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Technical Efficiency of Aquaculture system in Oyo State, Nigeria: Stochastic Frontier Approach

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Abstract

Aquaculture is becoming one of the fastest growing farming systems in the world. This farming system is important in bridging supply gap of animal protein in Nigeria. In view of this, the study evaluated technical efficiency (TE) and its determinants on catfish farms in Oyo State using single-stage procedures of Stochastic Production Frontier Approach. In a cross-sectional survey, a multi-stage random sampling technique was employed to elicit primary information from 60 catfish farmers. The result showed that TE of catfish farmers ranged between 0.41 and 0.90 with mean of 0.74. Average output of catfish has positive and significant elasticities with respect to every input variable except feed and labour. Similarly, technologies employed in catfish production in Oyo State are shown to be associated with decreasing positive return to scale. The result also revealed that observable socio-economic variables such as fishers' age, gender, fishing experience, and educational status were responsible for the technical efficiency variation. However, years of fishing experience was significant (P<0.01) and was the only socio-economic variable contributing significantly to inefficiencies in aquaculture systems in Oyo State. Fishing experience now appears as important human capital needed to enhance catfish productivity in Oyo State. Thus, effective and sustainable transformation of fisheries exploit in the State will yield better productivity among the well experienced fishermen than the new fishers if years of experience is given due consideration during interventions in catfish production system.

Keywords

Catfish production; elasticities; Fish farming; returns to scale; technical inefficiency

Introduction

Global captured fishery is in a crisis with a majority of the world's fisheries being fully exploited and about one third of them being either depleted or over exploited [1]. According to FAO [2], between 1980 to 2005, world fish output increased tremendously from 7.4 million tons to 47.8 million tons rising by about 73% within the period. Ever since capture fish production relatively become static due to finite production limits in the late 1980s, continuing impressive growth in the supply of fish for human consumption has been made possible by the intensified efforts in non-captured fish production [3]. This is because maximum sustainable fishing limits for most of the world's lakes, rivers and oceans have been exceeded, therefore, bridging the global gap of fish supply and demand will require alternative method of fish production commonly known as aquaculture [3,4].

Aquaculture is the management of aquatic organism in a controlled environment for the economic and social benefits. As a form of farming system, aquaculture managed both fish and non-fish aquatic animals in an artificial environment. The subset of aquaculture that focuses mainly on management of fish alone under controlled or semi-control conditions for the benefit of making profit is called fish farming (pisciculture).

Across the world, fishery industry is made up of subsistence and large-scale mechanized fish farms that directly or indirectly provide jobs for over 200 million people [5,6]. According to FAO [1], about 36 percent and 23 percent of the 56.6 million people engaged globally in the primary sector of capture fisheries and aquaculture in 2014 were full time and part time fishers respectively while the remainder were either occasional fishers or of unspecified status [1]. Farmed fish therefore represent about 53% of the global fish production in 2016 when it reached it's peaked at approximately 171 million tonnes.

Aquaculture is of significant important in Nigerian agriculture as it contributes about 4.0% to the Gross Domestic Product (GDP) in 2016. Aside, it makes provisions for some important services including nutritional well-being support, export opportunities, feedstock for the industrial sector, rural development contributions, effective administration of natural resources, and the conservation of biological diversity for mankind [7]. Report by FDF [5]; Adewuyi *et al.* [8]; and Adekoya and Miller [9] have it that average Nigerian obtains about 40% of the dietary intake of animal protein and 60% of the total protein intake for an adult in rural areas from fish. Fish also replenishes the human body with phosphorous, calcium, Vitamin A and D lysine, sulphur and amino acids and remains a good source of protein for livestock [10].

Fish remains one of the cheapest and most accessible sources of high-quality protein in Nigeria [11,12]. As a substitute for locally farmed fish, Nigeria imports over $200 million US dollars' worth of stocked and frozen fish per annum, which amounted to over 50% of fish consumed annually [13,14]. Considering the population growth rate of 3%, the fish supply gap deficit is expected to increase continuously [13]. With this increasing trend in fish consumption, demand far exceeds supply resulting to a huge potential area expansion for fishery sector (12-14 million hectares) that is producing below 700,000 million tons of fish annually [15]. A minimum of 2 million metric tons of fish is therefore needed annually to offset the existing fish supply gap and feed the population of over 140 million Nigerian [13].

Statement of the problem

Evidences in literature have shown that farm level productivity increase has potential to generate output growth without increment in input quantities that can cause additional negative environmental externalities [16]. This productivity growth can be met with either technological modification or advancement in technical efficiency, but the most cost-effective strategy is dependent of inefficiencies magnitude in the system [17]. It is possible to make large productivity gain especially if new technologies that are developed from research and development efforts are employed by efficient producers. With large inefficiencies, however, productivity friendly policies are likely to be the most cost-effective means to enhance productivity.

In a bid to boost productive capacity of fishery-sub sector, the Nigerian government in recent time, through institutional reforms and other various economic measures provided subsidy on fish farm inputs and tax exemption for fishermen, however, the fish sector is yet to record considerably improvement in fish output to close demand-supply gap facing the sector in Nigeria [18].

The aquaculture environment is associated with relative resource use and farm management inefficiencies [19,20,21]. According to Squires *et al.* [21], fishers' age and educational quantification have mixed impacts on technical efficiency. Young and educated fishers are likely going to take advantage of their youthfulness to gain technical skills whereas; old age comes with experience which is invaluable in farm management [22,23].

Managerial decisions and activities in catfish production can be influenced to a reasonable degree by the experience of fishers, and this can contribute invariably to inefficiencies in catfish production system [22,23]. Family involvements in catfish farming could be another source of technical inefficiency [22, 24]. According to Edward *et al.* [25], family members play both domestic and farm roles in fish production. Unlike men, women combine both roles simultaneously thus, gender could be a possible factor for inefficiency [25, 23].

There are limited studies on technical efficiency of commercial catfish production system in Nigeria in spite of the recent methodological developments and continuous trend in the use of alternative frontier approaches in fishery management. According to Onoja and Achike [26], fish production system in Nigeria is faced with low technical efficiency. This efficiency is determined by some factors including variable input use [27, 23].

Across the south-western zone, Nigerian fish farms operate below optimal frontier Production level, of whose efficiency level can be improved by a range of 20-40% [28]. The study also realized that catfish production system is characterised with a mix of first and second stages of production wherein most farms experiences decreasing positive return to scale.

Besides the associated bottlenecks encountered in data collection, fisheries management authorities tend to show more interest in the biological aspects of fisheries resources rather than fisher's economic performance [29]. Based on its use in other fisheries studies (see for example, [29,21,20], this study employed stochastic production frontier model to evaluate technical efficiency and the socio-economic factors responsible for inefficiencies of catfish production in Oyo State with a view to provide workable strategy to increase catfish productivity in the State [30]. This knowledge if well utilized can come handy to fish policy makers in designing effective policies that will enhance efficiency of catfish production and overall welfare of fishing households in Nigeria.

Materials and Methods

This study was carried out in Oyo State, a major catfish production States in South-western zone of Nigeria. Oyo State lies between latitude 8° 10'N and longitudes 4° 15'E and has average of 5,591,589 human residences [31]. The State experiences two climates annually-the dry and wet seasons. The dry season comes between November and March and rainy season between April and October. With four distinct agricultural zones: Ogbomoso, Shaki, Ibadan/Ibarapa and Oyo, this study purposively selected Oyo agricultural zone due to predominance of catfish farmers in the zone. Oyo zone is made up of six Local Government Areas (LGAs) out of which ten catfish farmers were selected randomly from each of the LGAs in the zone. A total number of sixty respondents were sampled. Using primary data, a well-structured questionnaire was administered to elicit information on catfish production in the immediate past season (2016/2017 farming season). Arrays of information were collected on the price, quantity of inputs used in catfish production including hired and family labour, feed, fingerling, lime; farmers' socio-economic characteristics, and quantity of catfish output produced. The information obtained was subjected to a stochastic production frontier analysis using version 4.1c.

Technical efficiency Model specification

In accordance with [32], there is an assumption that farmers maximize expected profits. Following this, Cobb-Douglas stochastic production model was used in a single equation below to analysis technical efficiency of catfish farmers in Oyo State.

$$\ln Y_i = \beta_o + \sum_{i=1}^{6} \beta_i \ln X_i + (v_i - \mu_i) \ldots\ldots\ldots\ldots\ldots$$

(1) (explicit form)

Where;

Y_i = quantity of catfish output in kilogram (kg) of the i-th farm

X_1 = quantity of lime used (kg)

X_2 = total numbers of labour used in man days (family and hired labour)

X_3 = fish pond size (ha)

X_4 = quantity of feed used (kg)

X_5= cost of other materials: such as fertilizer, fuel, farm land rent, maintenance and depreciation costs, cost of chemicals, and electricity

X_6 = quantity of fingerlings stocked (kg)

μ= a non-negative random variable associated with farm-specific factors which contribute to farms not achieving maximum efficiency

V = a stochastic error term (including extreme weather, measurement errors; and other noise errors such as misspecification problems; poaching industrial action)

β_o = constant parameter

β_i = coefficients to be estimated; ln= natural logarithm

Note: Computation of man-days is based on the rule that one-day work (18 hours) for adult male, one adult female and one child (<18 years) are equivalent to 1 man-day; 0.75 man-day; and 0.50 man-day respectively.

The appropriateness of Cobb-Douglas model for testing efficiency of catfish production system is based on the assumption that Cobb-Douglas model methodology has self-duality of choice [33]. In line with this, [29, 34-35] used Cobb-Douglas to analyse technology of tilapia grow out ponds in Philippines and estimates technical efficiency in carp production in Nepal and Pakistan respectively. This same approach is therefore employed in this study.

The equation for inefficiency model (μi) is given below

$$\mu_i = \partial_0 + \sum_{i=1}^{5} \partial_i Z_i \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where,

Z_1= fishers' household size (number)

Z_2 = Age of the catfish farmers (years)

Z_3 = Catfish farmers' experience in fish farming (years)

Z_4 =catfish farmer's education (1 for formal education and 0, otherwise)

Z_5 = Gender (Dummy 1 for male and 0, otherwise)

∂_i = Parameters estimated;

μ_i = technical inefficiency measure of individual catfish farmer.

Results and Discussion

The Parameter Estimates for Stochastic Production Frontier Model

Table 1 shows maximum likelihood estimates for Cobb-Douglas production function. In this table, both the stochastic frontier and inefficiency models were estimated simultaneously. The result shows that coefficient of gamma (γ) is significant (***P***<0.05), which suggests possibility of one-sided error component. This implies that technical inefficiency is very significant on the performance of catfish production system, which means that average production function is not adequate as representative of the entire data. Coefficient of gamma, (0.73) suggests that about 73% variations in the output of catfish farmers were due to effects of technical inefficiencies while the remaining 27% could be attributed to other factors outside catfish farmers' horizon of influence. On the other hand, sigma-square (σ^2) had a value that is significantly different from zero (***P***<0.05). This shows that sigma has a good fit and assumptions of composite error term distribution were specified correctly. Estimate for Log likelihood was 102.5 showing good maximization of the joint densities of the model estimates. The coefficient of explanatory variables in the Cobb-Douglas model (Table 1) shows a positive and significant expected elasticity of the average catfish output corresponding to the quantities of input variables. However, quantity of feed used was significant (***P***<0.1) but negative. Positive coefficient of the significance variable is an indication that these factors are very importance to output change in catfish production system. This is in agreement with findings by [36, 23].

Generally, the implication of positive estimated coefficients is that a unit increase in the magnitude of the significant variables will lead to a corresponding increase in the average quantity of catfish produced (kg) that is based on the margin of their respective coefficients. Specifically, pond size coefficient was significant

(P<0.05) and revealed that economies of scale is a possibility in the study area. A similar finding is seen in the study area by [36]. However, the possibility of economic of scale associated with firm size might likely be limited among catfish farmers due to small pond size. The elasticity of quantity of catfish fingerling stocked was the highest (0.638) and significant (P<0.1). This is a clear indication that 1-unit increase in the amount of catfish fingerlings stocked will yield a corresponding 0.64-unit increase in the quantity of catfish output. Labour has a negative co-efficient and not statistically significant at all conventional level showing that it is not an important factor in explaining changes in output of fishery production.

On the other hand, the negative significance (P<0.10) of the co-efficient of quantity of feed used is confirmation of inverse relationship with quantity of catfish output. These results shows that 1-unit increase in quantity of feed consumed in catfish production will result in 0.5-unit decrease the quantity of catfish output. This implies that catfish farmers had used catfish feeds in excess, thus, feed is a limiting variable since feed alone cover over 60% of the total cost of catfish production [37], it is therefore imperative that catfish feeding are well regulated to enhance production efficiency.

If consideration is given to the significant coefficients only, returns-to-scale parameter is estimated to be 0.469. Therefore, it is suggestive that catfish production system in Oyo state has a positive decreasing return to scale. As revealed in the coefficient for feed, effort to add a unit of input into the production system will yield a less than the corresponding unit in the output gain than in the preceding unit. Catfish production in this study area can then be categorized into the rational stage of production, which is stage II where factor usage is efficient. From the foregoing, catfish farmers can increase their efficiency of production if the quantity of feed administered per annum is reduced. The implication of this is that the more input one puts in, the more inefficient the system will be. However, other input variables show positive response of output to input. The results are consistent with the "*a priori*" expectations.

This can be partly explained by inadequate skilfulness among the fishermen and imperfect output markets, poor transport and communication infrastructure.

Variable /Production Function	Parameter	Coefficient	t-ratio
Constant	β_0	0.753	3.42*
Ln (pond size)	β_1	0.293	2.13**
Ln (qty of feed used)	β_2	- 0.462	1.96***
Ln (qty of lime used)	β_3	0.155	0.65
Ln (amount of labour)	β_4	- 0.330	2.79
Ln (other materials employed)	β_5	0.160	0.24
Ln (qty of fingerlings stocked)	β_6	0.638	1.96***
I Inefficiency model			
Constant	δ_0	-0.36	2.24**
Fish farming experience (Years)	δ_1	-0.880	-3.27*
Fisher's age (Years)	δ_2	-0.240	-1.17
Household size (Number)	δ_3	0.410	2.99**
Years of education (Years)	δ_4	-0.477	-0.12
Gender	δ_5	0.090	0.03
Parameters for variances			
Sigma^2	$\sigma^2 = (\sigma_v^2 + \sigma_\mu^2)$	0.091	2.20**
Gamma	$\gamma = (\sigma_\mu^2 / \sigma^2)$	0.725	2.51**
Log of likelihood function	Λ	102.45	
Average Technical efficiency		0.74	

Table 1: Parameter Estimates for Maximum-Likelihood of the Cobb Douglas Stochastic Frontier Production for catfish farms in Oyo State.

NB: α significance- * at 0.01, ** at 0.05 and *** at 0.1 levels respectively. Qty=quantity

Determinants of technical inefficiency

As shown in (Table 1), the result of inefficiency analysis revealed that coefficients of fish fishers' age, gender, years of experience in aquaculture and educational status were negative however, the years of experience and household size were the only variables significant (***P***<0.01). Having negative values in the inefficiency measures means that the variable with negative coefficient will affect technical efficiency positively and vice versa. Therefore, it is suggestive that efficiency of catfish production will be enhanced as experience is gained in the practice. In other words, farming experience is a vital human capital for productivity growth in catfish production. In agreement with this finding, [22,23] established that there is correlation between technical efficiency and fisher's experience which eventually impact catfish output positively. This is because farmers' skills to make optimal allocation of input resources increase with increase in farming experience. This is in conformity with findings by some other earlier studies like [20]; [21] and [19]. Similarly, household size has a positive estimated coefficient and significant (***P***<0.05). The result showed that household size has positive association with technical inefficiency (Table 1). The implication is that technical efficiency decrease as household size increases. That is, fishers with large households' size are more likely to be less efficient than those having small household size. This could be attributed to degree of dependence and other commitment that come with large households. This report agreed with submissions of [22]. Congruently, the effect of dependence on farm performance may outweigh labour provision by households. This may mean that most large household members do not participate much in the activities of the farms.

The coefficients of insignificant variables include education status, age and gender. Coefficient of education was negative, which mean that improvement in education level among catfish farmers can increase technical efficiency of catfish production in Oyo State. This result agreed with the work of [38]. Education has a negative implication on technical inefficiencies. This is in support of hypothesis by [39] that the capability to perceive, think, interpret and responsive to innovation that can improve the managerial skills of farmers on efficient allocation and use of farm resources can be enhance through education. However, this coefficient was insignificant but agreed with the "*a priori*" expectation. Thus, education made no significant contribution to the inefficiencies in catfish production system in the study area. Age co efficient had a similar response. It was insignificant but negative. The coefficient shows that the older a catfish farmer is, the more efficient he becomes technically. The coefficient of gender was also insignificant and negative, which means fishermen operate more efficiently than fisherwomen.

Distribution of Farms according to Technical Efficiency

Stochastic production frontier model has a very useful advantage in estimating technical efficiencies by individual and farm specificity. As shown in (Table 2), technical efficiency varied in levels across farms. As revealed in the table, the range was between 41 % and 90 % with about 73 % on average. This implies that relatively, majority of the catfish production farms in the study area operates with a high level of technical efficiency. Average technical efficiency suggests that mean catfish output is performing below the maximum possible production level by a shortfall of about 27 %. The implication is that for an average catfish farmer to operate at optimum technical level the most efficient fish farmer operates, such farmer, could save 18.8 % cost [that is, 1 - (73/90)x100]. Similarly, the most technically inefficient farmer will be able to save 54.4 % in production cost [that is, 1-(41/90) x100]. In general, the technical efficiency values of more than two-third (78.3%) of the fish farmers is greater than 80 %, which means with the use of the current technology, majority of these catfish farmers are highly efficient technically.

Technical Efficiency Range (%)	Frequency	Percentage
Less than 10	-	-
10-20	-	-
20-30	-	-
30-40	-	-
40-50	1	1.67
50-60	2	33.3
60-70	5	83.3
70-80	5	83.3
80-90	47	78.3
90–100	-	-
Total	60	100
Mean TE (%)=74		

Table 2: Distribution of farmers' technical efficiency in decile range

Conclusion and recommendations

This study evaluated catfish farm technical efficiency and its determinants in Oyo State using single-stage modeling of stochastic frontier approach. The results revealed that elasticities of catfish output in correspondence to quantity of lime used, pond size, fingerlings stocked, and other materials used had positive elasticities while feed and labour had negative elasticity but only feed was significant. On the average, fish farms had 74% technical efficiency, which shows that improvement in the realized output is possible to a tune of about 26% using the existing resources and production factors alone.

In addition, catfish farms operate at a decreasing positive return to scale. The combination of farm specific and operational factors influence efficiency significantly explain possible variation in technical efficiency. Given the favourable environment for fish production, climate friendly fish species and abundant water resources, increasing trend in fish demand, and impressive profit associated with catfish production; aquaculture is posed with huge potential for future expansion and productivity growth if farmers can regulate catfish feeding in a sustainable manner by adopting a feeding regime that is efficient and can enhance technical efficiency of fish production system in Oyo State. In view of this, it is imperative that fish farmers are taken through special trainings on catfish feeding regime so as to minimize efficiency loss to fish feeding.

Continuous study is therefore necessary on feed management in the commercial catfish production system whereby technical efficiencies of local and imported feed users are compared across States. This will become relevant if the problem of feeding in catfish production system is to be resolved.

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