Technical Efficiency of Shrimp and Prawn Farming: Evidence from Coastal Region of Bangladesh

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Abstract. Shrimp and prawn farming in Bangladesh have experienced spectacular growth in response to expanding global demand and higher economic return. In 2011, 180 shrimp and prawn farms were surveyed in Bangladesh to estimate their production efficiency and determine factors affecting the efficiency level. The results show that there are substantial inefficiencies among shrimp and prawn farms. The technical efficiency ranges from 55% to 97% (Mean±SD: 88±9%) for shrimp farms and from 39.56% to 99.79% (72.41±16%) for prawn farms, suggesting that shrimp and prawn farms could increase their output by 12% and 27.59%, respectively. For a land scarce country like Bangladesh this gain could increase income and ensure better livelihood for farmers. The results of the stochastic production frontier approach indicate that farmers could operate at an optimal scale for increasing their product. Farmers' education, training, age and water quality significantly affect efficiency.

Keywords: Technical efficiency, shrimp and prawn, coastal region, Bangladesh.

1 Introduction

Bangladesh is widely recognized as one of the most suitable countries in the world for brackish water shrimp (marine crustacean) (*Penaeus monodon*) and freshwater prawn (*Macrobrachium rosenbergii*) farming because of its favorable resources and agro-climatic conditions. A sub-tropical monsoonal climate, low laying agricultural land, saline water availability and a vast area of shallow water provide ideal conditions for shrimp and prawn production (Ahmed *et al.,* 2008a). Within the frame of the agro-based economy of the country, the contribution of shrimp and prawn production has been considered to hold good promise for creating jobs, earning foreign exchange and providing protein to an undernourished population. During the

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last three decades development of shrimp and prawn farming has attracted considerable attention due to its high export potential. The prawn and shrimp sector is the second largest export industry after readymade garments, generating US$396 million annually and contributing by 5.7% to the total value of exports (DOF, 2013). During 2012-2013, Bangladesh exported 50,333 tons of prawn and shrimp, valued at US$ 337.62 million, 82% of which was shrimp and the remaining 18% was prawn (Export Promotion Bureau, (EPB), 2013).

Bangladesh, like most tropical countries, derives fish from a large number of complex natural systems. In 2012-13, 3,410,254 MT of total fish were produced in Bangladesh of which 82.73% came from inland sources. Of the inland sources, 65.92% of the total catch came from the culture sector and the rest from the capture fisheries. Four sources culture fishes are: baors, ponds and ditches, commercial shrimp farms and semi-closed floodplains. Baors or oxbow lakes account for a negligible number of fish catch. In 203, 88% of total inland culture fish came from the ponds and ditches. Commercial shrimp farms account for about 11% of total culture fish catch. Marine fisheries represented about 17.27% of total catch. Most of it comes from marine artisanal source (87.60%).

In 2010, the total area under shrimp and prawn farming was estimated to be around 275,274 hectares (Ministry of Fisheries (MOF), 2013) while in 1980 it was 20,000 hectares, indicating an average increase of 35% per annum (Department of Fisheries (DOF), 2013. This level of expansion reflects the government's priorities as shrimp and prawn farming are recognized as an essential component of economic development for the country. Most shrimp and prawn farms (53%) are located in southwest Bangladesh mainly in the districts of Bagerhat, Khulna and Satkhira, and produce 46% of country's total shrimp and prawn production (DOF, 2013). The families of southwest Bangladesh having a high population density tend to be resource poor, income poor and vulnerable to environment, climate and economic variability (Bundell and Maybin, 1996; Muir, 2003). Shrimp and prawn farming therefore creates prospects for increased income and sustainable livelihood for farmers. The most spectacular boost of shrimp and prawn farming have taken place in the Satkhira and Bagerhat districts where a large number of farmers have converted their rice fields to profitable shrimp and prawn farms (Ahmed *et al.,* 2008b). In spite of the spectacular expansion of shrimp and prawn farms during the last decades, as well as the adoption by some farms of semi-intensive systems that produced higher yields, still the average yield is low compared to other Asian countries. Moreover, the expansion of shrimp and prawn farms have been accompanied by disease outbreaks and environmental degradation including destruction of vegetation and social forests, reduction in crop production (especially rice) and pasture land that have spread and threaten the sustainability of shrimp and prawn production. Disease outbreaks and environmental degradation have resulted from increased competition for limited resources linked to intensified production, overuse of chemicals, absence of proper water treatment and degradation of water quality. Besides its direct economic losses, long-term environmental degradation also creates losses that are irreversible and irrecoverable. Therefore, new ways of developing and expanding this sector in an economically viable and environmentally sustainable manner need to be identified. In this respect, among many other factors, increasing the efficiency of resource use in shrimp and prawn production at the farm level stands as an attractive option because it has the potential to generate output growth without increasing quantities of inputs generating negative environmental externalities. Based on this promises, this paper estimates the level and the determinants of technical efficiency in an attempt to modify the management strategy and increase shrimp and prawn farming productivity in Bangladesh. The objectives are pursued in parallel for two different production systems that both play important roles in Bangladesh aquaculture. The first one corresponds to shrimp culture in brackish water and the second one, corresponds to prawn culture in freshwater.

A number of studies have been conducted on shrimp and prawn farming in Bangladesh, including, technical efficiency of shrimp farming (Begum *et al.,* 2013), economic analysis of shrimp farming (Alam *et al.,* 2007), determinants of efficiency in prawn farming, conversion of rice fields to prawn farms (Ahmed *et al.,* 2010a), and sustainability of freshwater prawn farming (Ahmed *et al.,* 2010b). However, there is a lack of studies on the production performance and resource use efficiency of shrimp/prawn farming in Bangladesh, which is the major source of expansion of the shrimp/prawn industry in the country. In this context, a stochastic production frontier model is applied to investigate the level of technical efficiency as well as the factors that have an effect on the estimated (in)efficiency of shrimp/ prawn farming in Bangladesh. This study is expected to generate information that will be useful for farmers in adopting best observed production techniques, in identifying and eliminating inefficiencies, and in attaining the highest possible output within the resource endowments.

2 Materials and Methods

2.1 Data and the Study Area

The empirical analysis is based on farm-level cross sectional data collected in 2011 from Shyamnagar upazila in the Satkhira district, in the brackish water area, and Fakirhat upazila in the Bagerhat district, in the freshwater water area of southwestern Bangladesh. Shyamnagar and Fakirhat upazilas were selected because most of the brackish water shrimp and freshwater prawn farms are concentrated in this area, farmers are experienced in shrimp and prawn farming and resources and climatic conditions are favorable for shrimp and prawn farming. The shrimp and prawn farms of the selected region account for the 33% and 15% of total country's shrimp and prawn farms, respectively (DOF, 2012). Three villages from each upazilas were selected on the basis of shrimp and prawn farms concentration. A total of 90 shrimp and 90 prawn farmers (30 farms from each village) were randomly selected. A pre-tested questionnaire was used to collect technical and economic data from the shrimp and prawn farmers, as well as socio-demographic and environmental characteristics.

2.2 Theoretical Model: Stochastic Frontier Model

Farrell (1957) defined technical efficiency as the ratio between inputs per unit of output at the production frontier and inputs per unit of output in the observed case. In a more recent presentation, which is adopted in the present study, technical efficiency of the firm, which produces output y with inputs x is given by y/y*, where y* is the frontier output associated with the level of inputs x (Coelli *et al.,* 1998).

Aigner *et al*. (1977) and Meeusen and Van den Broeck (1977) proposed a stochastic frontier production function model with the following structure:

$$L\,n\,Y = f\,(X_i : \beta\,) + \varepsilon_i \qquad (1)$$

$$\varepsilon_i = V_i - U_i, \quad I = 1, \dots, N \qquad (2)$$

where Y denotes production level, X_i is input level and β is a vector of unknown parameters to be estimated. ε_i is the composed error term and f is the Cobb–Douglas function form. V_i are independently and identically distributed random errors, having $N\,(0, \delta\nu^2)$ distribution while U_i are non-negative stochastic variables, called technical inefficiency effect, associated with the technical inefficiency of production of farmers involved.

According to Battese and Coelli (1995), technical inefficiency effects are defined by

$$U_i = Z_i\,\delta + W_i\,, \quad i = 1, \dots, N \quad (3)$$

where Z_i is a vector of explanatory variables associated with technical inefficiency effects, δ is a vector of unknown parameters to be estimated, W_i are unobservable random variables, which are assumed to be identically distributed, obtained by truncation of the normal distribution with mean zero and unknown variance σ^2, such that U_i are non-negative.

The stochastic frontier production function was estimated through the application of the maximum likelihood approach, using the FRONTIER computer program developed by Coelli (1994). The stochastic frontier technique can only handle one single output. Therefore, the different outputs from shrimp and prawn production were aggregated to a single output using the actual farm gate prices. The following model specifications were used in the analysis:

$$\ln Y_i = \beta_0 + \beta_1 \ln X_{1i} + \beta_2 \ln X_{2i} + \beta_3 \ln X_{3i} + \beta_4 \ln X_{4i} + \beta_5 \ln X_{5i} + \beta_6 \ln X_{6i} + \beta_7 n X_{7i} + v_i - u_i \qquad (4)$$

where,

ln represents the natural logarithm (i.e., to the base *e*) and *i* refers to the i^{th} farm in the sample;

Y_i represents geometric mean based on revenue share of multi-output (such as shrimp/prawn production, other fine fish production, dike crops and rice production) which is an ideal output variable in the production frontier analysis as suggested Iinuma *et al.,* 1999;

X_{1i} represents the total area of land/gher[1] size in hectares;

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[1] *Gher* is Bengali word used to describe coastal fisheries in the south-western region of Bangladesh. G*her* means encirclement of brackish water areas along the coastal belts by building dwarf earthen dykes in order to hold tidal water containing shrimp fries until they grow to marketable size.

X_{2i} represents the human labor employed in man-days per hectare;
X_{3i} represents total number of shrimp/prawn fingerlings released/stocked per hectare per year;
X_{4i} represents quantity of feeds in kg (pulses, oilcake and wheat bran) applied per hectare per year;
X_{5i} represents quantity of lime applied in kg per hectare per year;
X_{6i} represents quantity of manure/fertilizer used in kg per hectare per year;
X_{7i} represents quantity of pesticide used in kg per hectare per year/amount of cost incurred for other inputs in Taka per hectare per year;
β_1 - β_7 are parameters to be estimated;
v_i represents the random variations in output due to factors outside the control of the farm operator such as: degree of water salinity, shrimp fry availability in the sea water, disease of shrimp, existence of carnivorous (predator) fish species during the entry of sea water in the farms.

Following Battese and 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:

$$U_i = \delta_0 + \delta_1 z_{1i} + \delta_2 z_{2i} + \delta_3 z_{3i} + \delta_4 z_{4i} + \delta_5 z_{5i} + \delta_6 z_{6i} + \delta_7 z_{7i} + \delta_8 z_{8i} + \delta_9 z_{9i} \quad (5)$$

where z_{1i} denotes the age of the ith farmer in year;
z_{2i} denotes the education (year of schooling) of the ith farmer;
z_{3i} denotes the training received by the ith farmer (1 if received, 0 otherwise);
z_{4i} denotes the involvement in fish farm associations of ith farmer (1 if involve, 0 otherwise);
z_{5i} denotes share of non-farm income to total income of ith farmer in percent;
z_{6i} denotes the family size of ith farmer in persons;
z_{7i} denotes the distance of the farm from the canal of ith farmer (1 if less than 500 metres, 0 otherwise);
z_{8i} denotes the water quality of gher of ith farmer (1 if good enough, 0 otherwise); and
z_{9i} denotes the proportion of lease area to total shrimp/prawn farm area of ith farmer;
δ_1, δ_2, δ_3, δ_4, δ_5, δ_6, δ_7, δ_8 and δ_9 are unknown parameters to be estimated.

2.3 Sample characteristics

A summary of the sample data from the survey for the variables incorporated in the stochastic frontier model is presented in Table 1. The table shows that considerable variation exists among the farmers in terms of production practices and the socioeconomic attainments. The average gher size of the sampled shrimp farms is 2.0 ha, ranging from 0.53 ha to 6.68 ha, while 28% of operations have a gher size of less than 1.0 ha. The average gher size for the prawn farms is 1.96 ha, ranging from 0.20 ha to 6.32 ha and 30% of the farms have a gher size of less than 1 ha.

Table 1. Summary statistics for variables in the stochastic frontier production functions for shrimp and prawn farmers of different farming types

Variables	Farm types	Sample mean	Standard deviation	Minimum value	Maximum value
Geometric mean of total return (Taka/ha)	Shrimp	16125.68	7728.79	6485.89	44608.69
	Prawn	9133.44	2325.93	4737.19	18206.71
Land (Hectares)	Shrimp	2.00	1.52	0.53	6.68
	Prawn	1.96	1.37	0.20	6.32
Labour (Person-days/ha)	Shrimp	116.79	37.45	35.93	220.45
	Prawn	88.61	22.37	39.58	151.25
Labour (Person-days/ha)	Shrimp	116.79	37.45	35.93	220.45
	Prawn	88.61	22.37	39.58	151.25
Shrimp/Prawn fry/fingerlings (Number/ha)	Shrimp	8034.15	1191.71	4574.07	10977.78
	Prawn	13052.84	677.62	11805.15	14250.00
Feed (kg/ha)	Shrimp	134.55	116.61	0.00	428.13
	Prawn	1086.23	160.15	833.30	1504.00
Lime (kg/ha)	Shrimp	53.13	114.56	0.00	439.95
	Prawn	168.31	74.19	67.33	301.00
Organic fertilizer (kg/ha)	Shrimp	168.49	61.37	44.85	274.44
	Prawn	170.32	72.38	75.74	290.00
Pesticide	Shrimp (kg/ha)	9.56	9.13	0.00	37.05
	Prawn (Other cost Taka)	5638.01	1476.89	3694.44	15607.11
Education (years of schooling)	Shrimp	10.17	3.45	0.00	16.00
	Prawn	11.27	2.09	5.00	16.00
Age (years)	Shrimp	45.36	10.16	25.00	70.00
	Prawn	42.89	6.32	29.00	55.00
Nonfarm income (Taka)	Shrimp	44103.33	35847.67	0.00	150000.00
	Prawn	59455.56	32719.83	12000.00	150000.00
Family size (persons)	Shrimp	5.16	1.39	2.00	10.00
	Prawn	5.16	1.11	3.00	8.00
Proportion of lease area (%)	Shrimp	6.76	19.33	0.00	100.00
	Prawn	7.28	1.55	0.00	81.00

The average gher size of shrimp farming (2.0 ha) is comparatively larger compared with prawn (1.96 ha) farming. Stocking density of shrimp farms on average (number of fingerling released per ha) is appeared to be 8034.15 pieces while stocking density of overall prawn farms is 13052.84 pieces on average, which has considerable variation in the two farm types as prawn farmers used more fingerlings compared with shrimp farmers. The average feed application in shrimps is 134.55 kg/ha which is higher compare to earlier studies as shrimp is grown naturally without any feed or little feed application. The average feed application in the prawn system is 1086.23 kg/ha. In prawn farming farmers used more feed compared to shrimp. Prawn farmers used more lime (168.31kg/ha) compared with shrimp farmers (53.13 kg/ha). All the sample shrimp and prawn farmers apply organic fertilizer for gher preparation and water treatment which ranges from 44.85 kg/ha to 274.44 kg/ha with a mean of 168.49 kg/ha and from 75.74 kg/ha to 290.00 kg/ha a mean of 170.32 kg/ha, respectively, indicating that farmers of both production systems use almost the same quantity of fertilizer. The mean of nonfarm annual income of the shrimp and prawn farmers are Tk. 44103.33 (US$ 543.48) and Tk. 59455.56 (US$ 732.66) respectively. The average labor use in the shrimp and prawn farming is 116.79 man-days/ha, ranging from 35.93 man-days/ha to 220.45 man-days/ha and 88.61 man-days/ha ranging from 39.58 man-days/ha to 151.25 man-days/ha, respectively. Although intensity of inputs use varies across gher, the overall technology practice is largely improved extensive (33% of sample farmers) (relying more on naturally food produced in the water body and to some degree on supplementary inputs) to semi-intensive (67%, relying mostly on supplementary feed and fertilizer). The average age of farmers vary from 45.36 years in shrimp to 42.89 years in prawn farming. Average general educational level is seemed to be moderate varying from ten years in year round to eleven years in shrimp and prawn farming (Table 1).

3 Empirical Results

3.1 Stochastic Frontier Results

The estimates of the stochastic frontier analysis which shows the best practice performance, i.e., efficient use of the available technology, is presented in Table 2. The empirical results in Table 2 indicate that the output elasticity with respect to gher size in overall shrimp farming was estimated to be -0.281 and is significant at 1% level which is unexpected but might be due to over use of input. This indicates that, if the gher size of shrimp farms is increased by one percent, then the per hectare return from shrimp is estimated to decrease by 0.281%. In the overall shrimp farming the elasticity of output with respect to labor, fingerlings, organic fertilizer and pesticide are estimated to be 0.104, 0.302, 0.149 and 0.063 respectively and statistically significant. The elasticity of output with respect to fingerlings implies that, if the number of shrimp fingerlings is increased by one percent, the shrimp return is estimated to increase by 0.302%. The increase in the use of shrimp fingerling is expected to have a positive effect on shrimp production, unless the quality of fingerling is very poor or diseased.

In the case of prawn farming, elasticity of frontier production with respect to gher size is -0.167 and significant at 1% level. This indicates that if the area under prawn production is to be increased by one percent, the average return from prawn is estimated to decrease by 0.167% which is wondering as land has some impacts on production. It might be due to over use of inputs of the small farmers and less use of inputs of the large farmers. Further, the elasticity of output with respect to fingerlings, feed, organic fertilizer and pesticide are estimated to be 0.089 and 0.741, 0.297, 0.310, 0.162, respectively, and statistically significant.

Gher size may have some influence on production of output but we encountered a negative sings for gher size both shrimp and prawn farming which are significant. Whether small lands are more productive or not is still dilemma. No definite answer is established as yet. Rahman (2005) found medium sized gher having the highest yield. The small gher get intensively input fed since additional of a small quantity of inputs adds very little to the overall cost that is not usually felt burdened. However, this small addition of inputs might get proportionately higher than the gher requires. It is likely that this might have happened beyond the knowledge of the farmers. On the contrary, larger land owners also seldom add inputs proportionately with the gher size because costs associated with the inputs application for bigger gher are high. Therefore, they are likely to add proportionately less than the gher requires. This feeling often results in proportionately higher input feeding for small ghers and lower for larger ghers. This is general scenario in particularly the shrimp and prawn farming system under the existing economic conditions of the farmers. Appearance of a negative signs for the coefficient of gher is therefore not surprising.

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 2). In overall shrimp farming, education of the farmers, training, age and nonfarm income have positive impact on technical efficiency (negative impact on technical inefficiency and involvement in fish farm associations, family size, distance, water quality and lease area have negative impact on technical efficiency (positive impact on technical inefficiency).

Results indicate that education significantly improves technical efficiency of shrimp farming, consistent with Asadullah and Rahman (2009) and Sharif and Dar (1996) for Bangladeshi farms. The educated farmers are expected to follow the shrimp management practices properly, which might have led to higher efficiency for them. The age coefficient is positive and significant with technical efficiency in shrimp farming 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 confirms to the results obtained by Dey *et al.* (2000); Alam *et al.* (2011) and Rhaman *et al.* (2011).

In the case of prawn farming factors such as nonfarm income, family size and water quality were positively related to inefficiency while education, training, age, involvement of fish farm associations, distance of the farm from the canal, and lease area were negatively related to inefficiency. It is expected that the coefficient of nonfarm income (not significant) to be positive however the findings of this study is consistent with the findings of Haque (2011).

Table 2. Maximum Likelihood estimates of the stochastic frontier production function of the shrimp and Prawn farming

Variables	Parameters	Shrimp		Prawn	
		Coefficients	Standard error	Coefficients	Standard error
Production frontier					
Constant	β_0	6.580***	1.303	12.474***	0.955
Land (x_1)	β_1	-0.281***	0.032	-0.167***	0.047
Labour (x_2)	β_2	0.104*	0.058	0.089	0.081
Fingerlings (x_3)	β_3	0.302**	0.150	0.741***	0.236
Feed (x_4)	β_4	0.004	0.009	0.297	0.258
Lime (x_5)	β_5	0.008	0.009	-0.346**	0.165
Organic fertilizer (x_6)	β_6	0.149***	0.048	0.310**	0.148
Pesticide (x_7)	β_7	0.063***	0.0137	0.162***	0.038
Inefficiency function					
Constant	δ_0	-2.411	3.354	1.748***	0.370
Education	δ_1	-0.166**	0.176	-0.096***	0.026
Training	δ_2	-0.755	0.818	-0.103*	0.119
Age	δ_3	-0.016*	0.014	-0.014*	0.009
Involvement of fish farm association	δ_4	0.561	0.680	-0.015	0.198
Non-farm income	δ_5	-0.005	0.008	0.211	0.918
Family size	δ_6	0.385	0.391	0.021	0.055
Distance	δ_7	0.183	0.306	-0.076	0.237
Water quality	δ_8	0.216*	0.209	0.154*	0.131
Lease area	δ_9	0.008	0.135	-0.129	0.825
Variance parameters					
Sigma-squared	σ^2	0.415	0.470	0.091***	0.011
Gamma	γ	0.975***	0.031	0.999***	0.0006
Log likelihood		37.23		25.73	
Mean TE index		87.84%		72.41	

*** Significant at 1%, ** Significant at 5% and * Significant at 10%

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 and 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 utilize the appropriate quantities of purchased inputs while applying available and acceptable techniques to achieve the portfolio of household pursuits such as income. The training coefficient is positively significant with technical efficiency in prawn farming, which consistent with Rashid (2002).

It is evident from Table 2 that the estimate of σ^2 and γ are large and significantly different from zero, indicating a good fit and the correctness of the specified distributional assumption. Moreover, the estimate of γ, which is the ratio of the variance of farm-specific technical efficiency to the total variance of output, is 0.98 of shrimp; and significant at 1% level. In the case of overall prawn farming the γ-parameter associated with the variances in the stochastic production frontier is estimated to be close to 1 (Table 2). This suggests that the technical inefficiency effects are significant component of the total variability of shrimp output for different farming methods. Therefore, the traditional production function with no technical inefficiency effects is not an adequate representation of the data.

3.3 Efficiency Distribution

The mean technical efficiency of the shrimp farmers in Bangladesh is 88±9% (Mean ± Standard deviation), ranging from 52% to 97% (Table 3). And the mean technical efficiency of the prawn farmers in Bangladesh is 72.41±16% ranging from 39.56% to 99.79%. The implication is that, on average, shrimp and prawn farming could generate 12% and 25% higher output, respectively by eliminating technical inefficiency, which is substantial and could improve the competitiveness of the Bangladesh shrimp and prawn farming. The indices of TE indicate that if the average shrimp farmers of the sample could achieve the TE level of its most efficient counterpart, then average shrimp farmers could increase their return by 9% [1-(88/97)].

On the other hand, the indices of TE indicate that if the average prawn farmers of the sample could achieve the TE level of its most efficient counterpart, then average prawn farmers could increase their return by 27% [1-(72/99)]. Similarly, the most technically inefficient prawn farmers could increase the return by 60% [1-(40/99)] if he/she could increase the level of TE to his/her most efficient counterpart. Similarly, the most technically inefficient shrimp farmers could increase the return by 46.39% [1-(52/97)] if he/she could increase the level of TE to his/her most efficient counterpart. For a land-scarce country like Bangladesh, these gains in return will increase their overall income and ensure better livelihood for the farmers. The distributions of the efficiency scores are quite similar at the higher of the efficiency spectrum for farm types. About 4.44% of the shrimp farmers respectively are producing at an efficiency level of less than 60% while 57.78% of the shrimp farmers are producing respectively at an efficiency level of 90% and above, which are encouraging (Table 3). About 8.89% of the prawn farmers are producing at an efficiency level of less than 50% while 15.56% of the prawn farmers are producing at an efficiency level of 90% and above.

The mean technical efficiency of shrimp and prawn farms is 87.84% and 72.41% respectively, which is quite similar to the estimates of average agricultural farms (aquaculture and livestock/dairy farms) in Bangladesh and/or elsewhere in the world (Bravo-Ureta *et al.,* 2007; Coelli *et al.*, 2002; Wadud and White, 2000, Theodoridis *et al.*, 2009; Theodoridis *et al.*, 2011). Haque (2011) found the TE of shrimp culture to be 71%. Rashid (2002) found technical efficiency of extensive, improved extensive and semi intensive shrimp farming were 82%, 85%, 93% respectively. However, technical efficiency of shrimp farming in other countries appeared to be higher than that found in Bangladesh. Studies on India conducted by Reddy *et al.* (2008) estimated the TE of shrimp to be 93%. Other studies such as Alam *et al.* (2011) found the TE of tilapia in Bangladesh farmers at 78%. Sharma and 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%. This wide inefficiency spectrum is not surprising and is similar to those reported in the literature (Rahman *et al.,* 2011; Alam *et al.*, 2011; Bravo-Ureta *et al.*, 2007; Coelli *et al.,* 2002; Wadud and White, 2000).

3.4 Tests of Hypotheses

A likelihood ratio test was conducted to test the null hypothesis that the Cobb-Douglas production function could be replaced by the translog production function. The test statistic H_0: $\beta_{jk} = 0$, H_1: $\beta_{jk} \neq 0$, has a likelihood ratio value of 12.21 for shrimp and 9.35 for prawn farms, implies a rejection of the null hypothesis at the 5% significance level. In other words, the Cobb-Douglas production function is more suitable to the shrimp and prawn farms survey data that adequately captures the production behaviour.

Now we turn our attention to the tests of hypotheses for the study. Hypothesis (1): the inefficiency effects are not present, symbolically,

$$H_0: \gamma = \delta_0 = \delta_1 = \delta_2 = ... = \delta_9 = 0; \text{ and}$$

hypothesis (2): the coefficients of the explanatory variables in the inefficiency model are equal to zero (and hence that the technical inefficiency effects have the same truncated-normal distribution) i.e.,

$$H_0: \delta_1 = \delta_2 = ... = \delta_9 = 0$$

were tested using the generalized likelihood-ratio statistic, λ, defined by Equation 5. Formal tests of hypotheses associated with the inefficiency effects (hypotheses (1) and (2)) are presented in Table 4. It is evident from Table 4 that the null hypothesis H_0: $\gamma = \delta_0 = . . . = \delta_9 = 0$ is rejected for the shrimp and prawn farming indicating the significant presence of inefficiency effects on shrimp and prawn farming. Thus the traditional average response function is not an adequate representation for shrimp and prawn production, given the specification of the stochastic frontier and inefficiency model, defined by Equations (3) and (4).

The second null hypothesis H_0: $\delta_1 = \delta_2 = ... = \delta_9 = 0$ implies that technical inefficiency effects follow a standard truncated normal distribution (Stevenson, 1980) as the null hypothesis is rejected at 5% level of significance for both categories of farming. 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 shrimp and prawn production although, based on asymptotic t ratios, some slope coefficients are not significant individually.

Table 3. Distribution of technical efficiency scores

Variables	Estimates	
	Percent	
Efficiency levels	Shrimp	Prawn
≤ 50	0.00	8.89
50 ≤ 60	4.44	11.11
60 ≤ 70	3.33	30.00
70 ≤ 80	3.33	13.33
80 ≤ 90	31.11	21.11
90 ≤ 100	57.78	15.56
Mean efficiency level	0.88	0.72
Minimum	0.52	0.4
Maximum	0.97	0.99
Standard deviation	0.09	0.16
Number of observations	90	90

Table 4. Generalized 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 χ^2 value at 95%	Conclusion
1. No inefficiency effects (H_0: $\gamma = \delta_0 = \delta_{Ed} = \ldots = \delta_{Fs} = 0$)					
Shrimp farming	27.26	19.95	11	19.045	Reject H_0
Prawn farming	13.34	24.83	11	19.045	Reject H_0
2. No effects of inefficiency factors included in the inefficiency model (H_0: $\delta_{Ed} = \ldots = \delta_{Fs} = 0$)					
Shrimp farming	27.22	20.02	9	16.274	Reject H_0
Prawn farming	13.29	24.88	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 Kode and Palm (1986).

The next issue of interest is to test the hypothesis (3): shrimp farms are equally technical efficient with prawn farming operating under different farming types. A simple t-test was administered for testing this hypothesis. Assuming H_o to be true, the hypothesis can be written as, technical efficiency of shrimp farms = technical efficiency of prawn farms;
H_1 : H_o is not true.

Formal test of hypothesis (3) associated with the technical efficiency of farms is presented in Table 5. The null hypotheses considered in Table 5, $H_o: TE_{(sh)} = TE_{(pr)}$ is rejected at 1% level of significance which indicated that there are evidence that the mean of technical efficiency is significantly different.

Table 5. Statistics for test of hypothesis involving technical efficiency of the shrimp and prawn farms types

Null Hypothesis	Test Statistic t	Critical Value (5%)	Decision
$H_o: TE_{(sh)} = TE_{(pr)}$	7.870	1.654	Reject H_o

Note: sh = shrimp, pr = prawn.

4 Conclusions and Policy Implications

This study examines the efficiency of shrimp and prawn farming in Bangladesh. The production data and several farm-specific data were collected from a sample of shrimp and prawn farmers and analyzed using a stochastic production frontier, including a model for the technical inefficiency effects. The parameters for the production frontier and those for the technical inefficiency model are estimated simultaneously using a ML estimation technique. The results indicate that there are significant production inefficiencies among the sample shrimp and prawn farmers in Bangladesh. The mean technical efficiency level of shrimp and prawn farming were 88% and 72% respectively implying that a substantial 18% and 28% of the potential output from the shrimp and prawn farming system can be recovered by eliminating inefficiency. Reductions in technical inefficiencies are unlikely to bring about large productivity gains. Our estimates suggest that these efficiency gains could mainly come from increased production intensity, from the improvement in the adoption of management practices, and from making better use of other inputs. The key factors of the management practices of brackish water shrimp and fresh water prawn farming in Bangladesh are to be considered by farmers as feeding show improper application. The quality, quantity of feeds, and frequency of feeding are important considerations in shrimp and prawn farming management, which will enhance the productivity of shrimp and prawn farming. In addition, fingerlings, fertilizer and pesticides are significant factors contributing positively to the production of shrimp and prawn. Finally, education, age of farmers, and water quality, are significant determinants of technical inefficiency of shrimp and prawn farming. The study reveals that the level of understanding of shrimp/ prawn farming technology is different across farmers, particularly in terms of inputs application. The decision to add or not to add inputs must be reasoned. It has to be judicious and this could help farmers to increase their farm efficiency. Policies leading to the improvement of farm education would be favourable for improving the technical efficiency of farmers. 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 develop their 'learning by doing' practices and 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 raise income and standard of living of the farming people on the other.

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