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Determinants of technical efficiency of freshwater prawn farming in southwestern Bangladesh

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Abstract

This paper estimates a translog stochastic production function to examine the determinants of technical efficiency of freshwater prawn farming in Bangladesh. Primary data has been collected using random sampling from 90 farmers of three villages in southwestern Bangladesh. Prawn farming displayed much variability in technical efficiency ranging from 9.50 to 99.94 % with mean technical efficiency of 65 %, which suggested a substantial 35 % of potential output can be recovered by removing inefficiency. For a land scarce country like Bangladesh this gain could help increase income and ensure better livelihood for the farmers. Based on the translog production function specification, farmers could be made scale efficient by providing more input to produce more output. The results suggest that farmers' education and non-farm income significantly improve efficiency whilst farmers' training, farm distance from the water canal and involvement in fish farm associations reduces efficiency. Hence, the study proposes strategies such as less involvement in farming-related associations and raising the effective training facilities of the farmers as beneficial adjustments for reducing inefficiency. Moreover, the key policy implication of the analysis is that investment in primary education would greatly improve technical efficiency.

Keywords: Bangladesh, Prawn farming, Technical efficiency, Translog stochastic frontier production function

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1 Introduction

Bangladesh with its vast and highly diverse aquatic resources and agro-climatic conditions is widely recognised as one of the suitable countries in the world for freshwater prawn (*Macrobrachium rosenbergii*) (locally known as *golda*) farming. A sub-tropical monsoonal climate, low laying agricultural land and a vast area of shallow water provide ideal conditions for freshwater prawn production (Ahmed *et al.*, 2008a). Within the last three decades, prawn farming has become one of the most important sectors in the agricultural based economy of Bangladesh, because it has created jobs, earned foreign exchange and supplied additional protein to an undernourished population. Approximately 1.2 million people directly and an additional 4.8 million rural people indirectly earn income from prawn and shrimp production and its associated activities (USAID, 2006). In 2011–12, Bangladesh exported 48,007 tons of prawn and shrimp valued at US$ 428.75 million, of which 25 % was prawn (FSYB, 2013).

The total area under prawn cultivation in Bangladesh is estimated to be around 50,000 ha (Khondaker, 2009). More than 71 % of prawn farms are located in southwest Bangladesh, particularly in the Bagerhat, Khulna and Satkhira districts (Ahmed *et al.*, 2008a). The families living in the densely populated southwest Bangladesh tend to be resource poor, income poor, and vulnerable to environment, climate and economic variability (Bundell & Maybin, 1996; Muir, 2003). Prawn farming therefore opens a new frontier for income and live-

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lihood for farmers and other farming related people of this region (DIFTA, 1993; Ahmed, 2001; Ito, 2004). The most spectacular boost of prawn farming has taken place in the Bagerhat district where a large number of farmers have converted their rice fields to profitable prawn farms (Ahmed *et al.*, 2008b). The reasons behind the widespread adoption of prawn farming in southwest Bangladesh are the availability of wild postlarvae and low-lying rice fields, a warm climate, fertile soil, and cheap and abundant labour (Haroon, 1990; Ahmed *et al.*, 2008a).

However, the average yield of prawn is low, at 467 $\mathrm{kg\,ha^{-1}}$ (Ahmed *et al.*, 2010a) much lower than in other Asian countries[1]. The potential gain from closing this yield gap is high for Bangladesh. This gap indicates a difference in productivity between 'best practice' farm and another less efficient farm that operate with comparable resource constraints under similar circumstances (Wadud, 1999; Villano, 2005). The difference between the actual and potential output for prawn farming implies great opportunities for increasing income and foreign exchange through improvements in productivity. For a densely populated and resource scarce country such as Bangladesh, where opportunities to develop and adopt new technologies are rare, empirical investigations of technical efficiency and its determinants in prawn farming are a dire necessity. Such studies help to determine the level at which farmers are using existing technologies as well as explore the possibility of raising productivity by increasing efficiency for prawn farming.

In Bangladesh, a number of studies have been conducted on prawn farming, examining conversion of rice fields to prawn farms (Ahmed *et al.*, 2010a), sustainability of freshwater prawn farming (Ahmed *et al.*, 2010b), livelihood analysis of prawn farmers and associated groups (Ahmed *et al.*, 2008a), prawn farming in *gher* systems (Ahmed *et al.*, 2008b), history of prawn farming (Ahmed *et al.*, 2008c), economic returns to prawn and shrimp farming (Islam *et al.*, 2005), agrarian change and economic transformation (Ito, 2004), and prawn and shrimp marketing (Ahmed *et al.*, 2009; Islam, 2008). To the best of our knowledge, only two studies have analysed the technical efficiency of prawn and *gher* farming in Bangladesh namely diversification economies and efficiencies of prawn-carp-rice farming (Rahman *et al.*, 2011) and production efficiency of rice fish farming (Ahmed *et al.*, 2011), and two more studies in neighbouring countries, i.e. Devi (2004) in India and Thi *et al.* (2007) in Vietnam. Given this backdrop, the present study aims to estimate the determinants of technical efficiency and each factor's contribution to prawn farming inefficiency. The present study selects the appropriate functional form of the inefficiency component and a suitable production function model that fits the data best based on several empirical hypotheses. Our results reinforce existing theoretical arguments that education, non-farm income, training and tenure status may impact farm productivity and efficiency. An understanding of these relationships can provide policy makers with information about the nature of the problems facing prawn farms in Bangladesh and help design programs that improve efficiency.

2 Materials and methods

2.1 Study area

The study was undertaken in the Fakirhat upazila (lowest administrative unit) in Bagerhat district of southwest Bangladesh. Fakirhat was selected for this study as it is an important area for prawn culture because of the availability of natural- and hatchery-produced postlarvae, ponds and low-lying agricultural land.

2.2 Culture season and methods

The peak season of prawn farming in the study area is from May to January. Prawn postlarvae are stocked in May to June and are harvested primarily from December to January, a culture period of around nine months. Between January and April, some of the farmers grow HYV Boro rice on the land inside the *gher*[2], which is irrigated by water from the inside canals using either traditional methods (swing basket) and/or pumps. Farmers use lime to reduce soil acidity at the time of *gher* preparation and during the culture period. Farmers use a wide range of homemade and commercially available supplementary feeds to increase prawn production including snail meat, rice bran, wheat bran, oil cake, and pulses.

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[1] Prawn yield in China 1500 $\mathrm{kg\,ha^{-1}}$ (Weimin & Xianping, 2002), India 600–1000 $\mathrm{kg\,ha^{-1}}$ (Raizada *et al.*, 2005), Taiwan 1500 $\mathrm{kg\,ha^{-1}}$ (New, 1995), Thailand 2338 $\mathrm{kg\,ha^{-1}}$ (Vicki, 2007) and Vietnam 1000–1500 $\mathrm{kg\,ha^{-1}}$ (Ridmontri, 2002).

[2] The local term *gher* is an enclosure made for prawn cultivation by modifying rice fields through building higher dikes around the rice field and excavating a canal several feet deep inside the periphery to retain water during the dry season (Kendrick, 1994). During the rainy season the whole water body is used for the cultivation of prawn and other fishes, while only trenches are used for fish during dry season (Chapman & Abedin, 2002). The dikes are used for growing vegetables and fruits throughout the year.

The system is costly and labour intensive. Farmers repair the *gher* dikes and trenches almost annually, before releasing prawn postlarvae.

Almost all the freshwater prawn farming practice is intensive, while a few farmers (5 %) still practice extensive farming. The intensive production system is characterised by relatively high stocking densities and high inputs, such as industrial manufactured pellet feeds, chemicals and drugs that increase the nutrients and organic matter load to the ecosystem (Shang *et al.*, 1998). In contrast, the extensive system typically uses slightly modified versions of traditional methods and is called low density system (10,000–17,000 post larvae ha^{-1}) and low input system. The extensive system relies mainly on the natural productivity of the pond, but organic and inorganic fertilisers are occasionally used to promote growth of natural foods (Shang *et al.*, 1998).

2.3 *Analytical framework*

The seminal paper of Farrell (1957) developed several approaches to efficiency and productivity analysis. Among these, the stochastic frontier production function (Aigner *et al.*, 1977; Meeusen & van den Broeck, 1977) and Data Envelopment Analysis (DEA) (Charnes *et al.*, 1978) are the two principal methods for efficiency measurement. In developing countries' agriculture where data are heavily influenced by measurement errors and the effects of weather conditions, diseases, etc, the stochastic frontier analysis has more advantages compared with data envelopment analysis (Färe *et al.*, 1985; Kirkly *et al.*, 1995, 1998; Jaforullah & Devlin, 1996; Coelli *et al.*, 1998; Dey, 2000; Dey *et al.*, 2005). This also applies to the applications of frontier techniques to prawn farming, hence a stochastic frontier production function is specified.

The stochastic frontier production function for the cross section data can be defined as follows:

$$Y_i = f(X_i; \beta) + V_i - U_i \qquad (1)$$

where Y_i denotes the production for the i^{th} farm ($i = 1, 2, \ldots, n$); X_i is a $1 \times k$ vector of functions of inputs quantities used by the i^{th} firm; β is a $k \times 1$ vector of unknown parameters to be estimated; the V_i's are random variables which are assumed to be independently and identically distributed N(0, σ_v^2) and are distributed independently of the technical inefficiencies U_i's; and the U_i's are non-negative random variables associated with technical inefficiency in production, which are assumed to be independently distributed as truncations of the N($Z_i\delta, \sigma_u^2$) distribution.

Following Battese & Coelli (1995), U_i's can be represented as:

$$U_i = Z_i\,\delta + W_i \qquad (2)$$

where Z_i is a $1 \times p$ vector of variables which may influence efficiency of a farm; δ is a $p \times 1$ vector of parameters to be estimated; and W_i's are the random variables defined by the truncation of the normal distribution with mean 0 and variance σ_u^2, such that the point of truncation is $-Z_i\delta$, i.e., $W_i \geq Z_i\delta$. These assumptions are consistent with U_i being a non-negative truncation of the N($Z_i\delta, \sigma_u^2$) distribution (Battese & Coelli, 1995).

The technical efficiency of production for the i^{th} farm (TE_i) is defined as:

$$TE_i = \exp(-U_i) = \frac{Y_i}{f(X_i; \beta)\exp(V_i)} \qquad (3)$$

The prediction of the technical efficiencies is based on conditional expectation of expression in equation 3, given the model's assumptions.

2.4 *The data*

This study is based on farm level cross sectional data for the crop year 2011 collected from three villages (Faltita Baniyakhali, Saittala and Bailtali[3]) of Fakirhat upazila. For the sampling method, a database of prawn farmers was collected from upazila and district Fisheries Offices. A total of 90 *gher* farmers were randomly selected. The survey was conducted for a period of 3 months from August to October 2011. Questionnaire interviews with *gher* farmers were preceded by preparation and testing of the questionnaire and the use of enumerators to fill in the questionnaire.

2.5 *Limitation of the Study*

A caveat of the paper that needs to be mentioned is the sample size. Due to cost constraints, the researchers have been able to collect at present a small sample of *gher* farms. As mentioned, only a few attempts have been undertaken to determine prawn farm efficiency in Bangladesh. Thus, the results should be interpreted in this light.

2.6 *The empirical model*

The Cobb-Douglas (CD) and the transcendental logarithmic (TL) are the two most popular functional forms in the stochastic frontier analysis economics literature.

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[3] Total number of *ghers* of these three villages is 1565 which represents more than 10 % of *ghers* in Fakirhat upazila (Haque & Saifuzzaman, 2002).

Various studies have been conducted using a CD production function due to its linearity in logarithms; however its elasticity is constant and the elasticity of substitution is unity. The TL is more flexible in that it imposes few assumptions on the function and its elasticities, but it is more difficult to estimate due to the large number of parameters and the attendant problem of multicollinearity among the regressors (Irz & McKenzie, 2003). We first specified a translog (TL) stochastic frontier model in this study that is then tested against a Cobb-Douglas (CD) to determine which functional specification best fits the data on the prawn farming.

The translog (TL) functional form employed to estimate the stochastic production frontier is specified as:

$$\ln Y_i = \beta_0 + \sum_{j=1}^{7} \beta_j \ln \overline{X}_{ji} + \frac{1}{2} \sum_{j=1}^{7} \sum_{k=1}^{7} \beta_{jk} \ln \overline{X}_{ji} \ln \overline{X}_{ki} + V_i - U_i \tag{4}$$

where subscript i refers to the i^{th} farm in the sample; ln represents the natural logarithm; Y output variable and $\overline{X}$'s are means of input variables (creating variables by deducting each observation from its sample mean, i.e., $\overline{X}_1 = X_1 - \overline{x}_1$) as defined in Table 1. V_i's are iid $\mathrm{N}(0, \sigma_v^2)$ random variables; U_i's are independently distributed $(|N(Z_i\delta, \sigma_u^2)|)$.

Following Battese & Coelli (1995), it is further assumed that the technical inefficiency distribution parameter, U_i is a function of various operational and farm specific variables hypothesized to influence technical inefficiencies as:

$$U_i = \delta_0 + \sum_{k=1}^{9} \delta_k Z_{ki} + W_i \tag{5}$$

where Z's are various farm specific variables, as defined in Table 3; δ's are unknown parameters to be estimated; and W_i is a random variable as defined in equation 3. These farm specific variables (age, education, training, involvement in fish farm association, non farm income, family size, distance from the canal, water quality and lease area) may affect efficiency. Choice of these variables is based on the existing literature, and the justification for their inclusion is briefly discussed.

Use of the education level and training of farmers as a technical efficiency shifter is fairly common (Wang *et al.*, 1996; Wadud & White, 2000; Asadullah & Rahman, 2009; Haque, 2011; Rahman *et al.*, 2011). The education and training variables are also used as a surrogate for a number of factors. At the technical level, access to information as well as capacity to understand the technical aspects related to production are expected to improve with education and training, thereby, influencing technical efficiency. The justification for including age is straightforward as older, and hence more experienced, farmers are more likely to be more efficient in decisions regarding the use and allocation of scarce inputs (Liewelyn & Williams, 1996; Coelli & Fleming, 2004).

Large families seem to have the tendency to adopt earlier new technologies, as has been found in Bangladesh by Hossain *et al.* (1990). The number of family members is incorporated to test whether it influences technical efficiency as proposed by Haque (2011). The proportion of lease area is included in this study as the number of farmers who cultivate prawn solely on leased land was limited. The prawn farms were often a mixture of own land and leased land. Thus, in this case we have considered lease area as a continuous variable. Involvement in fish farm associations exposes them to information, technology and other facilities. Thus, the association of the prawn farmers with fisheries-related activities is expected to increase technical efficiency. Non-farm income is included as an indication of the farmers' economic condition. Closer distance of the pond to the main water channel has advantages as the water contains more postlarvae, natural foods and minerals. It is expected that the prawn farmers who are having more non-farm income would be able to invest more in the farms and hence would be able to achieve better technical efficiency.

At the point of approximation (i.e., sample mean), the translog production function should be well behaved, satisfying all regularity conditions namely positive and diminishing marginal products (the first order parameters are all between zero and one, while the bordered Hessian matrix of the first and second order partial derivatives is negative semi-definite).

We assume perfect competition in the prawn industry and monotonicity condition necessitates positive marginal product which can be derived from the translog production in equation 4. More specifically,

$$MP = f_i = \frac{\partial Y}{\partial X_i} = \frac{\partial \ln Y}{\partial \ln X_i} \times \frac{Y}{X_i} \tag{6}$$

$$f_i = \frac{Y}{X_i} \left(\beta_i + \sum_{j=1}^{n} \beta_{ij} \ln X_j \right) > 0 \tag{7}$$

Diminishing marginal productivity is

$$f_{ii} = \frac{Y}{X_i^2} \left[\beta_{ii} + \left(\beta_i - 1 + \sum_{j=1}^{n} \beta_{ij} \ln X_j \right) \left(\beta_i + \sum_{j=1}^{n} \beta_{ij} \ln X_j \right) \right] < 0 \tag{8}$$

where f_i is marginal product of inputs, f_{ii} is the diminishing marginal product of input, Y is the production of prawn, i and j are the inputs, X_i X_j are the input levels, β_i is the estimated coefficient of the X term and β_{ij} is the estimated coefficient of the X^2 term.

It should be noted that the technical inefficiency model in equation 5 can only be estimated if the technical inefficiency effects, U_i's are stochastic and have particular distributional properties (Coelli & Battese, 1996). Therefore, it is of interest to test the null hypothesis that the technical inefficiency effects are absent: $\gamma = \delta_0 = \delta_E = \delta_A = \delta_T = \delta_I = \delta_N = \delta_F = \delta_D = \delta_W = \delta_L = 0$ (where subscripts represent education, age, training, involvement in fish farm associations, non-farm income, family size, distance of the *gher* from the water channel, water quality and lease area, respectively). The stochastic frontier model reduces to a traditional average function in which the explanatory variables in the technical inefficiency model are included in the production function. Failure to reject the null hypothesis $H_0 : \gamma = 0$ implies the existence of a stochastic frontier. Similarly, $\gamma = 1$ implies that all the deviations from the frontier are due to the technical inefficiency (Coelli *et al.*, 1998). These and related null hypotheses can be tested using the generalized likelihood-ratio statistic, λ, given by:

$$\lambda = -2\,[\ln\{L(H_0)\} - \ln\{L(H_1)\}] \quad (9)$$

where $L(H_0)$ and $L(H_1)$ denote the values of the likelihood function under null (H_0) and alternative (H_1) hypotheses, respectively. If the given null hypothesis is true, λ has approximately χ^2-distribution or mixed χ^2-distribution when the null hypothesis involves $\lambda = 0$ (Coelli, 1995b,a).

Given the model specifications, the technical efficiency index for the i^{th} farm in the sample (TE_i), defined as the ratio of observed output to the corresponding frontier output, is given by

$$TE_i = \exp(-U_i) \quad (10)$$

The prediction of technical efficiencies is based on the conditional expectation of expression in equation 10, given the values of $V_i - U_i$ evaluated at the maximum likelihood estimates of the parameter of the stochastic production frontier model (Battese & Coelli, 1995). The frontier production for the i^{th} farm can be computed as the actual production divided by the technical efficiency

Table 1: *Description of output, input and farm specific variables*

Variable	*Description*	*Unit*
Y	Total production of prawn of the sampled farmers during the year	kg
Variables in the production frontier		
X_G	*Gher* size	Hectare
$X_L{}^*$	Quantity of labour employed per hectare per year	Man-days
X_{Fi}	Quantity of fingerlings stocked in pond per hectare per year	Number
X_{Fd}	Quantity of feeds (pulses, oilcake and wheat bran) applied per hectare per year	kg
X_{Li}	Quantity of lime applied per hectare per year	kg
X_{Fe}	Quantity of fertiliser used per hectare per year	kg
X_C	Amount of cost incurred for other inputs per ha per year	US$
Variables in the inefficiency function		
Z_E	Education (years of schooling) of the farmers	Year
Z_A	Age of the farmers	Year
Z_T	Training received by the farmers (1 if received, 0 otherwise)	1, 0
Z_I	Involvement of the farmers in the fish farm association (1 if involve, 0 otherwise)	1, 0
Z_N	Share of non-farm income to total income of the farmers	Percent
Z_F	Family size of the farmers	Persons
Z_D	Distance of the pond from the channel/creek (1 if less than 500 metres, 0 otherwise)	1, 0
Z_W	Water quality of the ponds (1 if good enough, 0 otherwise)	1, 0
Z_L	Proportion of lease area to total prawn farm area	Percent

* 1 man day equals 8 working hours/day estimate. The parameters for the stochastic production frontier function in equation 4 and those of the technical inefficiency model in equation 5 are estimated simultaneously using the maximum likelihood (ML) estimation method, using the computer programme, FRONTIER 4.1 (Coelli, 1994), which gives the variance parameters of the likelihood function in terms of $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2/\sigma^2$.

3 Results

3.1 *Sample characteristics*

Of the farms analysed, the average *gher* size is 1.96 ha ranging from 0.20 ha to 6.32 ha. About 30 % of operations have a *gher* size of less than 1 ha. Stocking density (number of fingerling released per ha) is 30,721 pieces on average. The supplementary feed application for prawn production is mostly a mixture of wheat bran, mustard oil cake and pulses. The average feed application is 3280 kg ha^{-1}. The mean yield of prawn is 589 kg ha^{-1} ranging from a minimum of 534.4 kg ha^{-1} to as high as 673.6 kg ha^{-1}. The mean of liming for pond preparation is reported 242.23 kg ha^{-1}. All the sample farmers apply fertiliser for pond preparation and water treatment ranging from 79 kg ha^{-1} to 888 kg ha^{-1}. The mean non-farm annual income of the prawn farmers is US$ 1995.78. The average labour use is 248.17 man-days ha^{-1} ranging from 118.78 man-days ha^{-1} to 576.49 man-days ha^{-1} (Table 2).

A likelihood ratio test was conducted to test the null hypothesis that the translog stochastic frontier production function can be reduced to a Cobb-Douglas production function. The test statistic H_0: $\beta_{jk} = 0$, H_1: $\beta_{jk} \neq 0$, has a likelihood ratio value of 165.21, which implies a rejection of the null hypothesis at the 5 % significance level. In other words, the translog production function is more suitable to the prawn farm survey data that adequately captures the production behaviour.

Before proceeding with any explanation to the analysis, monotonicity test is performed and results are presented in Table 4. The results show that the marginal products of the inputs are positive and diminishing marginal products are negative.

The maximum-likelihood estimates of the parameters for the stochastic frontier production model and those for the technical inefficiency model of prawn farming in Bangladesh are shown in Table 3. Most of the slope coefficients of inputs on the first order terms were positive, with the exception of the other cost coefficient. However, this negative coefficient was insignificant. The coefficients associated with *gher* size, labour and fingerling were highly significant while the coefficient for feed was significant at the 5 % level. Other independent variables such as lime and fertiliser have pos-

Table 2: *Summary statistics*

Name of variable	*Mean*	*Standard deviation*	*Minimum*	*Maximum*
Prawn production (kg ha^{-1})	589.1	28.54	534.4	673.6
Gher size (ha)	1.96	1.37	0.20	6.32
Labour (man-days ha^{-1})	248.17	79.84	118.75	576.49
Fingerlings (number ha^{-1})	30 720.6	2181.88	24 754.58	35 085.23
Feed (kg ha^{-1})	3280.09	529.37	2400	5200
Lime (kg ha^{-1})	242.23	34.12	155	301
Fertiliser (kg ha^{-1})	149.21	86.93	79	888
Other cost (US$)*	53.51	28.70	24.23	199.34
Education of head of household((years of schooling)	11.3	2.1	5	16
Age of head of household(years)	42.9	6.3	29	55
Total non-farm income (US$)	1995.78	1538.68	142.60	7130.13
Family size (persons)	5.16	1.11	3	8
Proportion of leased area to total operational area under prawn culture (%)	7.29	15.57	0	80.77

* US$ 1 ≈ 84.15 Bangladeshi Taka in 11/02/2012.

itive coefficients but are insignificant under the translog production function. The coefficients on second order terms are also significantly different from zero, thereby confirming nonlinearities in the production process, and hence, justify the use of translog production function specification.

The γ- parameter associated with the variances in the stochastic production frontier is estimated to be close to 1 (Table 3). Although the γ- parameter cannot be interpreted as the proportion of the total variance explained by technical inefficiency effects, the result indicates that technical inefficiency effects do make a significant contribution to the level and variation of prawn farming in Bangladesh.

3.2 Factors explaining inefficiency

The results indicate that the farm specific variables included in the technical inefficiency model contribute significantly, both as a group and several of them individually, to the explanation of the technical inefficiencies (Table 3). The parameter estimates showed that factors such as training, involvement in fish farm association, family size, distance and water quality were positively related to inefficiency while education, age, non-farm income and lease area were negatively related to inefficiency.

It is expected that involvement in fish farm associations should be positively related to technical efficiency. It is assumed that prawn farmers who belong to fish farm associations are likely to benefit from better access to inputs and to information on improved farming practices. Being a member in farmers' association may lead to sharing of information on farming technologies, which tends to influence the production practices of members through peer learning. However, our estimate showed a negative statistically significant relationship between membership in fish farm associations and technical efficiency.

3.3 Hypotheses tests for γ and δ parameters

Generalized likelihood ratio tests of various null hypotheses involving the restrictions on the variance parameter, γ, in the stochastic production frontier and δ coefficients in the technical inefficiency model are presented in Table 5. The first hypothesis is tested for the presence of inefficiencies in the model. Thus, γ is defined between zero and one, where if $\gamma = 0$, technical inefficiency is not present, and where $\gamma = 1$, there is no random noise. The test of significance of the inefficiencies in the model (H_0: $\gamma = \mu = 0$) was rejected at the 5 % significance level, indicating that the maximum likelihood estimation is a significant improvement over an Ordinary Least Squares (OLS) specification and inefficiencies are present in the model. The calculated value of the test statistic is 51.10, which is greater than the critical value (Table 5).

The second null hypothesis, H_0: $\delta_0 = \delta_{Ed} = \delta_{Tr} = \ldots = \delta_{Pl} = 0$, specifies that technical inefficiency follows a half-normal distribution with zero mean originally proposed by Aigner *et al.* (1977). This null hypothesis is rejected at 5 % significance level suggesting that, given the stochastic frontier with the model for technical inefficiency effects, the standard stochastic error component model is not appropriate for the half-normal distribution. The third null hypothesis, H_0: $\delta_{Ed} = \delta_{Tr} = \ldots = \delta_{Pl} = 0$, implies that technical inefficiency effects follow a standard truncated normal distribution (Stevenson, 1980) as the null hypothesis is rejected at the 5 % level of significance. This indicates that the farm-specific variables involved in the technical inefficiency model contribute significantly as a group to the explanation of the technical inefficiency effects in prawn production although, based on asymptotic t ratios, some slope coefficients are not significant individually (Table 5).

The confidence intervals of inefficiency parameters show the effect size of individual parameters has on technical efficiency (Table 6).

3.4 Technical efficiency distribution

The technical efficiency (TE) scores range from 9.50 to 99.94 %, with a mean score of 65 % (Table 7). The implication is that, on average, 35 % of the potential output can be recovered by eliminating technical inefficiency, which is substantial and could improve the competitiveness of the Bangladesh prawn farming. The indices of TE indicate that if the average farmer of the sample could achieve the TE level of its most efficient counterpart, then average farmers could increase their output by 34.67 % [1-(65/99.94)]. Similarly, the most technically inefficient farmer could increase the production by 90.45 % [1-(9.50/99.50)] if he/she could increase the level of TE to his/her most efficient counterpart. For a land-scarce country like Bangladesh, this gain in production will increase income and ensure better livelihood for the farmers.

The distribution of the efficiency score is quite similar at the higher and lower end of the efficiency spectrum. About 32 % of the farmers are producing at an efficiency level of less than 50 % while 27 % of the farmers are producing at an efficiency level of 90 % and above, which is encouraging.

Table 3: *Maximum likelihood estimates of the stochastic production frontier and inefficiency model*

Variable	*Parameter*	*Coefficient*	*Standard error*
Production frontier			
Constant	β_0	7.43187***	0.01624
ln *Gher* size	β_1	0.45219***	0.15078
ln Labour	β_2	0.37631***	0.13786
ln Fingerling	β_3	0.23425***	0.04939
ln Feed	β_4	0.12426**	0.05826
ln Lime	β_5	0.13062	0.10032
ln Fertiliser	β_6	0.03970	0.08494
ln Other cost	β_7	–0.07229	0.04835
ln *Gher* size × ln *Gher* size	β_{11}	0.78245***	0.14488
ln Labour × ln Labour	β_{22}	–0.19381***	0.05796
ln Fingerling × ln Fingerling	β_{33}	–0.07449***	0.00591
ln Feed × ln Feed	β_{44}	–0.04022**	0.02029
ln Lime × ln Lime	β_{55}	–0.12309**	0.05977
ln Fertiliser × ln Fertiliser	β_{66}	–0.03109	0.04922
ln Other cost × ln Other cost	β_{77}	–0.11126	0.07506
ln *Gher* size × ln Labour	β_{12}	0.08047*	0.04595
ln *Gher* size × ln Fingerling	β_{13}	0.00566	0.01457
ln *Gher* size × ln Feed	β_{14}	–0.05822***	0.02153
ln *Gher* size × ln Lime	β_{15}	0.02421	0.02908
ln *Gher* size × ln Fertiliser	β_{16}	–0.08853***	0.03137
ln *Gher* size × ln Other cost	β_{17}	0.29947***	0.03752
ln Labour × ln Fingerling	β_{23}	–0.00864**	0.00413
ln Labour × ln Feed	β_{24}	0.00342	0.00489
ln Labour × ln Lime	β_{25}	–0.01136	0.01093
ln Labour × ln Fertiliser	β_{26}	–0.01937	0.01345
ln Labour × ln Other cost	β_{27}	0.03941***	0.01478
ln Fingerling × ln Feed	β_{34}	–0.00308***	0.00273
ln Fingerling × ln Lime	β_{35}	0.02108***	0.00414
ln Fingerling × ln Fertiliser	β_{36}	0.00499	0.00454
ln Fingerling × ln Other cost	β_{37}	–0.04288***	0.00965
ln Feed × ln Lime	β_{45}	–0.00019	0.00953
ln Feed × ln Fertiliser	β_{46}	–0.00544	0.00505
ln Feed × ln Other cost	β_{47}	0.06487***	0.00489
ln Lime × ln Fertiliser	β_{56}	–0.01061**	0.00433
ln Lime × ln Other cost	β_{57}	0.07898***	0.01014
ln Fertiliser × ln Other cost	β_{67}	0.05461***	0.01784
Inefficiency function			
Constant	δ_0	1.67062*	0.89052
Education	δ_1	–0.13651***	0.03562
Training	δ_2	1.01326***	0.24709
Age	δ_3	–0.01661	0.01636
Involvement of fish farm association	δ_4	0.59012*	0.31291
Non-farm income	δ_5	–0.01471***	0.00541
Family size	δ_6	0.00039	0.07865
Distance	δ_7	0.72474**	0.30490
Water quality	δ_8	0.01216	0.22742
Lease area	δ_9	–0.01418	0.01039
Variance parameters			
Sigma-squared	σ^2	0.28584***	0.08179
Gamma	γ	0.99999***	0.00002
Log likelihood	–14.52533		
Mean TE index	65.0 %		

Note: *, ** and *** statistically significant at 10 %, 5 % and 1 % level respectively,
Number of observations: 90

Table 4: *Estimated output elasticities, marginal products and diminishing marginal products for prawn farming*

Inputs	*Output Elasticities*	*Marginal products*	*Diminishing marginal products*
Land	0.603	355.064	–319.857
Labour	0.0007	0.002	–0.00016
Fingerlings	0.058	1.310	–0.00013
Feed	0.027	0.005	–0.0000007
Lime	0.047	0.114	–0.00002
Fertiliser	0.005	0.029	–0.00002
Other cost	0.095	2.046	–0.00171

Table 5: *Generalised likelihood ratio tests of hypotheses of parameters*

Test of null hypotheses (H_0)	*Log-likelihood value of the reduced model*	*Test statistic (λ)*	*DF*	*Critical χ2 value at 95 %*	*Conclusion*
1. No inefficiency effects (H_0: $\gamma = \delta_0 = \delta_{Ed} = \ldots = \delta_{Fs} = 0$)	–40.08	51.10	11	19.045	Reject H_0
2. Technical inefficiency effects have a half normal distribution with mean zero (H_0: $\delta_0 = \delta_{Ed} = \ldots = \delta_{Fs}$)	–40.32	51.58	10	17.670	Reject H_0
3. No effects of inefficiency factors included in the inefficiency model (H_0: $\delta_{Ed} = \ldots = \delta_{Fs} = 0$)	–40.32	51.58	9	16.274	Reject H_0

Note: The value of the log-likelihood function under the specification of alternative hypothesis (unrestricted/full model) is 53.89. The correct value for the null hypothesis of no inefficiency effects are obtained from Kodde & Palm (1986).

Table 6: *Confidence intervals of inefficiency parameters on technical efficiency*

Inefficiency Parameters	*Coefficient*	*Std.err.*	*z*	*P > z*	*95 % Confidence intervals*	
					Upper bound	Lower bound
Education	–0.350	0.190	–2.850	0.015	–0.722	–0.821
Training	1.416	2.537	4.560	0.017	0.657	0.788
Age	–0.007	0.074	–0.100	0.920	–0.153	–0.138
Involvement of fish farm association	1.669	0.864	1.930	0.053	0.635	0.762
Non-farm income	–0.034	0.029	–2.990	0.013	0.590	0.622
Family size	0.145	0.407	0.360	0.722	0.653	0.943
Distance	1.286	1.009	3.180	0.040	0.690	0.753
Water quality	0.449	0.739	0.610	0.543	0.500	0.898
Lease area	–0.135	0.195	–0.690	0.487	–0.517	–0.746
Constant	–0.033	2.921	–2.690	0.090	–13.598	13.532

Table 7: *Distribution of technical efficiency scores*

Variables	*Estimates*
Efficiency levels (Percent)	
≤ 50	32.22
50 ≤ 60	14.44
60 ≤ 70	14.44
70 ≤ 80	5.56
80 ≤ 90	5.56
90 ≤ 100	27.78
Mean efficiency level	65
Minimum	9.50
Maximum	99.94
Number of observations	90

4 Discussion

4.1 Output coefficient

The coefficient of output with respect to *gher* size is the highest among all the inputs, which demonstrates the importance of scarce land in boosting prawn production in Bangladesh. The policy implication of this finding is that the government could encourage farmers to keep and increase their existing *gher* size. Coefficient of labour is the second highest, but excess use of the labour exerts negative impacts on output as observed from the second order of labour.

4.2 Parameters of the inefficiency function

Results indicate that education significantly improves technical efficiency, consistent with Asadullah & Rahman (2009) and Sharif & Dar (1996) for Bangladeshi farms. Similar results have been reported in studies that have focused on the association between formal education and technical efficiency (Uaiene & Arndt, 2009; Bozoglu & Ceyhan, 2007). In general, more educated farmers are able to perceive, interpret and respond to new information and adopt improved technologies. The educated prawn farmers are expected to follow the prawn management practices properly, which might have led to higher efficiency for them. This result is consistent with the findings by Abdulai & Eberlin (2001), which established that an increase in formal education will augment the productivity of farmers since they will be better able to allocate family-supplied and purchased inputs, select and utilise the appropriate quantities of purchased inputs while applying available and acceptable techniques to achieve the portfolio of household pursuits such as income. The age coefficient is positive and insignificant with technical efficiency, which indicates that older farmers are more capable to take proper decisions regarding farm management practices as they have many years of practical experience. This conforms to the results obtained by Dey *et al.* (2000); Alam *et al.* (2011) and Rahman *et al.* (2011). The training coefficient is negatively significant with technical efficiency, which was unexpected but consistent with Bhattacharya (2008). This contradictory result may be due to lack of participation of the most successful farmers in training programs, and thus the real impact of training may be disguised. In general, the participants of training programs in Bangladesh are farmers who have good contact with NGOs, local extension officers, and other organisations. Small and medium-scale farmers have lack of such contacts and only large farmers have good relations with the aforementioned organisations. However, large-scale farmers are not actively participating in farming activities. Only their representatives take the responsibilities in farm operation. The training program might, also in addition, be inappropriate for the farmers that are participating. The prawn farmers might require a more hands-on training, rather than a governmental/NGOs/other organisations' lecture-based training program. Involvement in fish farm associations is negatively related to the technical efficiency and is significant at the 10 % level. Thus, we conclude that the association is not useful and not fit for the job. This result conforms to that obtained by Bhattacharya (2008) who found similar relations for shrimp farmers in India. Non-farm income is positively and significantly related with technical efficiency of prawn farmers. This indicates that higher non-farm income increases the technical efficiency of prawn farmers as they are able to invest the earned money in their farming activities. This result is consistent with Haque (2011). There are large numbers of farmers who have higher level of education and who have income from non-farm activities, especially working as government employees. The family members of the farmers also contribute to non-farm income as they work outside the farms, even abroad. As prawn farming activities incur high cost, non-farm income significantly contributes additional income. Family size is negative and insignificant with technical efficiency, consistent with Irz & McKenzie (2003), which indicates that those farmers that have large families are less efficient. This might be the result of large families having excess labour if all members stay on the farm which is often the case in Bangladesh. Distance from the water canal significantly degrades technical efficiency due to inferior water quality (less natural food, organic materials and postlarvae).

4.3 Technical efficiency

The mean technical efficiency of 65 % is quite similar to the estimates for agricultural farms (aquaculture and livestock/dairy farms) in Bangladesh (Bravo-Ureta *et al.*, 2007; Coelli *et al.*, 2002; Wadud & White, 2000). Rahman *et al.* (2011) found the technical efficiency of prawn farming to be 68 %. Technical efficiency of carp culture in other Asian countries, however, ranges from 42 % in all farm types in Malaysia (Iinuma *et al.*, 1999) as well as in extensive farms in Vietnam, to 93 % amongst intensive farms in China (Dey *et al.*, 2005). Other studies such as Alam *et al.* (2011) found the TE of tilapia for Bangladesh farmers at 78 %. Sharma & Leung (2000) estimated the TE of carp polyculture in Bangladesh to be 47.5 % for extensive farming and 73.8 % for semi-intensive farming. ICLARM (2001) found the TE of carp polyculture at 70 % while Arjumanara *et al.* (2004) estimated TE of 62 and 86 % for different groups of carp farmers in Bangladesh. The wide inefficiency spectrum in this study is therefore not surprising and is similar to those reported in literature.

The inefficiency effect is significant, and education, age, training, involvement in fish farm associations, family size, non-farm income, water quality, distance of the farm from the canal and lease area, as a group, are significant determinants of technical inefficiency. By operating at full technical efficiency levels, prawn production can be improved on average from the current level of 589 to 795 kg ha^{-1}. As a result farm income would increase on average Tk. 134377 (US$ 1655.91).

5 Conclusion and Policy Implications

This study uses a translog stochastic frontier production function on survey data to determine the technical efficiency and its determinants in prawn farming in Bangladesh. The production frontier involves seven variables, including *gher* size, labour, fingerling, feed, lime, fertiliser and other cost. Similarly, the technical inefficiency model includes nine farm-specific variables, namely education, training, age, involvement to fish farm association, non-farm income, family size, distance, water quality and land lease.

The level of technical efficiency of prawn farming is low at 65 % implying that a substantial 35 % of the potential output from the system can be recovered by eliminating inefficiency, given the existing technology and resource endowments. Our results confirmed that training, involvement in fish farm associations, family size, distance and water quality positively affected technical inefficiency whereas education, age, non-farm income and lease area negatively affected technical inefficiency. In particular, policies leading to improving water quality through lime application, construct the ponds close to the water channel or digging supplementary channels for reducing farm distance, proper involvement in farming-related associations which ensure the information flow and technology change, encourage the family members involvement in the off farm activities, consider all farmers as participants of training programs (encourage small and medium farmers to participate in training programs) could be beneficial for reducing inefficiency in prawn farming in Bangladesh.

More investment in education in rural areas through private and public partnerships, initiating progress to encourage those at school-going age and ‘food for education’ programs may be harnessed as a central ingredient in the development strategies. Moreover, the farmer field schools (FFS) program, promoted by different development agencies may be rigorously implemented and practiced. This would help farmers through ‘learning by doing’ to improve their analytical and decision-making skills that contribute to adapting improved farming technologies. These measures in the long run may shift the farmers’ production frontier upward, which may in turn, reduce technical inefficiency on the one hand and lead to increase income and standard of living on the other.

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