Log likelihood	-48.877		

*Statistical significant at 0.1 level
**Statistical significant at 0.05 level
***Statistical significant at 0.01 level

which less than one (0.686), indicating that one percent increase in feed would only lead to 0.686 percent increase in shrimp yield. This finding is found similar with previous findings (Bamiro *et al*., 2006; Binuomote *et al*., 2008; Islam *et al*., 2014). Theoretically, increase the shrimp yield by increasing the giving of feed would be considerable. However, this incident directly constrained by price of feed. Cost of feed is known as the most important cost in shrimp farming operation (Kuhn *et al*., 2010). It is always the greatest challenge faced by the shrimp farmers.

Input elasticity of seed is 1.52, indicating that one percent increase in shrimp seed stocked would lead to 1.52 percent increase in shrimp yield. The positive value of seed elasticity is in line with previous findings (Bakhsh *et al*., 2006; Binuomote *et al*., 2008; Ghee-Thean, *et al*., 2012; Piya *et al*., 2012; Islam *et al*., 2013). This result indicates that shrimp seed, as the most important input, has a very direct impact on shrimp yield. Subject to outbreak of diseases, farming technology and size of pond, the more shrimp seed stocked by shrimp farmer typically encourage the more yields. This finding shows that Malaysian shrimp farmers are generally conservative and risk averse with less shrimp seed stocked.

An estimated return to scale of Malaysian white shrimp aquaculture is 0.556, implying that summation of elasticity of all the inputs (labour, feed and seed) is less than one. Hence, Malaysian white shrimp aquaculture has been recognized as a decreasing return to scale industry with an increase one percent of all inputs (labour, feed and seed) would only lead to production of shrimp farms to be increased by only 0.556 percent.

Conclusion

This study shows that Malaysian white shrimp aquaculture achieves 81.2 percent of technical efficiency level. Besides, Pahang shrimp farms are found having the highest estimated average technical efficiency level (91.3%). Seminar, land ownership and shrimp seed size are the factors showing significant effects on technical inefficiency, proposing these three factors are playing vital role in improving the technical inefficiency. Thus, this study attempts to provide some implications on enhancing efficiency performance of Malaysian white shrimp aquaculture by suggesting that seminar should be frequently conducted by shrimp aquaculture extension agents with the purpose to deliver useful knowledge and information to shrimp farmers (Agahi *et al*., 2008). Furthermore, organizing seminars that invite local and abroad experienced shrimp aquaculture experts as speakers of seminar would be a good idea to attract farmers to attend and improve farmers' skill and knowledge. Malaysian government should assist the shrimp farmers to own the lands of their shrimp farms by providing financial support or allocating lands for the high yield farms, as well as the potential shrimp farms. Besides, this study reveals that size of shrimp seed has a significant positive impact on technical efficiency. Hence, subsidy on shrimp seed should be given by the government to encourage shrimp farmers to embrace and adopt quality shrimp seed in order to improve the efficiency performance. Last but not least, this study encourages research on shrimp seed size and farm productivity growth to be carried out in future.

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