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TECHNICAL EFFICIENCY OF SHRIMP FARMERS IN BANGLADESH: A STOCHASTIC FRONTIER PRODUCTION FUNCTION ANALYSIS

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ABSTRACT

This study examines the technical efficiency of shrimp farmers of south-eastern and south-western Bangladesh. Farm level data were collected from 155 farmers taking into account three farming methods viz extensive, improved extensive and semi-intensive. Stochastic production frontiers are estimated for shrimp in two regions of Bangladesh. Sources of yield variations, i.e., production input, technical efficiency and other factors in all the three methods are investigated in this study. Factors affecting technical inefficiency are also analyzed simultaneously with the production frontiers using maximum likelihood method by Frontier 4.1 program. The study showed that 85%, 61% and 87% variation respectively in output among the farming methods in shrimp cultivation is due to differences in technical efficiency. Land, fry and feed have significant influence on the level of shrimp production. Varying from 0.56 to 1.00 the mean technical efficiency was found to be 0.82, 0.85 and 0.93 respectively in extensive, improved extensive and semi-intensive farming methods.

I. INTRODUCTION

The measurement of efficiency (technical, allocative and economic) has remained an area of important research both in the developed and developing countries. Especially in developing agricultural economies where resources are meager and opportunities for developing and adopting better technologies are dwindling, efficiency measurement is very important because it is a factor for productivity growth (Tadesse and Krishnamoorthy 1997). Such studies help benefit these economies by determining the extent to which it is possible to raise productivity by improving the neglected source, i.e., efficiency, with the existing resource base and the available technology. Hence, by doing so, they could help decide whether to improve efficiency first or develop a new technology in the short run.

Shrimp farming has had a significant impact on the economy of Bangladesh in terms of its contribution to export earnings and employment generation on and off-farm through a series of backward and forward linkages. However, this process has entailed high environmental costs, including destruction of mangrove forests, reduction in crop production (especially rice) and green vegetation. It has also set in motion socio-economic changes. All these changes may have serious implications for sustainability of shrimp farming. The shrimp industry is influenced by a range of government policies and institutional arrangements that

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have been designed over time to achieve various individual socio-economic objectives. The measures used in the industry include *inter alia* subsidized credit to promote diffusion of intensive and semi-intensive technologies and leasing of government land for shrimp farming. These and other agreements are in place to achieve a range of objectives including raising production/productivity in shrimp farms, generating employment and earning foreign exchange. Expanding shrimp cultivation consistent with ecologically sustainable development is a priority area identified by the government (MOFL and FAO 1992).

Although Bangladesh has a great potential for shrimp culture, its production level is low. The fisheries sub-sector, and especially shrimp culture contributes a lot to the country's gross domestic product (GDP) and export earnings. The present production level of about 240 kg/ha is quite low compared to other Asian shrimp producing countries. Taiwan, Thailand, India, Philippines and Indonesia are the major Asian shrimp producing countries having 3,571 kg, 2,583 kg, 750 kg, 625 kg and 400 kg per hectare yield, respectively. Moreover, Bangladesh ranks as the highest cost producer per kilogram (US $12.04), followed by India (US $5.96), Malaysia (US $5.50), Sri Lanka (US $4.56), Vietnam (US $3.34) and China (US $2.27) (Ling *et al.* 1999).

If one knows the existing efficiency level of farmers in using the inputs for shrimp production, then viable plans could be taken to increase shrimp production up to the maximum level. If the farmers are found to be technically inefficient, production can be increased to a large extent with the existing level of inputs and available technology by rearranging input combinations. On the other hand, if the farmers are found to be technically efficient, then the government can increase investment on information and education and can try to promote new technologies in order to increase production to earn more foreign exchange. The main objective of this study is to determine the level of efficiency of shrimp farmers and to compare it across the farming methods. This is because determining the efficiency status of farmers is very important for policy purposes. In an economy where resources are scarce and opportunities for new technologies are lacking, inefficiency studies will be able to show that it is possible to raise productivity by improving efficiency without changing the resource base or developing new technology. It also helps determine the under and over utilization of factor inputs.

A number of studies have been undertaken on different economic aspects of shrimp culture in Bangladesh. The studies include review and appraisal of different public and private policies and schemes (Nuruzzaman 1991; Rahman 1993; Chowdhury 1993; Toufique 1997), costs, returns and profitability analyses (Hussain *et al.* 1986; Ahmed 1986), socio-economic condition of shrimp farmers (DANIDA/DOF mission 1989), marketing of shrimps (Guimaraes 1989) and on environmental issues (Mazid 1995; Chicoine 1996; Awal 1996; ESCAP 1988).

However, no study on production efficiency in shrimp farming has yet been undertaken. The present study looks at the production behavior of the farms operating under the three different farming methods (viz extensive, improved extensive and semi-intensive), and the intrinsic characteristics and variations in the efficiency level across the methods. Therefore, this study differs from the others conducted in the past in a number of important ways. Firstly, it attempts to deal with technical efficiency of shrimp farming in Bangladesh. Secondly, it deals with the comparison of efficiency across the farming methods. Third, it addresses the inefficiency effects of some farm specific variables which are not under the control of farm operator. Finally, it deals with the effect of some important factor inputs on the shrimp production process.

Results and information gathered in this study should be useful to farmers, extension workers, non-government organizations (NGOs) and policy makers in choosing or suggesting better production method/technology to have higher yield and to maximize profit within the resource endowments. Findings of this study will also help to become aware of the environmental degradation and other socio-economic consequences of the expansion and intensification of shrimp farming. Hopefully people will become cautious and take adequate steps and measures in future production programs.

II. THEORETICAL MODELS

Production Frontier Estimation

To examine technical efficiency for shrimp production under extensive, improved extensive and semi-intensive methods, frontier production functions need to be estimated. As in Bravo-Ureta and Evenson (1994), Bravo-Ureta and Rieger (1991) and Xiaosong Xu and Scott R. Jeffrey (1998), the parametric technique used in this study follows the Aigner, Lovell and Schmidt (ALS) (1977) stochastic frontier model to estimate the technical efficiency. The production functions for extensive, improved extensive and semi-intensive methods are specified as

$$Y_i = X_i\beta_i + \varepsilon_i \quad (1)$$

where Y_i = shrimp output, X_i = a $1\times k_i$ matrix of inputs, β_i = a $k_i\times 1$ matrix of parameters associated with X_i, ε_i = error terms, and i = the i^{th} observation. The 'stochastic frontier' (also called 'composed error') model, introduced by ALS (1977) and Meeusen and van den Broeck (1977), postulates that the error term ε_i is made up of two independent components,

$$\varepsilon_i = v_i - u_i \quad (2)$$

The error component v_i represents the symmetrical disturbance that captures random errors, erroneous data, etc., and is assumed to be identically and independently distributed as a N(0, σ_v^2). The error component u_i is the asymmetrical term that captures the technical inefficiency of the observations and is assumed to be distributed independently of v_i. Therefore, statistical distributions for u_i must be one sided.

Hence, the production frontiers may be written as

$$Y_i = X_i\beta_i + v_i - u_i \quad (3)$$

where v_i is two sided N(0, σ_v^2) and u is normal variate truncated at the mean as

$$f(u) = \frac{2}{\sigma_u \sqrt{2\pi}} \exp\left(\frac{-u^2}{2\sigma_u^2}\right) \qquad (u \geq 0) \qquad (4)$$

The term u is the one-sided error. This implies that each observation is on or below the frontier. The u_i is non-negative random variable and called technical inefficiency effect, which is assumed to be independently distributed such that u_i is defined by truncation (at zero) of the normal distribution with means μ_i and variance σ_u^2 (Seyoum *et al.* 1998). v_i is the usual two-sided error that represents the random shifts in the frontier due to favorable and unfavorable factors. It captures measurement error in Y as well.

The estimation method proposed by ALS (1977) is the maximum likelihood (MLE). Starting from the density function of a symmetrical normal variable and a half-normal variable, and supposing that the production function is linear, they elaborate the likelihood function that must be maximized.

The density function of $\varepsilon = v - u$ is:

$$f(\varepsilon) = \frac{2}{\sigma} f^*\left(\frac{\varepsilon}{\sigma_\varepsilon}\right) \times \left[1 - F^*\left(\frac{\varepsilon\lambda}{\sigma_\varepsilon}\right)\right], \; -\infty \leq \varepsilon \leq +\infty \qquad (5)$$

where $\sigma_\varepsilon^2 = \sigma_u^2 + \sigma_v^2, \quad \lambda = \sigma_u / \sigma_v$

$f^*(.)$ and $F^*(.)$ are density and distribution functions of the standard normal. The log likelihood function, if there are N observations, can be written as

$$\ln L(Y|\beta, \lambda, \sigma^2)$$

$$= N\ln\frac{\sqrt{2}}{\sqrt{\pi}} + N\ln\sigma^{-1} + \sum_{i=1}^{N} \ln\left[1 - F^*\left(\varepsilon_i \lambda \sigma^{-1}\right)\right] - \frac{1}{2\sigma^2}\sum_{i=1}^{N} \varepsilon_i^2 \qquad (6)$$

Once λ and σ are obtained, σ_u and σ_v can be calculated. To measure average inefficiency, Aigner, Lovell and Schmidt (1977) suggested to use $\lambda = \sigma_u/\sigma_v$ and $E(u) = \frac{\sqrt{2}}{\sqrt{\pi}} \sigma_u$. In case of the Cobb-Douglas (C-D), the production frontier may be expressed as

$$Y = AK^{\alpha}L^{\beta}e^{-u}e^{v} \tag{7}$$

In this case the technical efficiency is

$$e^{-u} = Y/(AK^{\alpha}L^{\beta}e^{v}) \tag{8}$$

where u is half normal variate. The mean of technical efficiency is, then, obtained as

$$E\left(e^{-u}\right) = 2\exp\left(\frac{\sigma_u^2}{2}\right)\left[1 - f^*\left(\sigma_u\right)\right] \quad \text{(Maddala 1983)} \tag{9}$$

Jondrow *et al.* (1982) propose the method of estimation of individual farm inefficiency by showing that the expected value of u for each observation could be obtained from conditional distribution of u, given ε and with the normal distribution for v and half normal for u. The expected value of inefficiency for each farm, given ε, can be obtained as Bravo-Ureta and Rieger 1991 and Wang *et al.* 1996,

$$E\left(u \mid \varepsilon\right) = \frac{\sigma_u \sigma_v}{\sigma_\varepsilon}\left[\frac{f^*\left(\varepsilon\lambda/\sigma_\varepsilon\right)}{1 - F^*\left(\varepsilon\lambda/\sigma_\varepsilon\right)} - \frac{\varepsilon\lambda}{\sigma_\varepsilon}\right] \tag{10}$$

Technical Inefficiency Effect Equation

The u_is are non-negative random variables, associated with the technical inefficiency of production of the farmers in the population, assumed to be independently distributed such that the technical inefficiency effect for the i[th] farmer, u_i, is obtained by truncation (at zero) of the normal distribution with mean, μ_i and variance, σ^2, such that

$$\mu_i = \delta_0 + \delta_1 z_{1i} + \ldots + \delta_n z_{ni} \tag{11}$$

where $z_{1i}, \ldots, z_{ni}$ are explanatory variables.

The maximum-likelihood estimates for all parameter of the stochastic frontier and inefficiency effect model, defined by equations (3) and (11), respectively are simultaneously obtained by using the computer program FRONTIER Version 4.1 (Coelli 1996) which estimates the variance parameters in terms of

$$\sigma_\varepsilon^2 = \sigma_v^2 + \sigma_u^2 \tag{12}$$

and

$$\gamma = \sigma_u^2/\sigma_\varepsilon^2 \tag{13}$$

where γ is the ratio of the variances of farm-specific technical inefficiency to the total variance of output and has a value between zero and one.

The technical efficiency of a farmer at a given period of time is defined as the ratio of the observed output to the frontier output which could be produced by a full-efficient farm, in which the inefficiency effect is zero. Given the specifications of the stochastic frontier models (3 and 11), the technical efficiency of i^{th} farmer, can be shown to be equal to

$$TE_i = \exp(-U_i) \quad (14)$$

Thus, the technical efficiency of a farmer is between zero and one and is inversely related to the inefficiency effect. The efficiencies are predicted using the predictor that is based on the conditional expectation of $\exp(-U_i)$, presented in Battese and Coelli (1993), which is programmed in FRONTIER Version 4.1.

III. EMPIRICAL MODEL

A C-D type stochastic frontier production function has been specified in this study in order to estimate the level of technical efficiency in a way consistent with the theory of production function. The C-D form of production function has some well-known properties that justify its wide application in economic literature (Henderson and Quandt 1971). It is a homogeneous function that provides a scale factor enabling one to measure the returns to scale and to interpret the elasticity coefficients with relative ease. It is also easy to estimate and mathematically manipulate. On the other hand, the C-D production function makes several restrictive assumptions. It is assumed that the elasticity coefficients are constant, implying constant shares for the inputs. The elasticity of substitution among factors is unity in the C-D form. Moreover, this being linear in logarithm, output is zero if any of the inputs is zero, and the output expansion path is assumed to pass through the origin. However, it is also argued that if interest rests on efficiency measurements and not on an analysis of the general structure of the underlying production technology, the C-D specification provides an adequate representation of the production technology. In addition, its simplicity and wide spread use in agricultural economics outweigh its drawbacks (Rahman *et al.* 1999).

The explicit C-D stochastic frontier production function for the three shrimp farming methods is given as:

$$\ln Y_i = \beta_0 + \beta_1 \ln X_{1i} + \beta_2 \ln X_{2i} + \beta_3 \ln X_{3i} + \beta_4 \ln X_{4i} + \beta_5 \ln X_{5i} + v_i - u_i. \quad (15)$$

where

ln represents the natural logarithm and i refers to the i^{th} farm in the sample;

Y_i represents shrimp output in kg;

X_{1i} represents the area of land in hectares;

X_{2i} represents the quantity of labor in person-days;

X_{3i} represents the value of tools and equipment cost involved (pump, boat, nets, furniture, etc.)

X_{4i} represents the amount of shrimp fry in number;

X_{5i} represents amount of feed in kg;

β_1 - β_5 are parameters to be estimated;

v_i represents the random variable in output which encompasses 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.

The u_i is non-negative half normal variable, associated with the technical inefficiency of production and is specified as follows:

$$\mu_i = \delta_0 + \delta_1 z_{1i} + \delta_2 z_{2i} + \delta_3 z_{3i} + \delta_4 z_{4i} \quad (16)$$

where z_{1i} denotes the age of the i^{th} farmer;

z_{2i} denotes the year of formal schooling of the i^{th} farmer;

z_{3i} denotes the experience of the i^{th} farmer;

z_{4i} denotes farm size of i^{th} farmer;

δ_1, δ_2, δ_3 and δ_4 are unknown parameters to be estimated.

It is important to note that the above model for the inefficiency effects (16) can only be estimated if the inefficiency effects are stochastic and have a particular distributional specification. Hence, there is interest to test the null hypotheses that the inefficiency effects are not present;

$$H_0: \gamma = \delta_0 = \ldots = \delta_4 = 0; \text{ and}$$

the coefficients of the variables in the model for the inefficiency effects are zero,

$$H_0: \delta_1 = \ldots = \delta_4 = 0.$$

These null hypotheses are tested using the generalized likelihood-ratio statistic, LR, defined by

$$LR = -2 \ln[L(H_0)/L(H_1)] \quad (17)$$

where $L(H_0)$ and $L(H_1)$ are the values of the likelihood function under the specifications of the null and alternative hypotheses H_0 and H_1, respectively. If the null hypothesis is true then LR has approximately a Chi-square or a mixed Chi-square distribution (Coelli 1995).

IV. THE DATA

Two major shrimp producing regions of Bangladesh, viz, southwest (greater Khulna) and southeast (Cox's Bazaar) coastal regions were purposively selected for this study considering the importance of these regions in shrimp production. About cent percent of the brackish water shrimps are being produced in these regions. Considering the contribution of these two regions in total shrimp production in Bangladesh, selection of these regions was quite appropriate for a study on the efficiency of shrimp cultivation. Four districts of Bangladesh namely: Cox's Bazaar from southeast region and Bagerhat, Khulna and Satkhira from southwest region were chosen for collecting field data. It may be worth mentioning here that the most common and popular three shrimp farming technologies have been introduced in the above mentioned districts.

Primary data were collected from the farmers of these areas adopting probability sampling technique. A multistage sampling procedure was administered in selecting the sample shrimp farms. The first and the second stages of sampling procedure involved respectively the selection of districts and the shrimp farming Upazilas (sub-district) within districts where most of the technologies are practiced. This was done based on the Annual Shrimp Statistics of the Department of Fisheries Bangladesh which provides statistics on number of shrimp farms, acreage, production, export and a host of other related information by shrimp farming districts and Upazilas. List of shrimp farms along with names of farm owners were obtained from the relevant offices of the Department of Fisheries. Another list was collected from the office of the shrimp farmers' cooperative association and the Department of Fisheries within the selected Upazilas to know the actual number of farms operating in the area. The desired number of samples was chosen randomly from this list.

A sampling unit consists of a shrimp farmer owning a shrimp farm or gher (farming unit). The owner of the gher was interviewed by administering a pre-tested interview schedule. The total sample size covering the three different types of methods was 155. The total extensive sample of 65 farming units comprises 20 units from Bagerhat district, 25 from Khulna district and the rest from Satkhira district. The improved extensive sample of 65, on the other hand, consists of 25 units from Satkhira district and 20 from each Bagerhat and Khulna districts. The total number of semi-intensive shrimp farms operating in Bangladesh is about 30 of which 25 were surveyed and can be divided into 17 units from Cox's Bazaar district, 5 from Khulna district and 3 from Satkhira district.

V. RESULTS AND DISCUSSION

A summary of the sample data on different variables in the stochastic frontier and inefficiency model, defined by equations 3 and 11, is presented in Table L It is evident from the table that there is a wide range of variation in farm sizes within the farming methods. Average farm sizes vary from 23.74 ha in extensive method to 0.72 ha in semi-intensive method. Labor use in semi-intensive method where shrimp farming requires intensive care throughout the season is the highest followed by improved extensive and extensive methods. Cost of tools and equipment is the highest in semi-intensive method. Much of this is due to the high price of some modern machinery equipment and electricity cost. Number of post-larvae (pl) or fry stocked in the ponds (farms) is also the highest in the semi-intensive method. The average number of fry stocked in semi-intensive farms is 37.88 per square meter (m^2) followed by 2.17 and 0.99 pl/m^2 respectively in improved extensive and extensive farms.

Table 1. Summary statistics for variables in the stochastic frontier production functions for shrimp farmers of different farming methods in Bangladesh

Variables	Farming Method	Sample Mean	Standard Deviation	Minimum Value	Maximum Value
Yield (kg/ha)	Extensive	190.00	25.99	134.26	255.42
	Improved extensive	441.00	110.62	222.22	741.35
	Semi-intensive	5,602.00	547.16	4,560.00	6,520.00
Land (Hectares)	Extensive	23.74	37.40	1.08	188.93
	Improved extensive	11.93	16.11	1.48	80.96
	Semi-intensive	0.72	0.13	0.40	0.81
Labor (person-days/ha)	Extensive	113.00	90.01	10.48	500.00
	Improved extensive	126.00	45.75	22.00	201.00
	Semi-intensive	291.00	246.03	142.29	1,190.08
Tools and equipment (Taka/ha)	Extensive	689.38	269.11	178.19	1,427.20
	Improved extensive	737.33	303.83	242.01	2,041.67
	Semi-intensive	31,199.42	9,405.04	17,875.66	66,095.67
Shrimp Fry (pl/m^2)	Extensive	0.99	0.14	0.65	1.32
	Improved extensive	2.17	0.38	1.48	2.96
	Semi-intensive	37.88	4.89	20.00	43.00
Feed (kg/ha)	Extensive	39.00	7.39	23.00	53.00
	Improved extensive	68.54	9.49	45.00	90.00
	Semi-intensive	11,338.00	3,354.00	9383.00	27,273.00
Age of Farmer (years)	Extensive	39.00	10.25	20.00	64.00
	Improved extensive	40.00	11.63	20.00	60.00
	Semi-intensive	49.00	17.95	23.00	79.00
Schooling of Farmers (years)	Extensive	8.00	2.40	5.00	14.00
	Improved extensive	8.50	2.80	4.00	16.00
	Semi-intensive	10.00	3.56	5.00	16.00
Farming Experience (Year)	Extensive	9.90	2.73	5.00	16.00
	Improved extensive	7.00	2.81	2.00	15.00
	Semi-intensive	6.00	1.97	3.00	11.00

Source: Field Survey (2000).

It can be seen from the table that the semi-intensive farmers are using a substantial amount of feed whereas the rate of using feed in extensive and improved extensive farming is very low. This indicates that the farmers in extensive and improved extensive methods rely and depend almost entirely on natural feed.

The average age of farmers vary from 39.00 years in extensive to 49.00 years in semi-intensive method. Average general education level is seem to be moderate varying from eight years in extensive to ten years in semi-intensive method, while average years of performing shrimp farming was found to be varying 9.90 years in extensive to 6.00 years in semi-intensive method.

The average yield of shrimp in semi-intensive method is the highest (5,602.00 kg/ha) followed by improved extensive (441.00 kg/ha) and extensive method (190.00 kg/ha).

The maximum likelihood (ML) estimates for the parameters in the stochastic frontier and technical inefficiency model for the three methods involved are presented in Table 2. The ordinary least square (OLS) estimates are also shown to compare the results. OLS estimates of the parameters show the average performance of the sample farms. The coefficients of the input variables in the production function are partial elasticities of mean output with respect to the different inputs for the C-D model defined by equation (15). Table 2 reveals that the coefficients of land and feed are significant at 1% level and coefficient of fry is significant at 5% level. These results indicate that land, fry and feed are vitally important factor inputs for successful shrimp farming. The coefficients of labor and tools and equipment are insignificant.

It is evident from the table that in the cases of labor and tools and equipment, the standard errors are very high or the t-ratios are very low compared to the value of coefficients of these two factor inputs and the confidence intervals for these parameters are thus very wide. This situation indicates that the explanatory variables display little variation and/or high intercorrelations. In other words, we can say that there is multicollinearity in the data. It can also be said that the data we used in Cobb-Douglas production function cannot give us decisive answers to the questions we pose regarding labor and tools and equipment.

The estimates of the stochastic frontier 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 elasticity of frontier (best practice) production with respect to land in extensive farming method was estimated to be - 0.008 and is significant at 1% level. This indicates that, if the area of shrimp farms under extensive method were increased by one percent, then the per hectare yield of shrimp is estimated to be decreased by 0.008 percent. The elasticities of output with respect to labor, tools and equipment, fry and feed are estimated to be positive values and which are 0.62, 0.007, 0.18 and 0.0027 respectively and are significant.

Thus, if labor were increased by one percent, then the mean yield of shrimp is estimated to be increased by 0.62 percent for best practice shrimp production. If the total cost of tools and equipment used were increased by one percent, then the mean shrimp yield is estimated to increase by 0.007 percent. The value of the elasticity of fry implies that, if the number of shrimp fry were increased by one percent, the shrimp yield is estimated to increase by 0.18 percent. The increase in the use of shrimp fry is expected to have a positive effect on shrimp production, unless the quality of fry is very poor or diseased. The value of elasticity of feed implies that if the use of feed were increased by one percent, the shrimp production would be increased by 0.0027 percent.

Table 2. OLS estimates of a C-D production function and ML estimates of a C-D stochastic production frontier

Variables	Farming Methods					
	Extensive		Improved Extensive		Semi-intensive	
	OLS estimates	ML estimates	OLS estimates	ML estimates	OLS estimates	ML estimates
Constant	1.98 (1.22)	1.94 (0.98)	0.74 (1.48)	5.97 (1.52)	2.17 (1.16)	2.56 (0.99)
Land (x_1)	-0.50*** (0.16)	-0.008*** (0.0009)	-0.37* (0.21)	-0.0099*** (0.0007)	-0.42* (0.22)	- 0.0011*** (0.00037)
Labor (x_2)	0.001 (0.59)	0.62*** (0.20)	-0.26*** (0.10)	1.23*** (0.21)	0.03 (0.05)	0.58** (0.34)
Tools and equipment (x_3)	0.02 (0.053)	0.007*** (0.0016)	0.33*** (0.08)	0.0013*** (0.00023)	0.21** (0.13)	0.0055** (0.0032)
Fry (x_4)	0.32** (0.17)	0.18* (0.14)	0.51*** (0.14)	-0.15** (0.07)	0.37*** (0.12)	-0.057 (0.59)
Feed (x_5)	0.25*** (0.087)	0.0027* (0.0021)	-0.23 (0.18)	-0.00016** (0.00009)	0.29*** (0.09)	-0.0011 (0.0087)
R^2	0.51	-	0.57	-	0.53	-
Inefficiency Model Constant	-	3.45 (2.54)	-	-0.034 (0.75)	-	-0.003 (0.99)
Age (z_1)	-	-0.0017 (0.0019)	-	-0.002 (0.003)	-	-0.00128 (0.00122)
Schooling (z_2)	-	-0.052 (0.022)	-	-0.00014 (0.18)	-	-0.13 (0.14)
Experience (z_3)	-	-0.0009 (0.00057)	-	-0.0011** (0.0005)	-	-0.0017 (0.001)
Farm size (z_4)	-	0.0043 (0.77)	-	0.0005 (0.0004)	-	0.13 (0.67)
Variance Parameters						
λ	-	32.02	-	113.44	-	136.28
$\sigma_s = \sqrt{\sigma_v^2 + \sigma_u^2}$	-	0.41*** (0.04)	-	0.63*** (0.058)	-	0.26*** (0.009)
$\gamma = \sigma_u^2/\sigma_s^2$	-	0.85*** (0.06)	-	0.61*** (0.04)	-	0.87*** (0.09)
Log-likelihood Function	-	4.98	-	28.73	-	34.78

*** Significant at 1%
** Significant at 5%
* Significant at 10%

The estimated δ-coefficients in Table 2 associated with the explanatory variables in the model for the inefficiency effects are worthy of particular discussion. We observe that *age* of the farmers has relatively negative effect upon the inefficiency effects. That is, the older farmers tend to have smaller inefficiencies (i.e., are more efficient) than younger farmers.

The coefficient of *schooling* is negative, which indicates that farmers with more years of formal schooling tend to be more technically efficient. The coefficient of *Experience* of performing shrimp farming in the model for the inefficiency effects is also estimated to be negative. This implies that the levels of the inefficiency effects of farmers tend to decrease over time. That is, farmers tend to become more efficient over time. This time-trend variable may be picking up the influence of factors which are not included in the inefficiency model, such as government extension programs.

The estimated coefficient for *farm size* in the inefficiency model is positive, which indicates that the smaller farms are more technically efficient in shrimp production than the larger farms. This result supports the claim which is frequently made for developing country agriculture, that smaller farms tend to be more efficient in production than larger farms.

The estimate of λ (32.02) and δ (0.41) are large and significantly different from zero, indicating a good fit and the correctness of the specified distributional assumption. Moreover, the estimate of y, which is the ratio of the variances of farm-specific technical inefficiency to the total variance of output, is 0.85 and significant at 1% level. This suggests that the technical inefficiency effects are a significant component of the total variability of shrimp output for extensive farmers. Therefore, the traditional production function with no technical inefficiency effects is not an adequate representation of the data.

OLS estimates of the parameters of C-D production function in the improved extensive farming method are also presented in Table 2. The coefficient of land is significant at 10% level and the coefficients of labor, tools and equipment and fry are significant at 1% level. This indicates that these inputs have greater contribution to the shrimp production process.

The elasticity of frontier production with respect to land is -0.0099 and significant at 1% level. This indicates that if the area under shrimp production were to be increased by one percent, the average production of shrimp is estimated to decrease by 0.0099 percent. The value is obtained relative to the particular production function used, which involves only four other variables, labor, tools and equipment cost, fry and feed. Further, the elasticity of output with respect to labor, cost of tools and equipment are estimated to be the positive values, 1.23 and 0.0013, respectively. Thus the value of elasticity of labor implies that, if the number of labor is increased by one percent, the shrimp production is estimated to increase by 1.23 percent. If the total cost of tools and equipment used were to increase by one percent, per hectare production of shrimp is estimated to increase by 0.00 13 percent.

The OLS estimates of the parameters of semi-intensive farming method are also presented in Table 2. It can be seen from the table that shrimp fry and feed have great impacts on production process as the coefficients of these two input factors are positive and significant at 1% level. Coefficient of tools and equipment is significant at 5% level and coefficient of land is significant at 10% level but labor input shows a very insignificant impact.

Maximum likelihood estimates of the stochastic frontier production function under semiintensive farming method are presented in Table *2*. It is evident from the table that the coefficient of land variable is negative and significant at 1% level which means that per hectare shrimp yield decreases as farm size increases. Coefficients of labor and tools and equipment are significant at 5% level but the coefficients of fry and feed are negative and insignificant. The signs on δ-parameter in the inefficiency model are negative except farm size indicating decrease in the technical inefficiency as an increase in the age of farmer, year of formal schooling and year of farming practices and increase in the technical inefficiency as farm size increases. But the coefficients of the variables in the technical inefficiency model are not statistically significant.

Comparison of Technical Efficiency of Shrimp Farming Methods

An attempt has been made in this section to compare the technical efficiencies of the farms of extensive, improved extensive and semi-intensive methods. A simple frequency distribution of the farm-specific technical efficiencies is summarized in Table 3.

Table 3. Farm-specific technical efficiency scores of the extensive, improved extensive and semi-intensive farming methods

Efficiency (%)	Farming Method		
	Extensive	Improved extensive	Semi-intensive
50 - < 55	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
55 - < 60	3 (4.62)	0.0 (0.0)	0.0 (0.0)
60 - < 65	4 (6.15)	1 (1.54)	0.0 (0.0)
65 - < 70	5 (7.69)	3 (4.62)	0.0 (0.0)
70 - < 75	5 (7.69)	3 (4.62)	0.0 (0.0)
75 - < 80	8 (12.31)	8 (12.30)	0.0 (0.0)
80 - < 85	7 (10.77)	5 (7.69)	2 (8.00)
85 - < 90	12 (18.46)	22 (33.85)	2 (8.00)
90 - < 95	10 (15.38)	19 (29.23)	8 (32.00)
95 - ≤ 100	11 (16.92)	4 (6.15)	13 (52.00)
Maximum	1.00	0.97	0.99
Minimum	0.56	0.60	0.80
Mean	0.82	0.85	0.93
Standard Deviation	0.12	0.08	0.05

Figures in the parentheses are percentages

It is evident from the table that technical efficiency scores of extensive, improved extensive and semi-intensive farms range from 0.56 to 1.00, 0.60 to 0.97 and 0.80 to 0.99, respectively. The respective mean technical efficiency values are 0.82, 0.85 and 0.93 in extensive, improved extensive and semi-intensive farms.

The results clearly state that the semi-intensive farms are more technically efficient than extensive and improved extensive farms. It can be seen from Table 3 that 92.0 percent farms of semi-intensive method belong to the technical efficiency range from 0.85 to 1.0 followed by 69.23 percent of improved extensive and 50.76 percent of extensive farms. This also indicates the higher technical efficiency of semi-intensive farms in shrimp production.

Tests of Hypotheses

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

H_0: $\gamma = \delta_0 = \ldots = \delta_4 = 0$; and

hypothesis (b): the coefficients of the explanatory variables in the inefficiency model are equal to zero i.e.,

H_0: $\delta_1 = \ldots = \delta_4 = 0$

were tested using the generalized likelihood-ratio statistic, LR, defined by Equation 17. Formal tests of hypotheses associated with the inefficiency effects (hypotheses (a) and (b)) are presented in Table 4.

Table 4. Tests of hypotheses for coefficients of the explanatory variables for the technical inefficiency effects in the stochastic frontier production functions for three farming methods

Null Hypothesis	Log-likelihood Value	Test Statistic LR	Critical Value	Decision
H_0: $\gamma = \delta_0 = \ldots = \delta_4 = 0$				
Extensive method	– 11.03	32.02	11.07	Reject H_0
Improved extensive method	– 27.99	113.44	11.07	Reject H_0
Semi-intensive method	– 33.36	136.28	11.07	Reject H_0
H_0: $\delta_1 = \ldots = \delta_4 = 0$				
Extensive method	– 8.70	21.98	9.48	Reject H_0
Improved extensive method	– 20.53	84.26	9.48	Reject H_0
Semi-intensive method	– 25.74	96.30	9.48	Reject H_0

It is evident from Table 4 that the null hypothesis H_0: $\gamma = \delta_0 = \ldots = \delta_4 = 0$ is rejected for all the three farming methods indicating the significant presence of inefficiency effects on shrimp farming. Thus the traditional average response function is not an adequate representation for shrimp production under the three methods, given the specification of the stochastic frontier and inefficiency model, defined by Equations (1) and (11).

The null hypothesis H_0: $\delta_1 = \ldots = \delta_4 = 0$ considered in Table 4 is also rejected for the three farming methods. It could be concluded that the inefficiency effects are significantly influenced by the age, education and experience of the farmers, the size of farming operation.

The next issue of interest is to test the hypothesis (c): shrimp farms are equally technically efficient while operating under different farming methods. A simple t-test was administered for testing this hypothesis.

Assuming H_o to be true, the hypothesis can be written as,

H_o : Technical efficiency of extensive farms = technical efficiency of improved extensive farms = technical efficiency of semi-intensive farms.

H_1 : H_o is not true.

Formal test of hypothesis (c) associated with the technical efficiency of farms is presented in Table 5.

Table 5. Statistics for test of hypothesis involving technical efficiency of the three farming methods

Null Hypothesis	Test Statistic t	Critical Value (5%)	Decision
$H_o : TE_{(ext)} = TE_{(impext)}$	1.76	1.65	Reject H_o
$H_o : TE_{(ext)} = TE_{(semi)}$	6.14	1.67	Reject H_o
$H_o : TE_{(impext)} = TE_{(semi)}$	5.65	1.67	Reject H_o

The null hypothesis considered in Table 5, $H_o : TE_{(ext)} = TE_{(imp)}$, $H_o : TE_{(ext)} = TE_{(semi)}$ and $H_o : TE_{(imp)} = TE_{(semi)}$, specifies that technical efficiencies of extensive, improved extensive and semi-intensive farms are equal. These null hypotheses are rejected indicating a wide range of variation in technical efficiencies of the three farming methods.

VI. CONCLUSION

The results of the study showed that, with the use of more feed and fry, shrimp production could be increased. Contribution of fry is more prominent. Farmers were overusing land (farm size) in shrimp cultivation.

The overall mean technical efficiencies of 82%, 85% and 93%, respectively in extensive, improved extensive and semi-intensive methods are achieved by shrimp farmers in the areas showing the scope for increasing shrimp production by 18%, 15% and 7%, respectively with the present technology itself.

Consequently, shrimp farmers, in general, could be advised to use of more consolidated land (farm size). Besides strengthening extension services to enable farmers to follow the resource use pattern and practices of the shrimp farms under improved extensive and semi-intensive methods, attention should be given to improve the efficiency of shrimp farms with large holdings under extensive method through the adoption of practices of small and medium-sized farms of semi-intensive and improved extensive farms. This could help increase shrimp production in the areas in the short run.

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