NON-RADIAL TECHNICAL EFFICIENCY OF FISH FARMS IN OYO STATE-NIGERIA

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ABSTRACT

Non-radial measure of technical efficiency of fish farms in Oyo State was examined using Data Envelopment Analysis (DEA). Use of the non-radial measures to calculate overuse of inputs by inefficient fish farmers was demonstrated and the potential for reducing inputs used by improving efficiency was evaluated. Ordinary Least Square (OLS) was then used to determine producer characteristics that are likely to lead to higher technical efficiencies. Results indicate that the majority of fish farmers in Oyo State are not producing at the benchmark efficiency level advocated by the industry and all the determinants of efficiency had the expected sign and influence efficiency positively.
Keywords: non-radial, efficiency, Data Envelopment Analysis

INTRODUCTION

Agriculture including fisheries was once the dominant sector in coastal and riverine areas of Nigeria in terms of employment generation and export earnings before the era of oil boom. Since the discovery of crude oil, the situation in this sector has been that of complete marginalization. This process is reflected in the agricultural output growth that lags well behind the population growth. The gap widened significantly in the 1980s when the rate of growth of output fell below its long-term trend rate while population growth accelerated. Hence, Nigeria's food imports increased substantially. While imports were growing, exports were declining at least between 1970 and 1980 Uboma *et al.,*[19] and this continued until 1986 when a modest reform began.

Interestingly, the Nigerian government noted with concern the rapidly increasing population and the related demand for food fish products. The food import, which grew by about 700 percent between 1970 and 1980, was sustained by revenue from the oil boom, which eventually led to a stifling of domestic food commodity production and enterprise. Thereafter, various attempts were made to solve the emerging food fish crisis. The government became more actively involved in food production through various policies, programmes and institutions that were put in place by government to re-dress the crisis. However, scant attention was paid to fisheries as an important sub-sector of agriculture. Fisheries contribute a small portion of the total gross domestic product (GDP) but form an important component of integrated fish farming systems in inland areas of the country. Fisheries research institutes were established all over the nation among which is the Nigeria Institute of Oceanography and Marine Research (NIOMR) whose mandate covers all aspects of marine fisheries research and extension. The National Institute of Freshwater Fisheries Research (NIFFR) on the other hand is responsible for freshwater fisheries research and extension. In addition there is an African Regional Aquaculture Centre (ARAC) that was established with the assistance of United Nation Development Programme (UNDP) and Food and Agricultural Organisation (FAO) to cater for aquaculture research and training of professionals for the African region. Three Colleges of Fisheries were also established to offer training up to the Diploma Level with bases in Victoria Island,Lagos; New Bussa, Niger State and Maiduguri, Bornu State.

According to Jia *et al.,* [12] aquaculture has expanded, diversified, intensified and advanced technologically and, as a result, its contribution to aquatic food production has also increased substantially. It is highly diverse and consists of a broad spectrum of systems, practices and operations which ranges from simple backyard, small-household pond systems to large scale, highly intensive, commercially oriented practices. Though production from capture fisheries is declining, the supply of fish could be increased through reduction in and better use of by-catch e.g. fish meal; better management of fisheries resources and enhanced efforts to protect fishery resources from accelerating environmental degradation, particularly in inland waters and estuaries, may well contribute to sustained, if not enhanced, fish supplies in the medium to long term. However, aquaculture appears to have better potential to meet the increasing demand for fish in Nigeria. Potential contributions from aquaculture to local food security and livelihood cannot be over emphasized, especially among resource-poor rural dwellers.

Previous empirical studies on fish farms in Nigeria have been limited to use of radial measures of efficiency. One of the short coming of this method is that it implies that an inefficient fish farms can only be brought toward the frontier by shrinking inputs equi-proportionately. The use of radial efficiency to calculate input overuse presents serious drawbacks because it implicitly assumes that a technically inefficient farm will have the same degree of input overuse for all variable inputs. Using a non-radial measure, on the other hand, one can shrink each component of the observed input vector as much as possible until the frontier is reached. The objectives of this paper are: (i) to determine farm-level technical efficiencies of fish farms in Oyo State using non-radial and radial measures, (ii) to project the inefficient fish farms onto the frontier, calculating the degree of input overuse and the savings in inputs that could be obtained without sacrificing output, and (iii) to evaluate the degree of association between technical efficiency and farm characteristics or production practices.

Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) refers to non-parametric techniques that have been extensively used in agricultural economics research. Introduced by Fare *et al.,* [10] and developed independently by Charnes and Cooper [6]. In addition, Banker and Thrall [5] generalized the model to allow for fixed and exogenous factors, while Banker and Morrey [4] further developed the use of returns to scale in DEA models. Other approaches to measure technical efficiency include those pioneered by Afriat [1] and developed by Richmond [17].

In DEA models for measuring input-oriented technical efficiency, the objective was to contract all inputs at the same rate to the extent possible without reducing any output. In practice, however, some inputs are more valuable than other inputs and conserving such inputs would be more efficient than saving other inputs. When market prices of inputs are available, the firm would seek to minimize the total input cost for a given level of output. This would mean not only that inputs are changed by different proportions but also that some inputs may actually be increased while others are reduced when that is necessary for cost-minimization. In non-radial measures of efficiency, although disproportionate changes in inputs and outputs were allowed, it did not consider the possibility that some inputs could actually be increased or that some outputs could be reduced. This is principally due to the fact that DEA was originally developed for use in a non-market environment where prices are either not available at all or are not reliable, even if they are available. This may give the impression that when accurate price data do exist, it would be more appropriate to measure efficiency using econometric methods with explicitly specified cost or profit functions and not to use DEA. This, however, is not the case. DEA provides a nonparametric alternative to standard econometric modeling even when prices exist and the objective is to analyze the data in order to assess to what extent a firm has achieved the specified objective of cost minimization or profit maximization.

Consider a fish farm j, each using N variable inputs and K fixed inputs in the production of M outputs. Let x = $(x_1 ....x_N)' \in \Re^N +$ denote the vector of variable inputs;
y = $(y_1 ....y_N)' \in \Re^M +$ the vector of variable outputs; and z = $(z_1 ....z_k)'$ the vector of nonnegative quasi-fixed inputs. In addition, let the matrix of observed inputs of dimension N X J be represented by X and the matrix of observed outputs of dimension *M X J* be represented by Y. In the presence of fixed inputs, the input set (which yields at least output y) satisfying variable returns to scale (V) and strong disposability of inputs and outputs (S) is given by (Fare, Grosskopf, and Lovell):

$$L(y/V,S) = \left\{ \begin{array}{l} x : Y\alpha \geq y, X\alpha \leq x.Z\alpha = z \\ y \in \Re^M, \sum_{j=1}^{j} \alpha_j = 1, \alpha_j = 1, \alpha_j \geq 0 \end{array} \right\} \quad \text{(i)}$$

where $(\alpha = (\alpha_1 ....\alpha_j)'$ is the input utilization rate or intensity vector (also interpreted as the vector of weights associated with each observation) that forms the convex combinations of the observed input and output vectors. Non-increasing returns to scale are imposed by relaxing the constraint on the intensity vector to $\sum \alpha_j \leq 1$ and constant returns to scale are imposed by eliminating the constraint altogether, A farm is technically efficient in the production of an output bundle y if, and only if, the inputs used belong to the efficient subset, defined by:

Eff. L(y/VS) = $\left\{ x : x \in L(y/V,S), \hat{x} > x \rightarrow \hat{x} \notin L(y/V,S) \right\}$ ....(ii)

The input-based radial technical efficiency is defined as:

$E_R = (V,S) = Min_{\theta.\beta} \left\{ \theta : \theta x \in L(y/V,S \right\}$ ....(iii)

where L(,) is given by equation 1 and θ is a scalar $(0 \leq \theta \leq 1)$. The radial technical efficiency of a farm with observed inputs and outputs may be interpreted as the ratio of observed inputs to potential inputs located in the frontier. An inefficient fish farm can be made more efficient by projecting it into the frontier through proportional reduction of all inputs keeping output constant, i.e., the input levels are reduced along a ray until the frontier is reached. Thus, an inefficient point (x,y) projected to the frontier becomes (øx, y). The notion of radial efficiency has its strength and weaknesses such as its duality relationships, that is, the radial efficiency is the inverse of the distance function and its cost interpretation, but it can lead to an overstatement of the “true” technical efficiency of an input vector Lovell and Schmidt [15], In addition, the use of radial efficiency to calculate input overuse presents serious drawbacks, because it is not realistic to expect that a technically inefficient fish farm will show the same degree of input overuse for all variable inputs. The use of non-radial efficiency is a way of avoiding this short coming, Fare *et al* and Fare and Lovell [8,9]. The non-radial overall efficiency of a fish farm is obtained by shrinking each component of the observed input vector as much as possible until the frontier is reached. The non-radial overall (input side) measure is defined as:

$$E_{NR}(V,S) = \left\{ \sum_{n=1}^{N} \theta_n / \breve{N} : (\theta_1 x_{1,..........,} \theta_n x_n, ..., \theta_N x_N) \in L(y/V,S) \right\} \quad \text{(iv)}$$

where $\breve{N}$ is the number of nonzero inputs (varies for each fish farm),
$\theta = (\theta_1, ...\theta_{n,.....................} \theta_N)$ is a vector and each component provides a measure of the efficiency in the use of that input. The non-radial efficiency reduces to the radial case
when $\theta_1 = \theta_2 = ... = \theta_n = ... = \theta_N = \theta$ for all *n* that corresponds to $x_{jn} > 0$ Fare and Lovell established properties of the non-radial efficiency. In particular, they show that for $x \in L(x)$ and x >0, the radial measure is greater than or equal to the corresponding non-radial measure. Intuitively, since the non-radial measure shrinks the input bundle at least as much as the radial measure, it follows that the ratio

of the ‘‘shrinked” input vector to the original vector, or input-based technical efficiency, should be larger (or equal) in the radial case than in the non-radial case.

ANALYTICAL MODEL AND EMPIRICAL METHODS

Study area and data

Oyo State is one of the major aquaculture zones of Nigeria that is located in the southwestern part of the country. With basically a tropical climate of 11-39 degree centigrade (minimum and maximum daily temperature), the state receives an average of 120 cubic centimeters per annum. It can also record a very high relative humidity of about 70 percent. The state is divided into four distinct agricultural development zones: Ibadan/Ibarapa; Oyo/Iseyin; Saki and Ogbomoso. Due to high concentration of fish farmers in Ibadan/Ibarapa zone, the zone was considered for the study. In Oyo state, there are five species of fish: tilapia, Heterotis, Ophocephalus, Clarias and Carp ssp. but four of the said spp. were found in the study area. The culture period varied between six and twelve months. In establishing the sample for the study survey, 80 respondents were randomly selected. Each of these 80 fish farmers were surveyed with respect to output levels and input use in fish production, as well as the socio-economic characteristics. Because some of the fish farms practice polyculture, the yield were expressed in kg, data were collected for pond size, feed, stocking density and labour (family and hired). Labour use is expressed in man day, with 1 day being equal to 8hr of labour; pond size is measured in square meter; stocking density is measured in kg of fingerlings put in the pond; and feed is measured in Kg. In addition to input-output, information were also collected on farm specific factors such as experience, frequency of extension visits, education and pond size, which were used to identify important characteristics influencing efficiency of fish production.

The radial efficiency is obtained by solving the following linear programming

Maximize θ_i

$\theta_i,\ \lambda_j$

Subject to……………………………………………………………………(v)

$$\theta_i y_{ri} - \sum_{j=1}^{n} \lambda_j y_{rj} + s_{ri} = 0$$

$$r = 1.........s(yield)$$

$$x_{ki} - \sum_{j=1}^{n} \lambda_j x_{kj} - e_{kj} = 0$$

$$k = 1.........m(inputs)$$

$$\lambda_j \geq 0; s_{ri} \geq 0; e_{ki} \geq 0$$

i,j =1…………n fish farms in the sample

$\theta =$ Possible proportional increase in yield

$s_r =$ rth output slack

$e_k =$ kth input slack, and

$\lambda_j =$ Weight or intensity variable used to derive all possible linear combinations of the sample observation

When the value of θ_i is one (1), $\lambda_i = 1$ and $\lambda_i = 0$ for $j \neq i$ the ith fish farm lies on the frontier and is technically efficient. Furthermore, input and output slacks will always be zeros for the efficient fish farms in the sample. For the inefficient fish farms, θ_i >1; $\lambda_i = 0$ and $\lambda_j \neq 0$ for $j \neq i$ where j denotes the efficient fish farms in the sample. Inefficient fish farms may also have some positive output or/ and input slacks. The output based technical efficiency index of the ith fish farm (TE_i) were computed as follows

$$TE_i = \frac{1}{\theta_i} \qquad \text{(vi)}$$

the projected or frontier production of the rth yield $(\hat{y}_{ri})$ was computed as follows

$$\hat{y}_{ri} = \sum_{j=1}^{n} \lambda_j y_{rj} = \theta_i y_{ri} + s_{ri} \qquad \text{(vii)}$$

r = 1…………………s yield

equation (v) shows that the projected output consist of two components, one representing the proportional increase in all outputs ($\theta_i y_{ri}$) and the other accounting for the non-proportional increase or slack (s_{ri}). DEA model in (i) also estimates the input slacks (excess inputs) that needed to be conserved for an inefficient fish farm to be fully efficient. The projected amount of the kth input of the ith fish farm ($\hat{x}_{ki}$) was expressed as

$$\hat{x}_{kj} = \sum_{j=1}^{n} \lambda_j x_{kj} = x_{ki} e_{ki} \qquad \text{(viii)}$$

k=1…………m (inputs)

it should be noted that the fish farms DEA model given in (v) implies constant returns to scale (CRS) technology. Following Battesse and Coelli [3], the corresponding model under variable returns to scale (VRS) was obtained by imposing addition constraint on (v). The technical efficiency score obtained from DEA CRS model (TEcrs) is often referred to as "overall" technical efficiency and that obtained from DEA VRS model is called "pure technical efficiency" (TEvrs). The VRS frontier is more flexible and envelopes the data in a tighter way that the CRS frontier and the relationship between TEcrs and TEvrs is often used to obtain a measure of scale efficiency as follows

$$SE = \frac{TEcrs}{TEvrs} \qquad \text{(ix)}$$

when SE=1 indicates scale efficiency and SE<1 indicates output based scale inefficiency.

Scale inefficiency is due to the presence of increasing or decreasing returns to scale, which can be determined by solving a non increasing return to scale (NIRS) DEA model which is obtained by substituting the VRS constraint with $\sum_{j=1}^{n} \lambda_j \leq 1$. Let θ_{NIRS} represent the proportional increase in all outputs under NIRS DEA model, for scale inefficient observations, $\theta_{CRS} = \theta_{NIRS}$ indicates operation in the region of increasing returns to scale; $\theta_{CRS} > \theta_{NIRS}$ indicates decreasing returns to scale Farrell [11]

$$Min_{\alpha,\theta} \sum^{N} \theta_n^0 / \breve{N}^0 \qquad \text{...(x)}$$

$$s.t \sum_{j=1}^{J} \alpha_j y_{mj} \geq y_m^0$$

$$\sum_{j=1}^{J} \alpha_j x_{nj} \leq \theta_m^0 x_n^0$$

$$\sum_{j=1}^{J} \alpha_j Z_{kj} \leq z_k^0$$

$$\sum_{j=1}^{J} \alpha_j = 1$$

x^0, y^0, z^0 represent the input-output vectors for the fish farms.

The effect of farm-specific factors on efficiency has generated considerable debate in the frontier analysis. There are several methods among which are regressing the efficiency estimate scores against the farm-specific factors, use of non-parametric statistics or analysis of variance (ANOVA) tests. Authors like Kaliba and Karole [13] and Kalirajan [14] defended this approach while Banker *et al.,* [2] challenged it and comfortable with incorporating these farm-specific factors directly in the estimation of production frontier, probably because such factors may have direct impact on efficiency. Despite this criticism, the procedure is still being widely used in investigating the relationship between efficiency and farm-specific variables. Incorporating firm-specific variables directly into frontier model is limited to parametric approach. Lovell and Schmidt [15]noted that without prior assumptions on whether the firm-specific factors have a positive or negative effect on the impact of economic performance, the non-parametric DEA technique could not easily incorporate firm-specific effects directly into the estimation of an efficient frontier. Hence this study used an ordinary least square (OLS) to examine the relationship between the efficiency index and farm-specific factors.

RESULTS AND DISCUSSION:

The indexes of both radial and non-radial technical efficiency were compared and shown in table 1 and 2 respectively. Expectedly, the non-radial technical efficiency indices were smaller than the corresponding radial efficiency technical indices under all the three cases of scale economies imposed in the technology and the difference of two means showed that they are significantly different from zero at 5 % probability level. The estimated efficiency scores for radial efficiency varied from 0.44 to 1.00 with a sample mean and standard deviation of 0.81 and 0.19 respectively while the non-radial measure varied from 0.19 to 1.00 with a sample mean and standard deviation of 0.60 and 0.24 respectively for “overall” technical efficiency which assumed constant returns to scale (CRS). Observation of wide variation in technical efficiency is not surprising and similar to the results from China and Malaysia. For example, Chen *et al* [7]reported mean technical efficiency level of 0.42 (range 0.7 to 0.99) for carp pond culture in Penisula Malaysia while Ray [16] observed mean technical efficiency indices of 0.83 (0.39 to 1) for the Chinese fish farms. Of the 80 fish farms in the analysis, 27 (about 34%) and 3 (3.75%) were found to radial and non-radial technically efficient. The “overall” technical efficiency was broken down to pure and scale technical efficiency and the result showed that for radial efficiency, pure technical efficiency and scale efficiency is 0.86 and 0.85 respectively while the mean for non-radial are 0.72 and 0.85.

Table 1:Frequency distribution of Technical and Scale Efficiency indices using radial measures

Efficiency interval	CRS-TE	VRS-TE	DRS-TE	Scale Efficiency
0.40-0.49	8	5	7	
0.50-0.59	7	4	5	1
0.60-0.69	11	10	12	2
0.70-0.79	5	7	8	6
0.80-0.89	6	5	8	8
0.90-0.94	3	2	3	7
0.95-0.99	13	8	14	16
1.00	27	39	23	40

Source: Data analysis, 2005

Table 2: Frequency distribution of Technical and Scale Efficiency indices using non-radial measures

Efficiency interval	CRS-TE	VRS-TE	DRS-TE	Scale Efficiency
0.10-0.29	6	5	6	1
0.30-0.49	26	17	26	4
0.50-0.69	18	15	18	7
0.70-0.89	18	11	18	24
0.90-0.94	2	1	2	19
0.95-0.99	7	23	4	15
1.00	3	8	6	10

With respect to scale economies using the traditional radial efficiency measure, among the 40 scale inefficient fish farms, 27 fish farms demonstrated inefficiently small scale or increasing return to scale (IRS) while 13 fish farms demonstrated inefficiently large scale of operation or decreasing returns to scale (DRS). The remaining sampled fish farms were operating well in terms of operation, that is, were scale efficient while for the non-radial measure, 64 fish farms demonstrated inefficiently small scale or increasing return to scale (IRS) while 6 fish farms demonstrated inefficiently large scale of operation or decreasing returns to scale (DRS).

Efforts were made to examine the input and output slacks for inefficient fish farms and the summary is shown in table 3. For radial measure, the findings revealed that the output slacks for the farm are that 16 fish farms showed positive output slack on tilapia, while 6 showed positive slacks on cat fish. This indicates that the output increment for some inefficient fish farms could come from the proportional increase in outputs, on average. Slacks for tilapia and cat fishes accounted for about 2.6 and 3.1 percent of potential levels of tilapia and cat fishes. Information on output slacks can be very useful for fish farm managers in identifying important areas for improvement. For the input slacks, the largest number of slacks was observed for feed (39) while fertilizer accounted for the minimum number of input slack. These slacks accounted for about 4.0 and 1.3 percent of feed and fertilizer input used by the sampled fish farms. One of the efficient fish farms had a non-zero slack and did not fully satisfy the Pareto-Koopmans efficiency, which is fully efficient if and only if it is not possible to improve any input or output without worsening some other input or output. This fish farm can be referred to as mix inefficient farm.

For non-radial measures, no fish farms showed positive output slack on tilapia, while 10 showed positive slacks on cat fish. This indicates that the output increment for some of inefficient fish farms come from the proportional increase in outputs, on the average, slacks for cat fish accounted for about 6.12 percent of potential levels of cat fish. Information on output slacks can be very useful for fish farm managers in identifying important areas for the improvement. For the input slacks, the largest number of slacks was observed for feed (52) as it was in the other zone while both hired and family labour accounted for the minimum number of input slack. These slacks accounted for about 2.4 and 2.6 percent of feed and fertilizer input used by the sampled fish farms. Unlike the radial measures, no fish farm exhibited mix inefficiency, that is, all efficient fish farms had non-zero slack.

Table 3: **Summary of Output and Input Slacks for Inefficient Fish Farms for radial and non-radial Measure**

	Radial measure		Non radial measure	
Outputs	Number	Average	Number	Average
Tilapia (Kg)	16	121.25	0	0
Catfish (Kg)	6	85.80	10	85.68
Inputs				
Seed (Kg)	18	24.65	15	17.80
Fertilizer (Kg)	12	17.43	39	48.19
Hired labour(Man-day)	22	21.78	12	1.56
Family labour (Man-day)	19	42.19	12	2.92
Feed (Kg)	39	54.42	52	4.64
Land (acre)	15	2.14	48	4.26

The importance of farmers' characteristics, farm practices and institutional support in explaining technical efficiency is reported in Table 4. As expected, it could be observed that all the explanatory variables have a positive association with the technical efficiency indices for both radial and non-radial measures. Experienced operators were expected to be more technically efficient than the relatively new operators and significant at 1%. Extension contacts is expected to facilitate technical know how of fish farms, thus fish farm manager who have high frequency of extension services are likely to be more technically efficient than others. As expected, the pond size has a positive relationship with technical efficiency and significant at one percent. This is expected because of the physical economies of scale and on the average smaller fish farms will tend to be less efficient and lie farther away from the efficient frontier in input space. This result agrees with other results on technical efficiency and farm size e.g. Kalirajan[14]. All the explanatory were significant for non-radial measure with the exception of education.

Table 4: Influence of Farm Characteristics on Technical Efficiency for radial and non radial measure

	Radial Measure		Non-radial measure	
Variables	Coefficient	t-ratio	Coefficient	t-ratio
Constant	2.29	6.71	3.92	8.35
Farm size	0.18	17.1*	0.18	12.9*
Extension	0.42	16.8*	-0.500	-2.05**
Education	0.18	6.9*	0.01	0.70
Experience	0.15	11.9*	0.01	4.7*

* and ** denotes, respectively, significance at 1 and 5 percent level

CONCLUSIONS:

The study used two different forms of non-parametric frontier to estimate the technical efficiency of fish farms in Oyo State, Nigeria and further demonstrated that the non-radial measure which overcome the short coming of the radial efficiency measure by not implicitly assume that a technically inefficient farm will overuse all variable inputs to the same degree is a better measure of technical efficiency indexes.

The technical efficiency was further broken down into overall, pure and scale efficiencies, it was observed from the findings that in terms of the overall efficiency, that is efficiency that is devoid of scale economies, the mea estimated efficiency scores are 0.81 and 0.6 for radial and non-radial respectively. The scale economies revealed that about 88 percent of the fish farmers were scale inefficient compared to 50 percent that are radially scale efficient Factors that could determine the technical efficiency of fish farms were examined and it was observed that farm size is statistically significant at 5 percent, which suggests that, large farms operate at a better efficiency level than small farms as indicated by the positive relationship between efficiency indices and farm size for both radial and non-radial measures. Thus, technical efficiency increases as farm size increases. Access to extension is statistically significant at 10 percent level with an expected sign. This observation followed an *a priori* expectation that access to institutional support such as extension service will improve the technical efficiency of the fish farmer. The coefficient of experience showed a positive association with technical efficiency, and is significantly different from zero.

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