PRODUCTIVITY AND TECHNICAL EFFICIENCY OF AQUACULTURE PRODUCTION IN NIGERIA- A STOCHASTIC FRONTIER PRODUCTION FUNCTION APPROACH

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ABSTRACT

Nigerian aquaculture industry is fairly well developed and ranks second in Africa. It has low production levels compared with the country's aquaculture production potentials. Aquaculture production in 2001 was 47,000 tonnes contributing 9.92% of total fisheries production. If aquaculture production is to play its expected role in economic development of the country, new ways of expanding the sub-sector in an economically viable and environmentally sustainable manner need to be defined. In this respect, increasing productivity and technical efficiency (TE) at the farm level represents an attractive option because they have the potential to generate output growth without increasing the quantities of scarce inputs. This paper therefore determines the productivities of factors involved in aquaculture production and the TE of its operators. Primary data were collected using a set of structured questionnaire administered on 100 freshwater fish farmers selected using a multistage sampling technique, and were analyzed using the stochastic frontier production function. The productivity analysis showed that the allocation and utilization of the technical and economic factors involved in aquaculture production are in the rational stage (stage II) of the production region and thus their usage is efficient but the returns to scale (RTS) was > 1. This implies that output needs to be enlarged by allocating more of the productive factors involved in the production process that is, enlarging the scale of operation. The TE of the farmers varied between 0.633 and 0.998 with a mean TE of 0.830 with the proportion of farmers having TE ≥ 0.70 being about 90%. This implies that aquaculture production is technically efficient in the study area. Therefore production and productivity growth in aquaculture should be enlarged by cost effective technological change.

Keywords: Productivity, Technical efficiency, stochastic frontier production function, Nigeria.

INTRODUCTION

Nigerian aquaculture industry ranks second in Africa and is fairly well developed. Yet it has low production levels when compared with the country's aquaculture production potentials in terms of available natural, environmental and socio-economic factors, which favoured increased aquaculture performance. Nigeria has a potential land area of about 600,000km^2 and 400,000km^2 for subsistence and commercial aquaculture respectively (Fagbenro et al 2004). Aquaculture production in Nigeria occurs mainly in-land and only recently has the coastal region been the focus of development. The country has a coastline of about 960km bordering a coastal zone of an extensive mangrove ecosystem comprising lagoons, estuaries, wetlands and series of inter connecting creeks. Aquaculture production is predominantly an extensive land based system practiced at subsistence levels while commercial aquaculture development is yet to become widespread. The contribution of aquaculture to total fisheries production between 1997 and 2003 is presented in Table 1. Its share of total fisheries production rose from about 7.38% in 1997 to about 10.11% in 2003 (CBN 2003). Though the percentage contribution is low, there is evidence of increased and improved production performance. The people living in the coastal regions depend mainly on fishery and fishing activities for their survival and contributing their quota to the nation's socio-economic development. Therefore if aquaculture is to play its expected role in the development of the country's economy, new ways of expanding the sub-sector in an economically viable and environmentally sustainable manner need to be defined. In that respect increasing productivity at the farm level stage stands an attractive option because they have the potential to generate output growth without increasing the quantities of inputs.

Table 1: Aquaculture Production ('000 tonnes) in Nigeria 1997-2003

Year	Aquaculture	Total fish	%Aquaculture/Total Fish
1997	38	405	7.38
1998	42	430	9.77
1999	43	443	9.71
2000	45	460	9.78
2001	47	474	9.92
2002	50	504	9.92
2003	52	514.3	10.11

Source: CBN 2003

Productivity growth can be achieved either through technological change (development and adoption of new technologies) or improvement in technical efficiency (ability to obtain maximum output from a given input mix at the existing technology (Xu & Jeffrey 1998). Productive efficiency means the attainment of production goal without waste while enterprise inefficiency involves the disproportionate and excessive usage of all inputs. Irz and Mckenzie (2002) opined that when producers are highly efficient in the use of inputs, large productivity gains could only come from new technologies developed from investments in Research and Development. And if inefficiencies are large, however, improving farm management by targeted policies is likely to be the most cost effective means of raising productivity. Since the low level of agricultural production in Nigeria is mainly due to low productivity of resources used in its production process and the technical efficiencies of its operators, this paper therefore examines the productivities of some of the resources involved in aquaculture production in Nigeria. It examines the factors influencing the productivity and technical efficiency of aquaculture production in Nigeria with a view to identifying:

- Contributions of each input to the output growth
- Presence of inefficiency effects in the production process and
- Predicting the Technical Efficiency of the farmers.

Analytical Framework:

The stochastic frontier production function in efficiency studies is employed in this study. The modeling, estimation and application of stochastic frontier production functions to economic analysis assumed prominence in econometrics and applied economic analysis during the last two decades. Early applications to economic analysis include those of Aigner et al (1977) in which they applied it in the analysis of the US agricultural data. Battese and Corra (1977) applied the technique to the pastoral zone of Eastern Australia. Empirical applications of the technique in efficiency analysis have been reported by Battese *et al* 1993, Ajibefun & Abdulkadri (1999), Ojo and Ajibefun (2000),Ojo (2003) and Ojo (2004), but it remains a relatively new methodology in aquaculture and artisanal production in Nigeria.

The stochastic frontier production function model is specified as $Yi = f(Xi\beta)+Ei$

Where,

Y is output in a specified unit

X denotes the actual input vector

β is the vector of production function parameters
Ei is the error term and the error term is decomposed into two component parts (V and U).

The V is a normal random variable that is independently and identically distributed (iid) with mean zero and constant variance (σ^2). It is introduced to capture the white noise in the production, which are due to factors that are not within the influence of the producers. It is independent of U. The U is a non-negative one-sided truncation at zero with the normal distribution (Tadesse & Krishnamoorthy 1997). It measures the technical inefficiency relative to the frontier production function, which is attributed to controllable factors (technical inefficiency). It is half normal, identically and independently distributed with zero mean and constant variance. The stochastic frontier production function model is estimated using the maximum likelihood estimation procedure (MLE), which is a maximization technique (Olowofeso and Ajibefun 1999). The Technical Efficiency (TE) of an individual firm is defined in terms of the observed output (Yi) to the corresponding frontier output (Y^*), maximum output achievable given the existing technology and assuming 100% efficiency. It is denoted as

$$Yi^* = f(X_i\beta) + Vi$$

That is

$$TE = Yi/Yi^*$$

Also the TE can be estimated by using the expectation of Ui conditioned on the random variable (V-U) as shown by Battese & Coelli (1988), that is

$$TE = \frac{f(Xi\beta) + V - U}{f(Xi\beta) + V}$$

And that $0 \leq TE \leq 1$

METHODOLOGY

The data used in this study were collected from a cross-sectional survey of aquaculture farmers in Ondo state, Nigeria. Ondo State is one of the 36 states in Nigeria (Figure 1). The data were mainly sourced from primary sources from 120 aquaculture farmers selected using multistage sampling method. The first stage was a purposive sampling method to select five local government areas with preponderance of fish farms. The selected Local Government Areas (LGA) were Akure South, Owo, Ondo west, Akoko North-East and Ilaje. The second stage of the sampling technique was the simple random selection of the 120 fish farms. About 120 fish farms were selected in simple random sampling method with 20 farms selected from each of the four of the LGA and 40 farms selected from Akure South LGA because Akure South LGA has about 46% of fish farms in the entire state partly because of the LGA being the seat of the state government and commercial nerve center of the entire state and even sub-region. Thus there is assurance of good market for fishery products by the high-income earning civil servants, businessmen and private sector big wigs. Information was collected with the use of a set of structured questionnaire on the following variables:

- Quantity of fish caught in kilogram.
- Pond size in meter squared.
- Stocking in number of fingerlings per meter squared.
- Survival as the ratio of fish harvested and number of fish stocked.
- Operating expenses as costs incurred on variable items such as feeds, liming materials, fertilizers, labour, repairs of equipment and procurement of equipment with about one year life span.
- Fixed costs such as depreciation charges on durable equipments and materials such as pond construction, farm building and fishing gears.
- pH status of pond (dummied as 1 for acidic and 2 for alkaline)

About 100 copies of the questionnaire were retrieved and analysed.

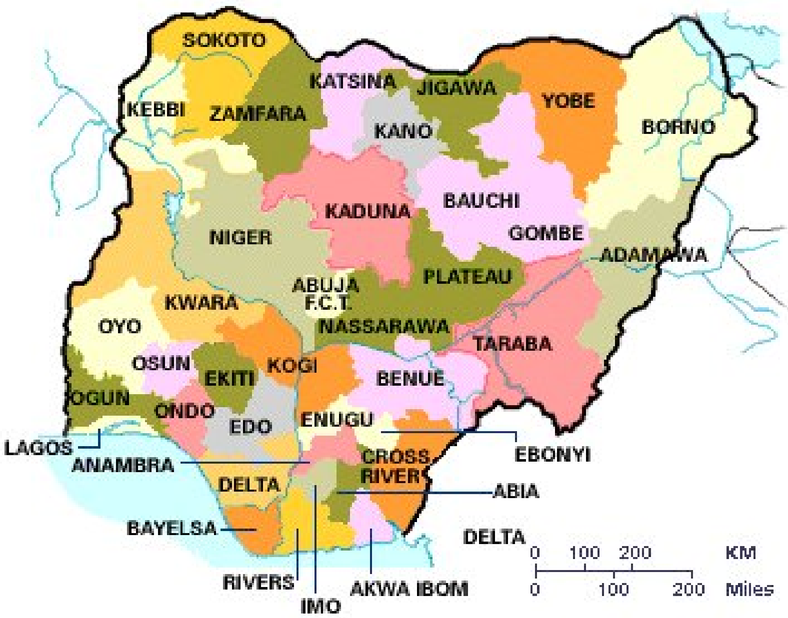

Figure 1. Map of Nigeria

Methods of Data Analysis

Descriptive statistics and stochastic frontier production function analysis were used to analyse the data collected. For this study, the Cobb-Douglas functional form was assumed for the production technology of the fish farmers. Two different models were specified. Model 1 assumed that the traditional response function was an adequate representation of the stochastic frontier model and there were no inefficiency effects in the production process, i.e., Ho: $\gamma = 0$. Model 2 assumed that inefficiency effects were present and involved all the parameters estimated, i.e., Ha: $\gamma \neq 0$. This is the full frontier production function, which involves no restrictions. It thus assumed that the traditional response function was not an adequate representation of the stochastic frontier model. In model 1, the measure of the variation in the fish farm output that are due to technical inefficiency effects is assumed to be zero, that is, gamma (γ) = 0 and that any variation in output is due only to stochastic (random) error. Whereas model 2, assumed that gamma (γ) is not zero ($\gamma \neq 0$) and that variations in output are both due to technical inefficiency effects (which could be controlled with efficient management of both human and material resources) and random error which do not come under the control of the efficient management. The farm model of the aquaculture farms in a linearised form is defined as follows:

$\text{Log } Yi = \beta_0 + \beta_1 \log X_{1i} + \beta_2 \log X_{2i} + \beta_3 \log X_{3i} + \beta_4 \log X_{4i} + \beta_5 \log X_{5i} + \beta_6 \log X_{6i} + V_i - U_i$

where

i = the number of respondent farms, i = 1,2…100

Y= output of fish harvested (kg)

X_1= pond size (m^2)

X_2= stocking density

X_3= survival %

X_4= PH status (dummied as 1=acidic,2=alkaline)

X_5= operating expenses (Naira)

X_6= fixed costs (Naira)

V_i and U_i as previously defined.

β_0 = constant term

β_1 to β_6, variances of V (σv^2), U (σu^2), model variance (σ^2) and gamma (γ) are unknown scalar parameters to be estimated using the program FRONTIER 4.1 (Coelli 1994). Gamma is calculated as: $\gamma = \sigma u^2 / \sigma^2$
Various tests of hypothesis on the significance of the parameters of the frontier model were conducted using the student's t-ratio and generalized likelihood ratio tests.
The student's t-ratio is defined by

$$t_c = \frac{\beta j}{\beta jx}$$

where

t_c = t- ratio computed
βj= estimated coefficient of parameter j^{th}
βjx = standard error of the coefficient of parameter βj

The estimated coefficient of parameter βj is significant at 5% level of significance if the t-ratio computed is greater than the tabulated t-ratio at 5%level of significance and degree of freedom (n-1).
The generalized likelihood ratio is defined by the chi-square distribution,X^2
$X^2 = -2 \text{ in } (L(Ho) / L(Ha))$ …………… (Battese et al 1993)
Where L (Ho) is the value of the likelihood function for the frontier model I in which parameter restriction specified by the null hypothesis (Ho) was imposed such that Ho: $\gamma = 0$, that is, there were no technical inefficiency effects in the production operations of the aquaculture farms. L(Ha) is the value of the likelihood function for model 2 in which there were no restrictions that is, $\gamma \neq 0$ indicating there were technical inefficiency effects in the production operations. The X^2 has a mixed chi-square distribution with the degree of freedom (df) equals to the number of parameter restrictions. If the computed chi-square (X_c^2) is less than or equal to the tabulated chi-square the null hypothesis (H_0) is accepted and rejected if chi-square computed is greater than chi-square tabulated.

RESULTS AND DISCUSSION

Summary Statistics of Variables:

The summary statistics of variables used in the stochastic frontier models is presented in Table 2. The average output of fish harvested per farmer was 1952.59kg with a wide variation as indicated by the large variability in standard deviation of 1785.50kg. The large variability implies that aquaculture fish farmers operated at different scale levels with small and medium scale farms accounting for about 38% and 62% of sampled farms respectively. Pond size ranged between 100m^2 and 2500m^2 with average pond size of 579.39m^2 and a standard deviation of 514.25m^2. This further confirms the different scale levels of aquaculture production in the study area. Small-scale farm has pond size <250m^2, medium scale farm's pond size is between 250m^2 and 3000m^2 and large farm's pond size is >3000m^2.

The farmers stocked mostly catfishes and tilapias in a "duoculture" system. The stocking density ranged between 4 and 20 fingerlings/m^2. The finding indicated an overstocking of the ponds since the recommended stocking density is about 2 fingerlings per m^2 for Catfish and 10-15 fingerlings for Tilapia. The incidence of overstocking observed could be as a result of limited knowledge of fish farming by the farmers. The overstocking greatly had its toll on the survival of the fish among other conditions and eventual reduction in output of harvested fish. Average survival was 44.56% with a standard deviation of 25.96%. Survival ranged between 12.8% and 100%. The low survival could be due to overstocking, condition of pond water and constraints from other essential production variables such as adequate and balanced feeding regime and efficient maintenance. The pH status of the ponds showed that about 70% had acidic status with 30% being slightly alkaline. It was observed that fish performed better with the PH status moving from acidic to alkaline regime. The operating expenses and fixed costs showed large variability due to the differential in scale of production of the sampled farmers.

Table 2: Summary statistics of variables for stochastic frontier models

Variables	Mean	SD	Minimum value	Maximum value
Output (kg)	1952.59	1785.50	350	10000
Pond size (m^2)	575.39	514.25	100	2500
Stocking (fingerlings/m^2)	11.10	4.02	4	20
Survival (%)	44.56	25.96	12.8	100
Operating expenses (₦)	197213.50	156185.7	50500	965800
Fixed costs (₦)	13365.77	8546.94	115	148900

PH status: Farms with alkaline ponds = 30%
Farms with acidic ponds = 70%
US$ = ₦ 120

Presence of Technical Inefficiency Effects

The summary of the two frontier models is presented in Table 4. In the two models the variables of pond size, survival %, operating expenses and fixed cost are statistically significant at 5% level of significance using a student's t-ratio test, indicating the variables are very important in aquaculture production. In order to decide which of the two models to select for further econometric and economic analysis, a generalized likelihood ratio test was carried out using the test statistic defined by the chi-square distribution (X^2)

$$X^2 = -2\ln(L\ (H_0)/L\ (Ha))$$

Where L (H_0) and L (Ha) are as previously defined. The result of the generalized likelihood ratio test for presence of Technical Inefficiency effects is presented in Table 3. The computed chi-square was 17.16 while the tabulated chi-square at 5% level of significance and one degree of freedom ($X^2_{0.05,\ 1}$) was 3.84.

Table 3: Generalized Likelihood Ratio Test of Technical Inefficiency Effects

$L(H_0)$	L(Ha)	$X^2_{computed}$	$X^2_{(0.05,1)}$	Decision
2.49	11.07	17.16	3.84	Reject H_0

The result showed that computed chi-square was greater than the tabulated chi-square. Therefore, the null hypothesis (H_0) that there were no technical inefficiency effects in aquaculture production was rejected and the alternative hypothesis (Ha) that there were technical inefficiency effects in aquaculture production and that variations in output of fish farms are mostly due technical inefficiency effects was accepted. The presence of technical inefficiency effects in aquaculture production in the study area made the use of traditional response function (ordinary least squares) inadequate in estimating the parameters of aquaculture production, hence, model 2 was chosen for further econometric and economic analysis.

Productivity Analysis

The estimated coefficients of parameters of the stochastic frontier production function of model 2 in Table 4 are also the elasticities of production of the variables involved in the production process. All the estimated coefficients of the variables had positive sign and the value of each coefficient was between zero and unity. This implies that the allocation and utilization of each of the factors (variables) was in stage II of the production function or positive decreasing returns to the factor. The allocation and utilization is therefore efficient. The Return to Scale (RTS), which is, the summation of the elasticities of production of variables of the production function is used to determine the stage overall production is in the production surface. A RTS that is > 1 implies increasing returns to scale or stage 1 and inefficient or irrational stage of production. Production once started should be expanded further in this stage. A RTS that is less than zero implies negative decreasing returns to scale or stage III of the production function and any further use of resources lead to reduction in total output Therefore, production once in stage III of the production function should be stopped. Stage II of the production function is where the RTS is between zero and unity. This is the stage of positive decreasing returns to scale and efficient allocation of resources and production of output. The RTS shown in Table 5 was 1.148. It was greater than unity and thus aquaculture production was in stage 1 of the production function. Allocating more of the variables for more output and efficient productivity should expand its production. That the RTS of aquaculture production was in stage I of the production function implies there is bright future in aquaculture production in Nigeria if the identified constraints to efficient production are looked into.

Table 4: Estimates of Parameters of Stochastic frontier models

Variable	Model 1	Model 2
General model		
Constant	0.158 (0.42)	0.417 (0.387)
Pond size	*0.177 (0.053)	*0.142 (0.046)
Stocking density	0.079 (0.174)	0.161 (0.166)
Survival %	*0.29 (0.098)	*0.331 (0.091)
PH status	-0.084 (0.189)	0.120 (0.180)
Operating expenses	*0.278 (0.062)	*0.255 (0.055)
Fixed cost	*0.145 (0.070)	*0.139 (0.064)
Variance parameters		
Sigma square	0.06	*0.048 (0.008)
Gamma	0	*0.601 (0.108)
Log likelihood function	2.493	11.07

* estimate is significant at 5% level of significance. Figures in parentheses are standard errors

Table 5: Elasticity of Production and Returns to Scale

Variables	Elasticity of production
Pond size	0.142
Stocking density	0.161
Survival %	0.331
PH status	0.120
Operating expenses	0.255
Fixed cost	0.139
RTS	1.148

Technical Efficiency Analysis

The value of gamma (γ) of 0.601 implies that about 60% variation in the output of aquaculture in the study area was due to technical inefficiency effects. The predicted TE of the fish farmers ranged between 0.633 and 0.998 with mean TE of 0.83 and standard deviation of 0.094. The study further revealed that about 90% of the respondents had TE >0.70 but only about 59% had TE above the mean TE while 41% others had TE < mean TE. The result of the TE analysis indicates that aquaculture farmers in the study area are quite technically efficient and could still improve on their technical efficiency by adopting better management techniques that would reduce the identified sources of their technical inefficiency effects.

CONCLUSION AND RECOMMENDATION

The study observed that aquaculture production was in the increasing returns to scale or stage I of the production function while allocation and utilization of variables involved in its production are efficient. There was the presence of technical inefficiency effects in the production, therefore, the traditional response function was not adequate in estimating the parameters of the production function and thus the stochastic frontier production function was a preferred model. The TE of the farms ranged between 0.633 and 0.998 with mean TE of 0.83 and about 59% of the farms having TE above the class average. This indicates that aquaculture farmers are relatively quite technically efficient in the study area. It is recommended that farmers should expand the scope of their production by increasing their allocation of variables involved in aquaculture production so that they can further reap the benefits of being in the stage II of resource allocation and also move away from stage 1 (increasing returns to scale) of the production surface. Also, efforts should be made by farmers whose TE is below the class average to adopt the management techniques of the best performed farms that have TE above the mean TE.

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