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Technical Efficiency Analysis of Shrimp Farming in Peninsular Malaysia: A Stochastic Frontier Production Function Approach

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ABSTRACT

Shrimp farming has become increasingly important in the aquaculture industry of Peninsular Malaysia. The culture areas for shrimp continue to expand with a view to achieve higher output and generating more export earnings. This paper uses farm level data gathered from Perak and Johor States of Peninsular Malaysia to investigate the technical efficiency of brackish water shrimp farms. Stochastic frontier production analysis is applied to examine the determinants of frontier production function and the technical efficiency of pond shrimp farming system. On average, 65% of the sampled shrimp farms are technically efficient. The results suggest high degrees of technical inefficiency exist among the shrimp farmers. This implies that great potential exists to increase shrimp production through improved efficiency in farm management in Peninsular Malaysia. Initiatives to undertake extension programmes at the farm level are needed to help shrimp farmers in utilizing their resources more efficiently in order to substantially enhance their shrimp production.

Key words: Brackish water shrimp, Peninsular Malaysia, stochastic production frontier, technical efficiency, production function

INTRODUCTION

Marine aquaculture has expanded significantly over the last two decades in Malaysia. It contributes about 70% of total aquaculture production in the country. The marine shrimp especially the black tiger shrimp (*Penaeus monodon*) culture had received much attention in the past due to its high potential to generate foreign exchange earnings for the country. Shrimp production increased from 149 m in 1982 to 69,278 m in 2009 with annual growth rate of 28.6% (Department of Fisheries Malaysia, 2011).

The government identified aquaculture as a key area for development to produce fish for the country both for local consumption and for export. To achieve these goals, Aquaculture Industrial Zones (AIZ) was established in 2007. The government took a number of initiatives to promote brackish water shrimp culture under the Third National Agricultural Policy (NAP3) of Malaysia from 1998-2010 (Ministry of Agriculture, 2003). About 491000 ha of additional land was allocated for construction of aquaculture ponds in Peninsular Malaysia in order to achieve the targeted shrimp production of 180,000 MT (RM 4.3 billion) by 2010.

Ponds are the main production system used for shrimp aquaculture in Peninsular Malaysia. This system has been substantially contributed to the aquaculture industry in Peninsular Malaysia since the mid 1980s. There were 1200 shrimp farmers culturing 7,315 ha of shrimp ponds producing two types of shrimp species such as tiger shrimp (*Penaeus monodon*) and banana shrimp (*Penaeus vannamei*) produced in marine pond environment in Peninsular Malaysia (Mazuki, 2008).

In mid 1990s, the black tiger shrimp (*Penaeus monodon*) firms had experienced severe outbreaks of disease results in huge loss of shrimp production in this region. Since 2001, farmers had effectively introduced banana or white shrimp (*Litopenaeus vannamei*) species which was more tolerant to diseases. Production of white shrimp has increased steadily over the years from 662 m in 2001 to 52,926 m in 2009. However, the production of black tiger shrimp (*Penaeus monodon*) has reduced (Department of Fisheries Malaysia, 2009).

In Peninsular Malaysia, pond shrimp culture system has been mostly semi-intensive or intensive. The productivity of shrimp in Malaysia is relatively low at 1500 kg ha^{-1} as compared to other neighbouring shrimp producing countries such as Thailand at 3116 kg ha^{-1} (Kumar and Birthal, 2004). The productivity of shrimp farming can be increased through improved technology adoption or by increasing production efficiency. Studies highlights that improvement in efficiency is more cost-effective than introduction of new technologies if the producers are not efficient (Belbase and Grabowski, 1985; Dey *et al*., 2000).

In the frontier production approach, the technical efficiency is either defined as a minimum set of inputs required to produce a given output or maximum output attainable using a given set of inputs (Farrell, 1957). Very few studies applied frontier analysis in estimating technical efficiency in aquaculture sector in Malaysia and other developing countries.

Few studies used stochastic frontier production function to measure technical efficiencies of different aquaculture products such as carps, tilapia and shrimp (Sharma, 1999; Sharma and Leung, 1998; Dey *et al*., 2000; Bhattacharya, 2009). Similar studies were conducted for aquaculture farms in Taiwan, Philippines, Vietnam and India (Chiang *et al*., 2004; Irz and McKenzie, 2003; Nguyen and Vu, 2007; Jayaraman, 1998). The main findings of the studies were that there was a high degree of technical inefficiency among the aquaculture farmers. Limited information is available to understand the current production technologies and management practices by shrimp farmers in Peninsular Malaysia. Iinuma *et al*. (1999) investigated technical efficiency of pond culture of carp in Peninsular Malaysia. A similar study was conducted by Sharma and Leung (2000) and they found that productivity of pond culture of carps in Peninsular Malaysia is low although there are potentials for increasing carp production through improved technical efficiency.

The objective of the present study is to estimate the technical efficiency of brackish water shrimp aquaculture in pond system among shrimp farmers in Peninsular Malaysia. In this paper we applied stochastic frontier approach in order to examine the farm level technical efficiency in shrimp pond system in Peninsular Malaysia. Based on the results of the technical efficiency estimates through stochastic frontier model, some recommendations are presented in this paper to enhance shrimp production in Peninsular Malaysia.

STOCHASTIC FRONTIER MODEL

The concept of technical efficiency was first introduced by Farrell (1957) who described technical efficiency as the ability to produce a given level of output with a minimum quantity of inputs used under certain specific production technology. Aigner *et al*. (1977) and

Meeusen and van den Broeck (1977) have developed the stochastic frontier production function to measure the technical efficiency of production. The Stochastic Frontier Production Function is more appropriate for measuring technical efficiency because it overcomes the inadequate characteristics of the assumed error term in conventional production functions which has limitations on statistical inference of the parameters and the resulting efficiency estimates.

The stochastic frontier production model can be written as:

$$Y_i = f(X_i;\, \beta)+\varepsilon_i \quad i = 1, 2, \ldots\ldots, n \tag{1}$$

where, Y_i denotes the output for the ith farm ($i = 1, 2, \ldots, n$); X_i is a ($1\times k$) vector of factor inputs of the ith farm and β is a ($k\times 1$) vector of unknown parameters to be estimated; ε_i is the error term that has two elements, namely:

$$\varepsilon_i = V-U_i \tag{2}$$

where, V_i's are random variables which are assumed to be independently and identically distributed $N(0, \sigma_v^2)$ and independent of the U_i's and can be positive or negative. The term U_i is a non negative random variable which accounts for pure technical inefficiency in production and is assumed to be independently distributed as truncations of the $N(Z_i\,\delta, \sigma_u^2)$ distribution (Aigner *et al*., 1977). The assumption of the independent distribution between U_i and V_i allows the separation of the stochastic and inefficiency effects in the model.

Battese and Coelli (1995) defined U_i as:

$$U_i = Z_i\delta+W_i \tag{3}$$

where, Z_i is a ($1\times p$) vector of variables affecting farm efficiency; δ is a ($p\times 1$) vector of parameters to be estimated; W_i's represent the truncation of the normal distribution with mean 0 and variance σ_u^2, in such a way that the point of truncation is $-Z_i\delta$, i.e., $W_i \geq -Z_i\delta$. This assumptions are consistent with U_i being a non-negative truncation of the $N(Z_i\,\delta, \sigma_u^2)$ distribution.

The maximum likelihood estimation technique is used to simultaneously estimate the parameters of the stochastic frontier model in (1) and those for the technical inefficiency model in (3). The parameters in Eq. 1 include β and variance parameters such as $\sigma^2 = \sigma_u^2+\sigma_v^2$ and $\gamma = \sigma_u^2/\sigma^2$ (Battese and Corra, 1977), where, σ^2 is the sum of the error variance, γ measures the total variation of output from the frontier that attributed to the existence of random noise or inefficiency. The value of γ lies between zero and one. Inefficiency is not present when $\gamma = 0$ which means that all deviations from the frontier are due to random noise. However, if $\gamma = 1$ then the deviations are completely caused by inefficiency effects (Battese and Coelli, 1995).

The farm level technical efficiency of production for the ith farm (TE_i) is defined as:

$$TE_i = \exp(-U_i) = \frac{Y_i}{f(X_i;\, \beta)\exp(V_i)} \tag{4}$$

The prediction of the technical efficiency is based on the conditional expectation expressed in Eq. 4, given the model specification (Battese and Coelli, 1988). The parameters for the stochastic production frontier model in Eq. 1 and for the technical inefficiency model in Eq. 3 were estimated simultaneously with Maximum Likelihood Estimation (MLE).

DATA AND VARIABLES

Data sources: Shrimp farmers were randomly selected from two major aquaculture producing states in Peninsular Malaysia namely, Perak and Johor. Specifically, 30 farmers from the Manjung district of Perak state and 15 farmers from the Kota Tinggi District of Johor State were sampled. The selected respondents were either owner or manager of shrimp farms. The economic and management related information for shrimp production were collected through face to face interviews of the sample respondents.

Sample characteristics: Shrimp ponds in Peninsular Malaysia are mostly located along the coastal mangrove swamp areas. The average farm size of grow out ponds was 6.54 and 22.5 ha in Perak and Johor, respectively, with an average size of 11.86 ha. Iinuma *et al.* (1999) also reported that the average farms under pond culture in Peninsular Malaysia range from medium to large size. The average shrimp production for all sampled farms was 4590 kg ha^{-1} of which farms in Perak produced on average 6165 kg ha^{-1} while those in Johor have a much lower production of 1438 kg ha^{-1} on average. These information show that shrimp output per hectare was relatively higher in smaller farms probably due to greater intensity of production inputs used. The commercial farms established reservoir ponds and installed separate inlet and outlet drains at the farm level for water supply. However, sea water pollution often disrupts shrimp aquaculture operation.

All sample shrimp farms used pellet feeds. The average feed costs per cycle (about three months) was RM19,751 ha^{-1}, with farms in Perak having relatively higher feed costs (RM25, 851 ha^{-1}) compared to those in Johor (RM 7, 550 ha^{-1}). About 91% of sample shrimp farms used lime for pond preparation. Farmers hardly use chemicals for pond treatment. Average number of labour days employed was 104 mandays in a single production cycle. Majority of the farms have own generators for electricity supply. Shrimp farmers obtain fries from local hatcheries.

EMPIRICAL MODEL ESTIMATION

The stochastic production frontier model for shrimp pond culture in Peninsular Malaysia has employed the Cobb-Douglas functional form, which has been commonly used in other aquaculture studies in developing countries (Iinuma *et al.*, 1999; Nerrie *et al.*, 1990; Hsiao, 1994). The empirical model is represented by Eq. 5 below:

$$\text{Ln } Y_i = \beta_0+\beta_1 \text{ Ln } X_1+\beta_2 \text{ Ln } X_2+\beta_3 \text{Ln}X_3+\beta_4 \text{Ln}X_4+\beta_5 X_5+V_i-U_i \quad (5)$$

where, Ln is the natural logarithm, β's are the regression coefficients of inputs (input elasticities) and V_i+U_i are the error terms. The definitions, measurements and summary statistics of all the variables in Eq. 5 are presented in Table 1. Maximum likelihood estimation of Eq. 5 provides the estimates for the β's and the variance parameters, $\sigma^2 = \sigma_v^2+\sigma_u^2$ and $\gamma = \sigma_u^2/\sigma^2$. The empirical specification for the random variable associated with technical inefficiency Eq. 3 is shown in Eq. 6:

$$U_{it} = \delta_0+\delta_1 Z_{i1}+\delta_2 Z_{i2}+\delta_3 Z_{i3}+\delta_4 Z_{i4}+\varepsilon \quad (6)$$

Table 1: Summary statistics for variables included in the stochastic frontier production and technical inefficiency models for shrimp culture

			Summary statistics			
Variable name	Definition	Measurement	Mean	SD	Min.	Max.
Output and input variables						
Y	Shrimp production/cycle	kg ha^{-1}	4,590	3,664	135	15,000
X_1	Shrimp fry	Pieces ha^{-1}	528,123	410,751	2632	1,333,333
X_2	Feed	kg ha^{-1}	6,375	5,256	217	20,625
X_3	Labour (own and hired)	Days ha^{-1}	104	100	3	580
X_4	Energy (fuel)	RM ha^{-1}	12,481	13,515	267	77,570
X_5	Utility (operational)	RM ha^{-1}	5,132	9,461	14	59,352
Farm specific variables						
Z_1	Age	Year	42	12	23	65
Z_2	Education	Year	10.73	2.66	3	16
Z_3	Experience	Year	9.47	5.84	2	26
Z_4	Production cycle	Day	116	25	75	180
Z_5	Farm area	Dummy	0.33	0.476	0	1

SD: Standred Deviation

where, $U_{it,}$ δ and ε are as defined earlier. The definitions, measurements and the summary statistics for variables Z_1 to Z_4 are presented in Table 1. Equation 6 can be estimated if the technical inefficiency effect, $U_i^{'}$s, are stochastic and have particular distributional properties (Coelli and Battese, 1996). Therefore, it is necessary to test for the absence of technical inefficiency effects by testing a number of hypotheses. The first hypothesis is $\gamma = \delta_0 = \delta_1 = ... = \delta_4 = 0$; that is the effects of the technical inefficiency are not present in the model, the second hypothesis is $\gamma = 0$, to test whether technical inefficiency is deterministic. Rejection of the null hypothesis indicates that the U term should be included in the model. The third hypothesis is $\delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$, is that the technical inefficiency effects follow a standard truncated normal distribution with no technical inefficiency effects. This hypothesis is used to test whether or not the technical inefficiency function, Eq. 6, is influenced by the level of explanatory variables. The fourth hypothesis $\delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$, is that the technical inefficiency effects are not stochastic. The null hypothesis can be tested using the generalized likelihood-ratio statistic, λ, given by:

$$\lambda = -2[\ln\{(H_0)\}-\ln\{L(H_1)\}] \quad (7)$$

where, $L(H_0)$ and $L(H_1)$ denote the values of likelihood function under the null (H_0) and alternative (H_1) hypotheses, respectively. If the given null hypotheses are true, λ has an approximate χ^2 distribution. In addition, when the null hypothesis involves $\gamma = 0$, λ has a mixed χ^2 distribution (Coelli, 1995) and the critical values can be found in Kodde and Palm (1986).

From the model estimation results, the output for each farm can be compared with the frontier level of output given the level of inputs employed. This deviation indicates the level of inefficiency of the firm. Therefore, the technical efficiency score for the ith farm in the sample (TE_i), can be defined as the ratio of observed output to the corresponding frontier output (Coelli *et al*., 2005), that is:

$$TE_i = \exp(-U_i) \quad (8)$$

where, TE_i is the technical efficiency of the farm (0<TE<1). When $U_i = 0$ then the i th farm lies on the stochastic frontier and is known as technically efficient. If $U_i>0$, the farm i lies below the frontier, which means that the farm is inefficient.

The prediction of technical efficiencies is based on the conditional expectation of U_i in Eq. 8. The equation gives the value of V_i-U_i evaluated at the maximum likelihood estimates of the parameters in Eq. 5. The parameters of the stochastic production frontier model Eq. 5 and those of the technical inefficiency model Eq. 6 are simultaneously estimated using the maximum likelihood technique.

RESULTS AND DISCUSSION

The Maximum Likelihood (ML) estimates of the parameters in Eq. 5 and 6 are presented in Table 2. The results show that all the estimated **β** coefficients have positive signs except that for the costs of other inputs. Only feed is significantly different from zero at 1% level which imply that this input has major influence on pond production of shrimp in Peninsular Malaysia. The coefficient for other input costs is negative but does not significantly correlate with shrimp production. Even though the coefficients are not statistically significant, the results show that the per hectare output in brackish water pond shrimp culture is positively related to shrimp fry, feed, labour days and operational costs incurred in shrimp production.

The results for the estimation of the technical inefficiency model's parameters show that the coefficient for experience and education are negative and significant. The result implies that an increase in aquaculture farming experience and an increase in the level of formal education of farm owners/managers will reduce technical inefficiencies in the shrimp farms, consistent with the results of other similar in the Philippines (Irz and McKenzie, 2003). Although the age coefficient is not significant, but its positive sign suggests that as the age of the farm owner/manager increases, efficiency in shrimp production will decrease. The positive coefficient for pond area (dummy)

Table 2: Parameter estimates of stochastic production frontier and technical inefficiency models

Variable	Parameter	Coefficients	Standard Error
Stochastic production frontier			
Constant	β_0	1.591	1.239
Ln Seed (shrimp fry)	β_1	0.111	0.101
Ln (Feed)	β_2	0.724***	0.110
Ln (Labour)	B_3	0.094	0.122
Ln (Operational costs)	β_4	0.038	0.073
Ln (Other inputs)	β_5	-0.156	0.089
Technical inefficiency model			
Constant	δ_0	0.506*	0.241
Age (No. of years) of respondent	δ_1	0.003	0.002
Experience (No. of years)	δ_2	-0.011**	0.004
Pond Area (dummy)	δ_3	0.087	0.047
Education (level)	δ_4	-0.018*	0.008
Variance parameter			
Sigma-square	$\sigma^2_s = \sigma^2_u+\sigma^2_v$	0.509***	0.189
Gamma	$\gamma = \sigma^2_u/\sigma^2$	0.819***	0.182
Log Likelihood		-31.069	
Mean of exp (-U_i)		0.647	

***Estimates are significant at 1%, **Significant at 5%, *Significant at 10%

indicates that smaller farms have lower technical inefficiency, similar to the findings of studies conducted in Bangladesh (Thomas *et al*., 2001). The results suggest that farming experience and education are the key determinants in reducing technical inefficiencies of pond shrimp culture in Peninsular Malaysia.

The value of the gamma coefficient is 0.819 and is significant at 1% level (Table 2). This shows that the output variations among the shrimp farms are dominated by technical inefficiency rather than random shocks. The predicted Technical Efficiencies (TE) of all the sampled farms range from 0.174 to 0.894 with the mean technical efficiency of 0.647 (Fig. 1). This indicates that if shrimp farmers use their existing level of inputs in an efficient manner, output on average can be increased by 35%. This result suggests that the potential for increasing shrimp production in Peninsular Malaysia through improved technical efficiency is rather substantial. If all sampled farmers are able to achieve the level of output of its most efficient counterpart, then a 28% [i.e., 1−(64.7/89.4)×100] saving on inputs use could be realized and the most technically inefficient farm could achieve saving on inputs used by 82% [i.e., 1−(17.4/89.4)×100]. The results indicate that the technical inefficiency have significant impacts on the levels and variations of shrimp production in Peninsular Malaysia. The distribution of the predicted efficiency levels of shrimp farms at the study sites is presented in Fig. 1. It can be observed from the figure that more than 65% of the shrimp farmers operate their farms within the efficiency of 60-90% range.

The results for the hypotheses tests discussed earlier are shown in Table 3. The first null hypothesis test showed that the inefficiency effect of the production frontier is stochastic as the LR

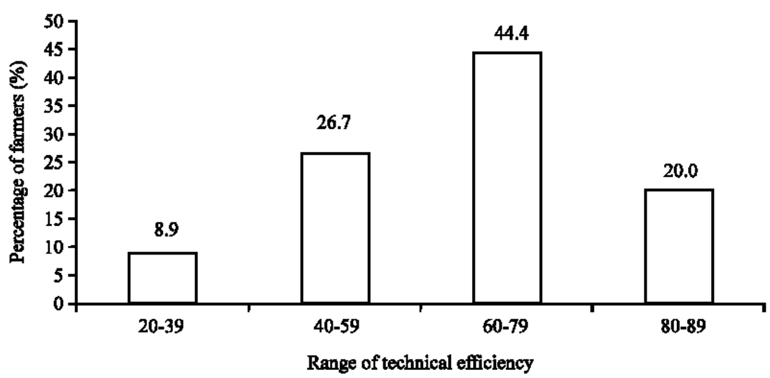

Fig. 1: Frequency distribution of technical efficiency for pond shrimp culture in Peninsular Malaysia. Mean technical efficiency for first group is 0.26 (range 0.17 to 0.38), 0.53 (range 0.43-0.60) for second group, 0.69 (range 0.61-0.77) for third group and 0.85 (range 0.83-0.89) for the last group

Table 3: Generalized likelihood ratio tests of hypotheses of parameters for the stochastic production frontier and technical inefficiency function

Null hypotheses	Symbolic form	Likelihood ratio	Test statistic (λ)	Critical value ($\chi^2_{0.05}$)	df	Decision
Technical inefficiency does not exist	$\gamma = \delta_0 = ... = \delta_4 = 0$	-33.834	45.354	13.742	6	Reject H_o
Technical inefficiency is deterministic	$\gamma = 0$	-31.069	39.824	3.840	1	Reject H_o
No technical inefficiency	$\delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$	-20.703	19.092	10.384	4	Reject H_o
Inefficiency effects are not stochastic	$\delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$	-18.963	15.612	12.103	5	Reject H_o

The correct critical values for the first hypotheses is obtained from Table 1 of Kodde and Palm (1986, pp: 1246); df: degree of freedom test led to the rejection of this hypothesis. The second null hypothesis is rejected indicating that inefficiency effects are stochastic. These two hypothesis test results imply that the traditional Ordinary Least Square (OLS) technique is not suitable to be used to estimate these functions. The third and fourth null hypotheses related to testing the coefficients in the technical inefficiency model. Both hypotheses are rejected at the 5% significant level. This indicates that the variation in output performance of the sampled shrimp farms in Peninsular Malaysia could be explained by the technical inefficiency effects.

CONCLUSION AND RECOMMENDATION

The mean technical efficiency of sampled shrimp farms is estimated to be 65%. This suggests that great potential exists for increasing shrimp production in Peninsular Malaysia through improving technical efficiency of brackish water pond culture of shrimp. The results of the study show that feed is the most important input in shrimp production. All sampled shrimp farms used pelleted feed. Feed production using cheaper local materials can reduce its cost and can increase productivity of shrimp farms in Peninsular Malaysia.

The results from technical inefficiency model indicate that experience and education of shrimp farm owners/managers were important factors significantly influencing the technical inefficiency of shrimp culture in Peninsular Malaysia. In order to increase the technical efficiency of their farms, information dissemination through extension and trainings should be provided to shrimp farm owners/managers to enhance their skills and knowledge related to shrimp aquaculture.

The relatively small pond area has more potential to improve the level of technical efficiency in shrimp farming in Peninsular Malaysia. Iinuma *et al.* (1999) stressed that pond area should be increased for commercialisation of aquaculture. Shrimp ponds area has been expanded recently which can promote commercial shrimp farming in pond system in Peninsular Malaysia. Extension workers should provide technical and extension support especially to the large shrimp producers to manage their farms effectively.

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REFERENCES

Aigner, D., C.A.K. Lovell and P. Schmidt, 1977. Formulation and estimation of stochastic frontier production models. J. Econ., 6: 21-37.

Battese, G.E. and G. Corra, 1977. Estimation of a production function model with application to the pictorial zone of Eastern Australia. Aust. J. Agric. Econ., 21: 169-179.

Battese, G.E. and T.J. Coelli, 1988. Prediction of firm-level technical efficiencies with a generalized frontier production function and panel data. J. Econ., 38: 387-399.

Battese, G.E. and T.J. Coelli, 1995. A model for technical inefficiency effects in a stochastic frontier production function for panel data. Empirical Econ., 20: 325-332.

Belbase, K. and R. Grabowski, 1985. Technical efficiency in Nepalese agriculture. J. Dev. Areas, 19: 515-525.

Bhattacharya, P., 2009. Economics of shrimp farming: A comparative study of traditional vs. scientific shrimp farming in West Bengal. A Technical Efficiency Analysis, Institute for Social and Economic Change Working Paper.

Chiang, F.S., C.H. Sun and J.M. Yu, 2004. Technical efficiency analysis of milkfish (chanos chanos) production in Taiwan-An application of the stochastic frontier production function. Aquaculture, 230: 99-116.

Coelli, T., 1995. Estimators and hypothesis tests for a stochastic frontier function: A Monte Carlo analysis. J. Prod. Anal., 6: 247-268.

Coelli, T.J. and G.E. Battese, 1996. Identification of factors which influence the technical inefficiency of Indian farmers. Aust. J. Agric. Econ., 40: 103-128.

Coelli, T.J., D.S.P. Rao, C.J. O' Donnell and G.E. Battesse, 2005. An Introduction to Efficiency and Productivity Analysis. 2nd Edn., Springer, New York.

Department of Fisheries Malaysia, 2009. Annual fisheries statistics. Ministry of Agriculture and Agro-Based Industry, Putrajaya, Malaysia.

Department of Fisheries Malaysia, 2011. Annual fisheries statistics. Ministry of Agriculture and Agro-Based Industry, Putrajaya, Malaysia.

Dey, M.M., F.J. Paraguas, G.B. Bimbao and P.B. Regaspi, 2000. Technical efficiency of tilapia growout pond operations in the Philippines. Aquacult. Econ. Manage., 4: 33-47.

Farrell, M.J., 1957. The measurement of productive efficiency. J. R. Stat. Soc. Ser. A, 120: 253-281.

Hsiao, C.K., 1994. Analysis of Demand for Aquaculture Water in Taiwan. In: Socioeconomics of Aquaculture: Proceedings of the International Symposium'93, December 14-17, 1993, Shang, Y.C., P.S. Leung, C.S. Lee, M.S. Su and I.C. Liao (Eds.). Tungkang Marine Laboratory, Taiwan Fisheries Research Institute, Taiwan, pp. 341-349.

Iinuma, M., K.R. Sharma and P. Leung, 1999. Technical efficiency of carp pond culture in peninsula Malaysia: An application of stochastic production frontier and technical inefficiency model. Aquaculture, 175: 199-213.

Irz, X. and V. McKenzie, 2003. Profitability and technical efficiency of aquaculture systems in pampaanga, Philippines. Aquacult. Econ. Manage., 7: 195-211.

Jayaraman, R., 1998. Economics and technical efficiency in carp culture in Thanjavur District, Tamil Nadu State, India. Proceedings of the 9th International Conference of the International Institute of Fisheries Economics and Trade, July 8-11, 1998, Tromso, Norway, pp: 71-82.

Kodde, D.A. and F.C. Palm, 1986. Wald criteria for jointly testing equality and inequality restrictions. Econometrica, 54: 1243-1248.

Kumar, A. and P.S. Birthal, 2004. Technical efficiency in shrimp farming in India: Estimation and implications. Indian J. Agric. Econ., 59: 413-420.

Mazuki, H., 2008. Introduction of whiteleg pacific shrimp (*Penaeus vannamei*) and its impact on aquaculture development in Malaysia. Proceedings of the 5th National Fisheries Symposium, July 14-16, 2008, Wisma Darul Iman, Kuala Terengganu, Terengganu, Malaysia.

Meeusen, W. and J. van den Broeck, 1977. Efficiency estimation from Cobb-Douglas production functions with composed error. Int. Econ. Rev., 18: 435-444.

Ministry of Agriculture, 2003. Third National Agricultural Policy (1998-2010). Ministry of Agricultural, Putrajaya, Malaysia, pp: 18.

Nerrie, B.L., L.U. Hatch, C.R. Engle and R.O. Smitherman, 1990. The economics of intensifying catfish production: A production function analysis. J. World Aquacult. Soc., 21: 216-224.

Nguyen, K.M. and Q.D. Vu, 2007. Parametric and non-parametric estimates of technical efficiency for aquaculture processing firms in vietnam. http://www.grips.ac. jp/vietnam/ VDFTokyo/Temp/Doc/2007/BookMar07_Tech_EChapter3.pdf

Sharma, K.R. and P.S. Leung, 1998. Technical efficiency of carp production in Nepal: An application of stochastic frontier production function approach. Aquacult. Econ. Manage., 2: 129-140.

Sharma, K.R., 1999. Technical efficiency of carp production in Pakistan. Aquacult. Econ. Manage., 2: 131-141.

Sharma, K.R. and P.S. Leung, 2000. Technical efficiency of carp pond culture in south Asia: An application of stochastic meta-production frontier model. Aquac. Econ. Manage., 4: 169-189.

Thomas, M.A., G. Macfadyen and S. Chowdhury, 2001. The costs and benefits of Bagda shrimp farming in Bangladesh. Bangladesh Centre for Advanced Studies, Dhaka, Bangladesh.