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Technical efficiency of fish culture in relation to technology adoption - the case of Tripura State in India

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ABSTRACT

The state of Tripura in the north-east India has developed few model aquaculture villages for improvement in fish productivity through demonstration of scientific technologies. The present study aimed at analysing the technical efficiency of fish culture of model aqua-villages (adopted villages) in comparison with other areas (non-adopted villages) where the State Government did not give such special attention. The objective of the study was achieved using stochastic frontier production function and measuring technical efficiency through error component model. The study has revealed that there is potential for increasing fish production in Tripura and there was significant difference between the mean technical efficiency of adopted (0.86) and non-adopted (0.77) villages in the state. Study estimated the production elasticities for different input variables like fish seed, cow dung, lime, pellet feed, mustard oil cake, rice bran, labour, and showed the possibilities to increase fish production by using more quantities of all the inputs except fish seed. Study also analysed the potential production frontier by following scientific recommendations and the technical efficiency realised for both categories of villages was found to be lesser than the potential. The results of the present study helped to identify the scope for technical improvement in fish culture development in Tripura State of India.

Keywords: Fish culture, Frontier production, Production elasticity, Production function, Technical efficiency

Introduction

Tripura is one of the important aquaculture states in north-east (NE) India where people have high preference towards fish as a food item. Fish production during 2008-09 was estimated at 36,991 mt, which needs to be increased up to 43,280 mt by 2010-2011 to achieve the target of 13 kg capita^{-1} yr^{-1} fish consumption (Government of Tripura, 2009). Improvement in the productivity of fish culture (from 2,074 to 3,000 kg ha^{-1} yr^{-1}) is a viable option to meet the targeted fish production in Tripura. It is well established fact that the improvements in efficiency are more cost effective than introducing new technology if the producers are not efficient in the use of the existing technology (Shapiro, 1983; Belbase and Grabowski, 1985; Dey *et al.,* 2000). If the producers are reasonably efficient, then new inputs and technology would be required to shift the production frontier upward (Ali and Chaudhary, 1990; Ali and Byerlee, 1991). Keeping this principle in mind, the Department of Fisheries, Government of Tripura (DoF, GoT) is implementing various area based developmental schemes to enhance productivity under perspective plan since 2004-05 (Government of Tripura, 2008). With this, DoF, GoT has started developing model aqua-villages to improve fish productivity from 2004-05 since the perspective plan was initiated. Till 2008-09, scientific fish culture technology was demonstrated in 34 aqua-model villages (Government of Tripura, 2009). These villages are termed as 'adopted villages' and the term 'non-adopted villages' has been used to indicate those villages where DoF, GoT has not implemented similar initiatives. Although the studies related to fish production efficiency at state level are few, recently Singh *et al*. (2009) and Singh (2008) analysed the technical efficiency of freshwater aquaculture and its determinants for Tripura during 2003-04 and 2004-05. These studies do not provide the efficiency of fish production in present transforming situation across the adopted and non-adopted areas. Against this background, the present study aimed at a comparative analysis evaluating the technical efficiency of fish culture across the adopted villages and non-adopted villages in Tripura.

Materials and methods

The study was conducted in Tripura State in NE India, where the contribution of agriculture and allied activities to the Gross State Domestic Product (GSDP) is 23% (Department of Economics and Statistics, 2009). Rice is Tripura's principal crop and high preference for fish as food item by the people of the state, made 'fisheries' a vital and potential sector for economic development of the state. The data for this study was based on cross sectional data collected through primary survey. A stratified multistage random sampling approach was followed and survey was carried out in 2010 regarding the farming details for the year 2009-10. The survey was designed to collect data from two categories of villages *i.e.*, adopted villages (AD) and non-adopted villages (NA). One hundred eighty samples from non-adopted and 90 samples from adopted villages were considered for the analysis covering all the four district of the state.

The definition of technical efficiency by Farrell (1957) led to development of methods for establishing the relative technical efficiencies of firms and it concerned with optimisation which implies efficiency. Of the various approaches to the estimation of farm efficiency, the Stochastic Frontier Production Function (SFPF) approach (Aigner *et al.*,1977; Meeusen and van den Broeck, 1977) is considered more appropriate in fisheries and agriculture applications, especially in developing countries, where the data are likely to be influenced by measurement errors and the effect of weather conditions, diseases *etc.* (Jaforullah and Devlin, 1996; Coelli *et al.*, 1998; Kirkley *et al.*,1998). Most of the applications of frontier analysis in Asian aquaculture (Gunaratne and Leung,1996; Gunaratne and Leung, 1997; Sharma and Leung, 1998; Iinuma *et al.*, 1999; Sharma, 1999; Bimbao *et al.*, 2000; Dey *et al.*, 2000; Sharma and Leung, 2000a, b; Irz and McKenzie, 2003; Singh, 2008, Singh *et al.*, 2009). Following Aigner *et al.* (1977) and Meeusen and van den Broeck (1977), the stochastic frontier production function used in this study assumes that the relationship between output and inputs can be modeled as follows:

$$Y_i = f(X_i;\beta_i) \exp (V_i - U_i) \text{.........}(1)$$

where, Y_i is the production of the i^{th} farm (i = 1, 2, 3……n), X_i is the vector of input quantities applied by the i^{th} farm, and βi the vector of unknown parameters to be estimated. The expression (V_i - U_i) is the random error and the error term V_i is associated to the usual exogenous shocks that are beyond the control of the farmer and is assumed to be independently and identically distributed with zero mean and variance equal to σ_v^2, *i.e.*, V ~ [N(0, σ_v^2)]. On the other hand, U_i is assumed to be a non-negative random error term associated with technical efficiency effects. Following Battese and Coelli (1995), U_i is assumed to be independently and identically distributed as a half-normal random variable truncated at zero with mean μ_i and variance σ_u^2, *i.e.,* | U~ N (μ_i, σ_u^2)|.

The functional model for fish culture in Tripura is specified as frontier production function which is defined as:

$$\text{In } Y = a + \beta_1 \text{ In } X_1 = \beta_2 \text{ In } X_2 = \beta_3 \text{ In } X_4 + \beta_4 \text{ In } X_4 + \beta_5 \text{ In } X_5$$
$$+ \beta_6 \text{ In } X_6 + \beta_7 \text{ In } X_7 + \beta_8 \text{ In } X_8 + (V_i - U_i) \text{..}(2)$$

where, Y = fish production (kg); α, β_1, β_2, β_3, β_4, β_5, β_6, β_7, β_8 are the parameters to be estimated; X_1 = pond water area (ha), X_2 = fish seed stocked (number), X_3 = cow dung (kg), X_4 = lime (kg), X_5 = Pellet feed (kg), X_5 = mustard oil cake (kg), X_7 = rice bran (kg), X_8 = labour (man-days); V_i = random error having zero mean which is associated with random factors; U_i = one-sided inefficiency component and ln = natural logarithm value.

The technical efficiency index (TE) of the i^{th} sample farm is derived as follows:

$$TE_i = Y_i/Y_i^* = f(X_i; \beta) \exp (V_i - U_i) / f(X_i; \beta) \exp V_i = \exp (-U_i)$$
$$\therefore TE_i = \exp (-U_i) \text{.........}(3)$$

Here, Y_i is the observed output of i^{th} farm and Y_i^* is the frontier output. The MLE of the parameters of the model defined by equation (2) and the generation of farm-specific technical efficiency (TE) defined by (3) are estimated using the FRONTIER 4.1 package developed by Coelli (1996) following Battese and Coelli (1995), to estimate the parameters of the stochastic production frontier and farm specific technical efficiency. Analysis was carried out across adopted and non-adopted villages in Tripura. The mean values of technical efficiency between adopted and non-adopted villages were tested for significance in difference using normal test.

Aigner *et al.* (1977) suggested that ML estimates of the parameters of the model can be obtained in terms of parameterisation $\sigma_u^2 + \sigma_v^2 = \sigma_s^2$ and $\gamma = \sqrt{} (\sigma_u^2 \div \sigma_v^2)$. Battese and Corra (1977) replaced σ_u^2 and σ_v^2 with σ^2 (variance of composite term) = $\sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2 \div (\sigma_u^2 + \sigma_v^2) = \sigma_u^2 \div \sigma^2$. This parameter (γ) measures the relative size of the efficiency effect of a given specific production system with respect to the total random component of the model. The parameter γ lies between 0 and 1. In the case of $\sigma_v^2 = 0$, γ would be equal to 1 and all the differences in the error term of frontier production function are results of management factors under control of the producer (Coelli *et al.*, 1998). When $\sigma_u^2 = 0$, γ would be equal to 0, which means all the differences in the error term of frontier production function are the results of the factors that the producer has no control on them, *i.e.* random factors. This also implies existence of a stochastic production frontier. γ close to 1 indicates that random component of inefficiency effects makes a significant contribution to the analysis of production system.

'γ' statistic was used for hypothesis testing concerning the existence of inefficiencies, if (H_0: $\gamma = 0$) is rejected, it means that there are inefficiencies and the function could be estimated using Maximum Likelihood Estimation (MLE) method. If H_0 is not rejected, ordinary least squares method gives the best estimation of the production function.

Results and discussion

Summary statistics of variables

The summary statistics of the variables (mean and standard errors) used for the estimation of Stochastic Frontier Production Function are given in Table 1. Variables were presented per acre to ascertain difference in level of input usage between adopted villages and non-adopted villages alongside the recommended use of inputs. The average pond area in non-adopted villages was found to be higher than that of adopted villages, may be due to different sample size covered under adopted and non-adopted villages. The average fish yield (production per acre) was found higher in adopted villages than in non-adopted villages. But interestingly, the yield in both the village categories was lesser than the expected yield that could be achieved by following recommended practices provided by DoF, GoT (2010). Among several inputs, fish seed stocking density was the only input with the mean value more than scientific recommendation in both adopted and non-adopted villages while being higher in the case of later as compared to former (Table 1).

Estimation of Stochastic Frontier Production Function

Cross section data on fish production and use of several inputs during the culture period 2009-10 were collected. Natural log of all the production and input quantity values were used for the analysis and the problem of taking the logarithms of input with zero was avoided by using (x + 1) as it is often used method of log transformation of zero values (Snedecor and Cochran, 1967).

The Maximum Likelihood (ML) estimates of stochastic frontier production function for adopted and non-adopted villages were estimated by using FRONTIER 4.1 software (Table 2). All the independent variables considered have positive coefficients in both adopted and non-adopted villages except a negative coefficient for fish seed *i.e.* β_2 in non-adopted villages. Positive coefficients indicate that there is a scope for increasing production by increasing the level of these inputs. The estimated elasticities of production of all the inputs are less than one in both the categories of villages.

Table 1. Summary statistics of variables of stochastic frontier production function for adopted and non-adopted villages in Tripura, 2009-10 (Mean ± SE)

Variables	Present study (2009 – 10)		Scientific recommendations*
	AD	NA	
Pond size (acre)	0.3508± 0.026662	0.4624± 0.032713	1.00
Production (kg acre^{-1})	762.2584± 19.44112	624.1290± 20.13445	1000 (target)
Fish seed (no. acre^{-1})	7397.5222± 473.7576	8020.4000± 160.3811	5000.00
Cowdung (kg acre^{-1})	3605.8889± 230.9754	3293.3556± 185.511	9000
Lime (kg acre^{-1})	161.7889± 14.42917	125.3444± 4.705777	280
Pellet feed (kg acre^{-1})	136.8556± 16.24216	44.3833± 2.475344	1050
MOC (kg acre^{-1})	185.3444± 9.560715	154.0944± 6.195825	180
Rice bran (kg acre^{-1})	306.1333± 28.03834	198.1000± 6.790306	-
Labour (Man-days)	567.9222± 46.72109	418.1167± 22.38365	-

* Department of Fisheries (2010), Government of Tripura

AD - adopted villages; NA - Non - adopted villages.

Table 2. Maximum likelihood estimates of the stochastic production frontier, fish production, Tripura, 2009-10

Variables		Adopted villages		Non-adopted villages	
		Co-efficient	SE	t-ratio	Co-efficient
Constant	α	4.5715**	0.9845	4.6434	7.0734**
Pond size (acre)	$\beta1$	0.6968**	0.0972	7.1651	0.8239**
Fish seed (no. per farm)	$\beta2$	0.0141	0.0803	0.1753	(-) 0.2951**
Cow dung (kg per farm)	$\beta3$	0.0810*	0.0355	2.2851	0.1396*
Lime (kg per farm)	$\beta4$	0.0348	0.0240	1.4525	0.1185*
Pellet feed (kg per farm)	$\beta5$	0.0444*	0.0219	2.0290	0.0269
Mustard oil cake (kg per farm)	$\beta6$	0.0185	0.0387	0.4783	0.0279
Rice bran (kg per farm)	$\beta7$	0.0353	0.0437	0.8065	0.1677**
Labour (man-days)	$\beta8$	0.2769*	0.1100	2.5179	0.0439
Sigma-squared	$\sigma2$	0.0493	0.0101	4.8383	0.1585
Gamma	γ	0.8397	0.0718	11.6991	0.9492
Sigma-squared (v)	$\sigma v2$	0.0080			0.0081
Sigma-squared (u)	$\sigma u2$	0.0414			0.1504
Log likelihood function		44.8372			7.4048
Return to scale		1.1339			0.9546

*=Significant at 5% level, **= Significant at 1% level

It indicates positive decreasing function to the factors *i.e.,* the input allocation is in the stage II of production surface. Elasticity of number of fish seed stocked (β_2) as an input is negative in case of non-adopted and it may be due to the over-stocking of fish seed. The average level of stocking fish seed in non-adopted village was found relatively higher than that of adopted villages.

The co-efficient of cow dung, the important common organic manure, is significant at 5% level for both adopted and non-adopted villages in Tripura (Table 2). For lime and rice bran, the other two important inputs, the coefficients were found to be significant in non-adopted villages only. Rice bran is significant at 1% level whereas lime is significant at 5% level in non-adopted villages. Rice bran was used as fish feed and it was supplementary input factor to pellet fish feed. Use of pellet feed was low and insignificant in non-adopted villages and therefore, use of rice bran was found to be significant for those farms (Table 2). In the opposite way, production elasticity of pellet fish feed was found to be significant at 5% level. Although the co-efficient for mustard oil cake was found to be positive, it was not significant in both the categories of villages. It is considered to be an important input in freshwater fish culture but it mainly depends on the way it is technically applied. The technical ignorance may be the cause for which MOC as an input in fish culture of Tripura has not been found significant (though it has positive coefficient). Co-efficient of labour as an input was found to be significant in adopted villages, but not in non-adopted villages. It may be because of unorganised management of labour in fish culture activities in the non-adopted villages.

The 'return to scale' are estimated at the levels of 1.1339 and 0.9546 in adopted and non-adopted villages respectively (Table 2), indicating prevalence of increasing return to scale especially in adopted areas. This shows that effort should be made to expand present scope of production to realise the potential in it, that is, more of variable inputs could be employed to realise more output.

Farm specific technical efficiency

The estimated values of σ_u^2 and σ_v^2 indicate that the difference between the observed output and frontier output is not due to the statistical variability alone, but also due to technical inefficiency of the farms in both categories of villages. The estimation of γ ($\gamma = 0.8397$ for adopted and 0.9492 for non-adopted villages) indicate the presence as well as dominance of inefficiency effect over random error in both categories of villages; but relatively higher in case of non-adopted villages. Further, and of the differences between frontier output and the observed output in adopted (83.97%) and non-adopted (94.92%) villages respectively are primarily due to factors which are under the control of farms, *i.e.* due to technical inefficiencies. A frequency and percent distribution of farms in both categories of villages in ranges of farm specific technical efficiency along with maximum, minimum, mean and median technical efficiencies of sampled farms is depicted in Table 3.

The mean technical efficiency in adopted and non-adopted villages was estimated at the levels of 0.86

Table 3. The frequencies of occurrence of fish production technical efficiency in decile range for adopted and non-adopted villages of Tripura, 2009-10

TE level	Adopted		Non-adopted	
	Frequency	%	Frequency	%
< 0.40	0	0	7	3.9
0.40 – 0.50	2	2.2	12	6.7
0.50 – 0.60	0	0	3	1.7
0.60 – 0.70	1	1.1	12	6.7
0.70 – 0.80	9	10	48	26.7
0.80 – 0.90	44	48.9	72	40
> 0.90	34	37.8	26	14.4
Total	90	100	180	100
Maximum	0.979113		0.976122	
Minimum	0.472183		0.248454	
SE	0.008839		0.01139	
Mean	0.86456206		0.77389124	
Median	0.88718750		0.81502250	

and 0.77 respectively. Maximum numbers of farm (48.9% in adopted villages and 40% in non-adopted villages) had technical efficiency in the class interval of 0.80 to 0.90. Looking at other studies on technical efficiency of fish production in Tripura, Singh (2008) and Singh *et al.* (2009) found that the mean technical efficiency in Tripura was 0.6838 and 0.6658 (using one stage with technical inefficiency model).

Mean technical efficiency of adopted and non-adopted areas were tested using normal test to know if any significant difference exist between the mean of two samples. The calculated $|Z|$ value was found to be 6.2890 which is more than the critical value (1.96 at 5% and 2.58 at 1% level of significance) and hence, null hypothesis was rejected.

The results of the study revealed that there is potential scope for increasing fish production in Tripura as there was significant difference between the mean technical efficiency of adopted and non-adopted villages in the state. It was observed that although adopted villages showed higher mean technical efficiency than non-adopted villages, it must be noted that the significant difference in mean technical efficiency does not necessarily reflect total impact of government activities. Several other demographic, institutional, social and political factors may be involved to measure actual impact of activities carried out by state government under adopted villages. This study, with its limitations, proved that technical efficiency and input use pattern in fish culture system is different in two categories of farms under adopted and non-adopted villages and it might be due to the government effort such as awareness programme, demonstration, training programmes *etc*. However, it is also important to mention that the technical efficiencies were estimated based on the frontier production realised by the analysis of primary cross section data collected during 2009-10.

Study estimated the production elasticities and showed the possibilities to increase fish production by use of more inputs except fish seed. It was found that the farmers of Tripura in both categories of villages followed higher stocking density (fish seed per acre) than the scientific recommendations. Although it is contradictory to the conventional concept, the study showed that it would be more efficient to use less number of fish seed per acre by the farmers of Tripura. Higher fish seed stocking may lead to higher production provided other inputs and management practices also support hand in hand. Present management and level of input use may not support such higher stocking density to get maximum production in fish culture system of Tripura. Indeed, there exists scope for technical improvement in fish culture development in Tripura State of India.

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