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Technical efficiency of freshwater aquaculture farms in the Union Territory of Puducherry : frontier production function approach

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ABSTRACT

Carp culture is a promising enterprise in the Union Territory of Puducherry. A survey of carp farms in Puducherry and Karaikal districts revealed yield gap of 56% between average yield and maximum yield obtained among the sample farms. The net returns realised were ₹ 31,485 acre^{-1}. Functional analysis indicated that feed had a positive and statistically significant influence on carp yield. Frontier analysis revealed that the mean technical efficiency of carp farms was 61%. The study suggests provision of cheaper feed and effective technology transfer to enhance adoption of recommended inputs and bridge the gap between maximum farm yield and actual farm yield of carp farms in the region.

Keywords: Freshwater aquaculture, Frontier production function, Technical efficiency

Introduction

Fisheries sector has undergone rapid transformation from a subsistence rural activity to a highly commercial venture. Fisheries are now being widely recognised as a vital sector in contributing to the nutritional and economic security of a nation. In India, fisheries sector contributes to 1.07% of GDP and US$ 2.84 billion towards foreign exchange earning during 2010-11. The efforts of the government through huge plan outlays and intensive fisheries development programmes have resulted in tenfold increase in fish production from 0.75 million tonnes in 1950-51 to 8.03 million tonnes in 2010-11 (provisional). The inland fishery sector alone contributes to 63.7% of the total fish production in the country. The eleventh plan has laid a target of 9.6 million tonnes envisaging a growth rate of 5.4%. Aquaculture is the fastest growing food production sector with an annual growth of around 7%. It was estimated that by the end of XI Five Year Plan (2011-12), the demand for fish would be around 9.74 million tonnes (Press Information Bureau, 2011). Therefore, there exists ample scope to augment fish production through inland aquaculture to meet the demand of the burgeoning population.

The Union Territory of Puducherry, located in the east coast of India, is endowed with varied types of inland fishery resources like tanks and ponds (359 ha), lakes (1065 ha) and fish farms (141 ha). The inland fish production of Puducherry was 5,572 t during 2009-10. The freshwater culture of carps is a promising enterprise gaining momentum in the region. Studies conducted in various parts of the country revealed that the average yield in carp ponds is only about 15% of the highest yield (Gupta, 1984), 11% of the potential yield level (Jayaraman, 1997) and 58% of the yield obtained in scientific composite fish culture (Singh, 2008), indicating the existence of yield gap in carp culture. Against this background, the present study was undertaken to analyse the economics of carp culture, identify the yield gap and examine the reasons for yield variations among carp farms using the stochastic frontier production function model.

Materials and methods

Study area

The U.T. of Puducherry encompasses Puducherry, Karaikal, Yenam and Mahe regions. Puducherry and Karaikal are contiguous districts with rich inland fishery potentials and were purposively chosen for the study. The centrally sponsored scheme, Fish Farmers Development Agency (FFDA) was established in 1988-89 in Karaikal and subsequently at Puducherry in 1993-94 to intensify aquaculture production in the region. The FFDA covered 494 fish farmers with 141 ha of water spread area during 2004-05. The agency supplies fingerlings and provides input subsidy apart from organising free training programs for fish farmers. It provides free consultancy to farmers on composite culture of carps. The composite fish culture of carps involves stocking of compatible indigenous and exotic carps that have diverse feeding habits to have higher yield as compared to carp monoculture (Srivastava *et al.,* 1990).

Generally, a six species combination of catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhinus mrigala*), silver carp (*Hypopthalmichthys molitrix*), common carp (*Cyprinus carpio*) and grass carp (*Ctenopharyngodon idella*) is recommended.

Sample size

From the FFDA list of fish farmers, 30 farmers were randomly chosen in probability proportion to the number of fish farms in the selected districts. Data were collected for the year 2004-05. The information pertaining to aquaculture practices, inputs used, yield, marketing as well as cost and returns from carp culture were collected from the sample farmers using interview schedule. The carp ponds were post-stratified into three categories based on the water spread area as small (< 1 acre), medium (1– 2 acre) and large ponds (> 2 acre), in order to know the cost and returns as well as technical efficiency of carp farms.

Method of cost estimation

Different cost concepts, Cost 'A', Cost 'B' and Cost 'C' have been followed in the analysis as shown below :

Cost A = comprises cash and kind expenses (paid out costs) actually incurred by the carp cultivators. This includes expenses incurred for i) seed carp; ii) manure and fertilizer; iii) feed; iv) hired human labour; v) depreciation; vi) lease amount; vii) interest on working capital and viii) other expenses

Cost B = Cost A + Interest on fixed assets (excluding land) + Rental value of owned pond

Cost C = Cost B + Inputed value of family labour

Technical, allocation and economic efficiency

Farrell (1957) initially explained the measurement of technical, allocation and economic efficiency in terms of (Fig. 1), the isoquant FF' that captures the minimum combination of inputs to obtain maximum output. So every package of inputs along the unit isoquant is considered technically efficient, while any point above and to the right of it, such as point P, defines a technically inefficient producer because they give less output at given levels of input. Hence, the distance RP along the line OP measures the technical inefficiency of producer located at point P. Geometrically, the technical inefficiency level associated with package P can be expressed by the ratio RP/OP and therefore, the technical efficiency (TE) of the producer under analysis (1-RP/OP) would be given by the ratio OR/OP.

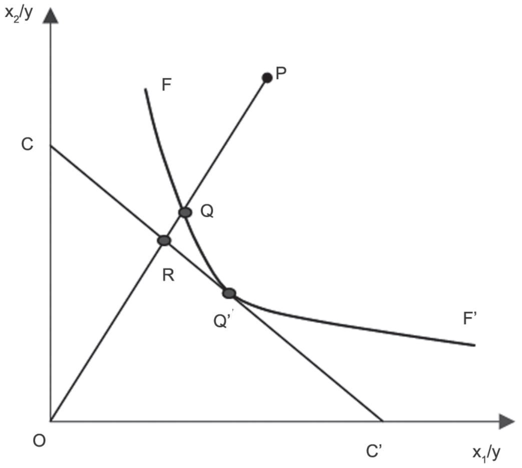

Fig. 1. Technical, allocation and economic efficiency

Secondly allocative efficiency is expressed as the ratio of the technically maximum possible output at the farm level of resources to the output obtainable at the optimum level of resources. Here, the cost minimisation is assumed in such a way that the input price ratio is reflected by the slope of the iso-cost-line CC', allocative inefficiency can also be derived from the unit isoquant plotted in Fig. 1. In this case, the relevant distance is given by the line segment RQ, which in relative terms would be the ratio RQ/OQ. With respect to the minimum cost combination of inputs given by point Q' is both technically and allocatively efficient one. Therefore, the allocative efficiency (AE) that characterises the producer at point P is given by the ratio OR/OQ. Together, the multiplicative interaction of both technical and allocative efficiency named as economic efficiency (EE) is calculated as:

$$EE = TE \times AE = \frac{OQ}{OP} \times \frac{OR}{OQ} = \frac{OR}{OP}$$

Stochastic frontier model

The stochastic frontier model is illustrated in Fig. 2. (adapted from Coelli *et al*., 1998). The inputs (x) are represented on the horizontal axis and the outputs (y) on

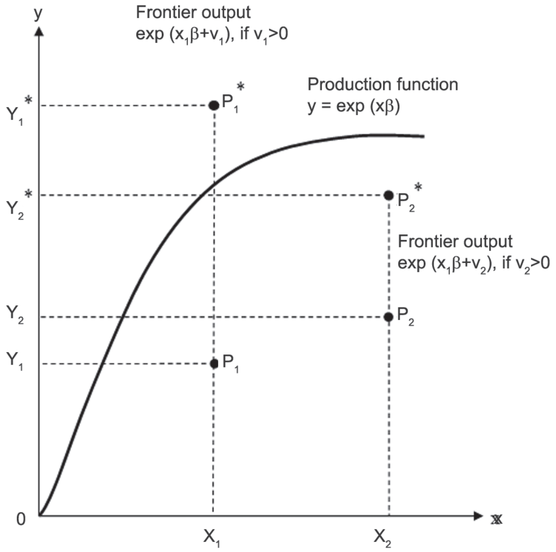

Fig. 2. Stochastic frontier production function

the vertical axis. The deterministic component of the frontier model, $y = \exp(x\beta)$ is drawn assuming that diminishing marginal returns to scale apply.

In Fig. 2, firm-1 uses the level of inputs, x_1 to produce output, y_1. The observed input-output value is denoted by the point P_1. The value of the stochastic frontier output, $y^*_1 = \exp(x_1\beta + v_1)$ is shown by point P^*_1. P^*_1 is above the production function as it is assumed that the random error, is positive. Firm 2 uses inputs of x_2 to produce output. The frontier output $y^*_2 = \exp(x_2\beta + v_2)$ denoted by the point, P^*_2 lies below the production function as it is assumed that the random error is negative.

The stochastic frontier outputs, y^*_1 and y^*_2, are not observed as the random errors, v, are not observable. However, the deterministic part of the stochastic frontier model is seen to lie between the stochastic frontier outputs. The observed outputs may be greater than the deterministic part of the frontier if the corresponding random errors, v, are greater than the corresponding inefficiency effects, u.

Econometric model

The stochastic frontier model can be represented as follows:

$$Y_i = f(X_i; \beta) \exp(V_i - U_i) \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where,

Y_i = Production of i^{th} farm

$f(X_i,\beta)$ = is a suitable function of the vector X_i of inputs for i^{th} farm and β is the vector of unknown parameters

V_i = Symmetric component of the error term

U_i = Non-negative random variable under the control of the farm

Given the density function of U_i and $V_{i,,}$ the frontier production function can be estimated by Maximum likelihood method. Jondrow *et al.* (1982) demonstrated that farm specific technical efficiencies can be estimated from the error terms composed of U_i and V_i, where i = 1,2, … n. The symmetric component V_i captures the random effects beyond the control of the decision maker including the statistical noise contained in every empirical relationship like bad weather, pest and disease outbreak. The one sided error term U_i captures deviations from the frontier due to technical inefficiency.

$$E(U_i/\varepsilon_i) = \sigma_u\sigma_v/\sigma[\phi(\varepsilon_i\lambda/\sigma)/\{1-\Phi(\varepsilon_i\lambda/\sigma)\}-\varepsilon_i\lambda/\sigma] \;\ldots\ldots(2)$$

ε_i = $U_i + V_i$, the composite error term

i = 1,2,……..n

Φ = represent the standard normal density function and ϕ the cumulative density function

λ = Ratio of standard errors, $(\sigma_{u/}\sigma_v)$

The advantage of a stochastic frontier production function is that it enables one to estimate U_i and therefore also to estimate farm specific technical efficiencies. The measure of technical efficiency is equivalent to the ratio of the production of the i^{th} farm to the corresponding production value if the farm effect U_i were zero. The farm specific technical efficiency can be estimated as:

$$\text{Technical efficiency } (TE_i) = Y_i/Y_i^* = f(X_i;\beta)\exp(V_i - U_i)/ f(X_i;\beta)\exp V_i = \text{Exp}(-U_i)\ldots(3)$$

$$i = 1,2,\ldots\ldots\ldots,n.\; 0 \le TE_i \le 1$$

The variance ratio γ, explaining the total variation in output from the frontier level of output attributed to technical efficiencies, can be computed as:

$$\tilde{a} = (\sigma^2_{u/}(\sigma^2_u+\sigma^2_v)$$

Model specification

The stochastic frontier production function of the Cobb-Douglas type was adopted for the study. The model used was as follows:

$$Y_i = \beta_0 + \beta_1\ln X_1 + \beta_2\ln X_2 + \beta_3\ln X_3 + \beta_4\ln X_4 + V_i - U_i \ldots\ldots(4)$$

where, i = 1,2,……..n

Y_i = Total fish production in kg ac^{-1}

X_1= Pond size in acre

X_2= seed (Number of fingerlings per acre)

X_3= Feed in kg ac^{-1}

X_4= Fertilizer in kg ac^{-1}

U_i = Farm specific technical inefficiency related factor and

V_i = Random variable

From the residual, using equation (3), the farm specific technical efficiencies were estimated.

Results and discussion

Details of fish ponds

The size of fish ponds ranged from 0.5 to 6.0 acres (Table 1). The average pond size of sample farms was 1.45 acres. Only four ponds were in the size range of 1-2 acres and over 2 acres each, while 22 farms had a pond size of less than 1 acre. With regard to the nature of operatorship, most of them were single owned and operated by themselves (70%) and the rest were either leased from farmers or municipality owned ponds leased from FFDA. The lease period ranged from 3-10 years.

Table 1. Details of fish ponds in the study area

Pond category	No. of ponds	Total area (acres)	Mean area of ponds (acres)
Small	22	21.8	0.99
Medium	4	6.7	1.68
Large	4	15.0	3.75
Total	30	43.5	1.45

Stocking density

The number of species cultivated in composite carp culture in the sample farms ranged from two to six. The cultivation of three species was common among 53.3% of farmers, followed by cultivation of five (16.7%), four (13.3%), two (10%) and six (6.7%) species in that order (Table 2).

Table 2. Distribution of species in sample ponds

No. of species	No. of farms	Percentage to total
Two	3	10.0
Three	16	53.3
Four	4	13.3
Five	5	16.7
Six	2	6.7
Total	30	100.0

Farmers adopted stocking of catla, rohu and mrigal with or without exotic carps like common carp, silver carp and grass carp. The recommended stocking density is 2000 acre^{-1} but the stocking ratio of each species varied with the number of species cultured in the ponds. The average number of fingerlings stocked in the sample ponds was 2271 acre^{-1} (Table 3). However, the stocking density was comparatively higher in small ponds followed by medium sized ponds while it was much less than the recommended level in large ponds, since maintenance comparatively easier in small and medium sized ponds than the larger ponds.

Table 3. Stocking density in the sample ponds

Pond category	Mean stocking density (no. acre^{-1})
Small	2842
Medium	2350
Large	1360
Overall	2271

Economics of carp culture

The stocking density and quantum of inputs use like feed, manure, fertilizers, supplementary feed and management are factors that influence the carp yield. The analysis of cost and returns from carp culture would throw light on the economic efficiency of the enterprise.

The average cost of fish cultivation at cost C was ₹ 23,077 acre^{-1} (Table 4). Cost A accounted for 56.59% of

Table 4. Economics of carp cultivation in sample farms

Particulars	Cost (₹ acre^{-1})	Percent to cost C
Hired human labour	3250.00	14.08
Seed fish	2406.81	10.43
Manure	230.57	0.99
Feed		
(a) Groundnut oil cake	2777.89	12.04
(b) Rice bran	1389.06	6.02
(c) Wheat bran	283.68	1.23
Fertilizer		
(a) Urea	150.00	0.65
(b) SSP	36.06	0.16
Lime	81.60	0.35
Depreciation	137.00	0.59
Miscellaneous charges	96.33	0.42
Lease amount	1100.00	4.77
Interest on working capital @ 9.5%	1121.19	4.86
Cost A	13060.19	56.59
Interest on fixed capital @11.5%	67.61	0.29
Rental value of owned pond	8500.00	36.83
Cost B	21627.80	93.72
Imputed value of family labour	1450.00	6.28
Cost C	23077.80	100.0
Yield	1364.08	
Gross income	54563.20	
Net income at		
Cost A	41503.01	
Cost B	32935.40	
Cost C	31485.40	

the average per acre cost C. The variable inputs accounted for 45.95% of total cost incurred in fish production in sample ponds. Among the various items of inputs, feed cost was high and it accounted for 19.29% of the average cost C. Human labour accounted for 14.08%, seed for 10.43% and imput value of family labour for 6.28% of the average per acre cost C. The average price of fish realised was ₹ 40 kg^{-1}. The net income per acre worked out to ₹ 31,485.

Carp yield

The average yield of carps in the sample farms was 1,364 kg acre^{-1} crop^{-1} (Table 5). There existed wide variability in yields and it ranged from 333 kg acre^{-1} crop^{-1} to 3,100 kg acre^{-1} crop^{-1}. The yields declined with increase in pond size.

Table 5. Average carp yield in sample farms

Pond category	Carp yield (kg acre^{-1} crop^{-1})
Small	1527
Medium	740
Large	354
Mean	1364

The frequency distribution of yield (Table 6) shows that 30% of the respondents had yields of 1,000 – 1,500 kg acre^{-1} crop^{-1}, 23.3% obtained yields ranging from 501 – 1,000 kg acre^{-1} crop^{-1}. Only 13.3% of the respondents realised yields above 2 t acre^{-1} crop^{-1}. The highest yield obtained among the sample fish farmers was 3,100 kg acre^{-1} crop^{-1}, while the average yield was only 1,364 kg acre^{-1} crop^{-1}, which indicated the existence of a yield gap of 56%. In the same agro-climatic conditions in which one farmer realised the maximum yield, while others did not, reasons could be farm specific technical and managerial constraints like inadequate availability of credit, quality of inputs, attitude and differences in skill of farmers practising the various recommendations. Hence a frontier production function analysis was done to know the magnitude of technical inefficiency of carp farms.

Table 6. Frequency distribution of yields in sample farms

Yield (kg acre^{-1} crop^{-1})	No. of farms	Percent to total
< 500	5	16.7
501 – 1000	7	23.3
1001 – 1500	9	30.0
1501 – 2000	5	16.7
2001 – 2500	4	13.3
Total	30	100.0

Production function analysis

Pond size, species diversification and quantity of inputs are the major factors influencing fish production (Suresh *et al*., 1990; Singh *et al*., 1995; Jeyaraman, 1997; Awoyemi *et al*., 2003). Hence a Cobb-Douglas production function was specified and estimated to measure the effect of pond size, seed, feed and fertilizer on fish production. The independent variables included in the model explained 75% of the variation in fish production. The elasticity of fish production with respect to pond size was negative and significant. This indicates a negative relationship between pond size and fish yield, which is also evident from the results given in Table 7. The production elasticities of all the other variables had the expected positive sign. The estimated model implied the need for maintaining optimum size of fish ponds and the scope for enhancing fish production by increasing the application of feed.

Table 7. Estimates of log-linear production function

Variables	Parameters	Coefficients	‘t’ ratio
Intercept	β_0	3.213(1.929)	1.666
Pond size (X_1)	β_1	-0.772***(0.201)	1.741
Seed (X_2)	β_2	0.358(0.255)	0.433
Feed (X_3)	β_3	0.087*(0.049)	1.405
Fertilizer (X_4)	β_4	0.009(0.023)	-3.848
R^2	0.75		
F	14.12		
n	30		

***and * denote significance at 1 and 10 % levels respectively

The results of frontier production function presented in Table 8 shows that the estimates λ and θ are statistically significant indicating a good fit and correctness of the specified distributional assumption respectively (Awoyemi *et al*., 2003). The estimates of the discrepancy parameter γ indicated that 98% of the difference between the maximum possible output and actual output were due to differences in technical inefficiencies of farmers. The coefficient of fertilizer variable though non-significant was negative and so caution may be exercised in the application of chemical fertilizer in carp culture. The results indicate that farmers need to be encouraged to apply more feed to increase carp production.

Table 8. Maximum likelihood estimates of stochastic frontier production function

Variables	Parameters	Coefficients	‘t’ ratio
Intercept	β_0	3.501	1.114
Pond size (X_1)	β_1	-0.676***	1.672
Seed cost (X_2)	β_2	0.376	-0.089
Feed cost (X_3)	β_3	0.114*	0.905
Fertilizer cost (X_4)	β_4	-0.002	-2.759
	$\lambda = (\sigma_{u/}\sigma_{v})$	7.572	
	$\gamma = (\sigma^2_{u/}(\sigma^2_{u} + \sigma^2_{v})$	0.983	
	$\theta = (\sigma_{u+}\sigma_{v})$	0.857	
	Log-likelihood	-10.746	
	n	30	

*** and * denote significance at 1 and 10 % levels respectively

The frequency distribution of technical efficiency of carp farms (Table 9) indicated that the technical efficiency was less than 40% in 23.4% of the sample farms. About 40% of the farmers had a high technical efficiency above the mean technical efficiency level of 61%. The farm specific technical efficiency varied from 14 to 95% with a mean of 61%.

Table 9. Frequency distribution of technical efficiency of carp farms

Technical efficiency (%)	Frequency			
	No.	Percentage to total	Cumulative frequency (%)	Mean technical efficiency
0 – 20	2	6.7	6.7	14
21 – 40	5	16.7	23.4	31
41 – 60	11	36.7	60.1	51
61 – 80	5	16.7	76.8	68
81 – 100	7	23.2	100.0	95
Overall	30	100.0		61

Conclusions and policy implications

The study revealed that inland aquaculture is a highly profitable enterprise yielding a net income of ₹ 31,472 acre^{-1}. Functional analysis indicated the contribution of feed in increasing fish production to be more prominent but feed cost at present accounted for a larger share (19.29%) of the total cost. Therefore, provision of cheaper feed and input subsidy would motivate the farmers to increase feed use and enhance fish production. The technical efficiency of sample farmers ranged from 14 to 95% and the mean technical efficiency was 61%. This implied that by rationalising input use, there exists two options for an average farmer to increase his production or save cost by 39% and for a least efficient farmer to increase his production or save cost by 87%. An effective technology transfer in this regard for convincing farmers on input use and their adoption would elevate them to an optimum level of production efficiency as attained by his counterpart in the same locality.

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