# Farm-level efficiency and resource use: Application of stochastic frontier analysis to aquaculture farms in Southwest Nigeria

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In Nigeria, fish provide the cheapest source of animal protein, especially in the rural and urban communities. Presently, the domestic fish supply in the country stands at about 400,000 t/yr. Eighty percent of the supply comes from the artisanal capture fisheries. The domestic fish supply is far below the demand because of the progressive increase in the country's population (Ojo *et al.* 2006). This has necessitated the importation of frozen fish to offset the gap in the domestic demand.

The annual trade statistic from the Central Bank of Nigeria shows that Nigeria expended over US$200 million annually on the importation of frozen fish to offset the production in the country (CBN 2006). Continued importation of frozen fish had been identified as one of the major sources of drain on the country's foreign reserves.

With the decrease in artisanal fish supply from ocean fisheries as a result of overfishing and pollution, many concerns are raised among the policymakers about the possibility of capture fisheries bridging the gap between supply and demand in the country. Aquaculture, in light of this development, had been suggested, over the years, as a more environmentally friendly source of fish protein for the country.

Aquaculture is predominantly an extensive land-based system, practiced at subsistence levels (Fagbenro 2002). Its current yield is put at 14,388 t/yr, so there is considerable potential for commercial aquaculture development (Fagbenro and Adebayo 2005). Recent published annual agricultural production statistics by the Central Bank of Nigeria, show that the contribution of aquaculture to total fisheries production in Nigeria increased from about 11 percent in 2003 to 21 percent in 2005 (CBN 2006). This is an indication that aquaculture activity in the country is taking a giant step toward repositioning. Continued expansion of aquaculture production across the country however, is expected to play an important role in ensuring sustainable fish production among other benefits in the country in the future.

Therefore, examining resource use and technical efficiencies of aquaculture farms in the country will provide the decision makers a control mechanism with which to examine the performance of these farms. This study intends to provide such an examination by comparing aquaculture farms across Southwest Nigeria.

## Study Methods

### Study area and the Data

The study was carried out in four states across southwest Nigeria: Ekiti, Osun, Ondo and Ogun. Southwest Nigeria has a total population of about 28 million people equivalent to about 20 percent of entire population (NPC 2007). A tropical climate characterizes the region which has moderate temperatures year round, a rainy season from April to October and a dry season from November to March.

A multistage sampling technique was employed for the study. Two local government areas (LGAs) in each of the states with the highest prevalence of aquaculture farms were selected. Successful identification of the LGAs was made possible by the fishery unit of the state`s agricultural development program (ADP). The ADPs have lists of the aquaculture farms in their respective states. The second stage involved random selection of 20 farms from each LGA. A total of 40 farms were selected in each state. In all, 160 farms were interviewed with the aid of a well structured questionnaire administered through trained enumerators in 2006. Information collected included mature fish harvested (Kg) and their price per Kg in naira within the period under consideration. Information on quantity and prices of input used in naira was collected also. This included pond size ($m^2$), feeds (Kg), labor (hours), numbers of fingerling stocked and costs of materials, including the cost of lime and fertilizer.

### Analytical technique

We employed stochastic frontier models proposed by Aigner *et al.* (1977) and Meeusen and Van de Broeck (1977) for the study. The specification of the models incorporate the deterministic function, error terms that account for the statistical noise, as well as a non-negative random component, to generate a measure of technical inefficiency.

Indexing the farms by *i*, the specification can be expressed as:

$$y_i = f\left(x_{ij};\beta_j\right)\exp\left(\nu_i - \upsilon_i\right) \qquad 1$$

where, $y_i$ is output of i-th aquaculture farm; $x_{ij}$-a vector of j-th inputs of i-th aquaculture farm; $\beta_j$-a vector of parameters to be estimated. The error term $\nu_i$ is i.i.d~ $N\left(0,\sigma_V^2\right)$. We assumed

$v_i$ captured random variation in fish production because of factors beyond the control of the farmers, such as variation in weather. The second error term $\upsilon_i$, captured technical inefficiencies in fish production. These were assumed to be farm-specific non-negative random variables, i.i.d.~ $N(\mu, \sigma_u^2)$ . A higher value for $\upsilon_i$ implies an increase in technical inefficiency. If $\upsilon_i$ was zero the farm was technically efficient.

Consequently, technical efficiency (TE) was defined as the ratio of the mean output for the i-*th* aquaculture farm, given the values of the inputs $x_i$ and its technical inefficiency effect $\upsilon_i$, to the corresponding mean output if there was no technical inefficiency in production (Battese and Coelli 1988).

The definition can be expressed mathematically when $y_i$ and $x_{is}$ are in logarithm form as:

$$TE_i = \frac{E(Y_i \mid u_i, X_i)}{E(Y_i \mid u_i = 0, X_i)} = \frac{f(X_j; \beta_j)\exp(v_i - \upsilon_i)}{f(X_j; \beta_j)\exp(v_i)} = \exp(-\upsilon_i) \qquad 2$$

All estimates of equations 1 and 2 were obtained through maximum likelihood procedures in the computer program FRONTIER 4.1c (Coelli 1996).

### Measure of input-specific allocative efficiency

This study followed a neoclassical production theory approach. Using the farm specific production function with the highest associated iso-profit line, we obtained a measure of input-specific allocative efficiency for the aquaculture farms. The highest iso-profit, however, was determined when marginal value product ($MVP_x$) of the inputs equated marginal factor costs ($MFC_x$). In other words, $MVP_x$ was obtained when the slope of the production function (marginal product -$MP_x$) equaled the ratio of the prices of the factor inputs and the output $(MFC_x / P_y)$[2] (Kalirajan and Obwona 1994). Mathematically:

$$MP_x = \frac{MFC_x}{P_y} \qquad 3$$

$$MP_x.P_y = \mathbf{MFC}_x \qquad 4$$

where

$$MP_x.P_y = MVP_x$$

$$MVP_x = \mathbf{MFC}_x \qquad 5$$

For this study, we expressed the derivation of the individual farm specific allocative efficiency for the inputs slightly different from the expressions 3 to 5. This is because of our choice of Cobb-Douglas functional form[3] to represent the frontier model (equation 1).

However, we derived the individual farm input specific allocative efficiency using the following expression because of the reasons outlined in note 2 as

$$\beta_j \left[Y_i / X_{ij}\right] = \frac{MFC_x}{P_y} \qquad 6$$

$$\beta_j \left[Y_i / X_{ij}\right] P_y = MFC \qquad 7$$

Here, $\beta_j$ was the estimated input elasticities (coefficient of the chosen Cobb-Douglas functional form); $Y_i / X_{ij}$ was average product of j-th input; $MFC_x$ was price of the factor input *j*; $P_y$ was price of output; $\beta_{ji}\left[Y_i / X_{ij}\right]$ equivalent to the marginal product $(MP_x)$ of the input.

The expression in equation 7 was the measure of the input specific allocative efficiency employed for the study. This was calculated for each variable input per aquaculture farm. The input specific allocative efficiency shows how farmers responded to price signals for output and inputs to allocate their resources (input-mix) in an optimal manner. This might have involved using less of one input or using more of another input to increase their production over time.

For an optimal input utilization, marginal value product (MVP) of input $x_j$ was expected to equate marginal factor cost (MFC) of the input for an optimum production level to be achieved (i.e. $MVP_x = MFC_x$ ). However, whenever MVP of an input $x_j$ was greater than its MFC (i.e. $MVP_x > MFC_x$ ) it implied that $x_j$ was underutilized in the course of production, thus not used sufficiently. Over utilization of the input was observed when its MVP was less than the MFC (i.e. $MVP_x < MFC_x$ ). The implications of the last two scenarios signal a non optimum production level. Such characterizations implied continued application of under-utilized inputs as well as decreased application of over utilized inputs to ensure an optimum production level.

### Model specification

For this study, Cobb-Douglas functional form was specified for the study for the reason stated in Note 3. The frontier functional form was, therefore, defined as

$$\ln y_i = \beta_0 \prod_{j=1}^{J} \beta_j \ln x_j + v_i - \upsilon_i \qquad 8$$

where, *ln* represented the natural logarithm; the subscript i-th sample farmer; $y_i$ represents the harvested fish (kg) for farmer *i* ; $x_j$ represents pond size, feeds, labour, numbers of fingerlings-stocked and costs of materials; $\beta_j$ represents the input coefficients while $\mathbf{v_i}$ , and $\mathbf{u_i}$ are as earlier defined.

## Emperical Results and Discussion

### Summary Statistics

The summary statistics of variables included in the regressions show that an average farm in Ogun, Ondo, Ekiti and Osun states produced about 23,000, 19,000, 15,000 and 13,000 Kg/yr, respectively. For the inputs, analysis showed that an average farm in Ogun state had about 341 $m^2$ of pond, 4,400 kg of feed used, 1,300 hours of labor, 34,800 of stocked fingerlings and ₦48,000 costs of materials. An average farm in Ondo state had about 260 $m^2$ of ponds, 3,100kg of feed used, 910 hours of labor; 26,000 fingerlings and ₦32,000 costs of materials. For an average farm in Ekiti state we observed 210 $m^2$ of ponds, 2,510 Kg of feed used, 968 hours of labor, 14,560 fingerlings stocked and ₦33,000 costs of materials. Finally, an average farm in Osun state had 194 $m^2$ of ponds, 2,240kg

Table 1. Estimates of the stochastic frontier production function.

| Variables | Parameters | Frontier ML estimates | | | |
|---|---|---|---|---|---|
| | | Ogun | Ondo | Ekiti | Osun |
| *Constant* | $\beta_0$ | 2.614*(3.95) | 5.039*(2.49) | 4.115*(3.74) | 1.851**(1.98) |
| *ℓn* Pond Size | $\beta_1$ | 0.149**(2.17) | 0.267**(1.98) | 0.223*(2.79) | 0.311*(3.64) |
| *ℓn* Feeds | $\beta_2$ | 0.368**(1.97) | 0.295**(2.26) | 0.187**(2.02) | 0.209**(2.12) |
| *ℓn* Labor | $\beta_3$ | 0.123*(2.54) | 0.169*(6.31) | 0.149**(1.99) | 0.003*(3.82) |
| *ℓn* fingerlings stocks | $\beta_4$ | 0.305*(1.96) | 0.297*(2.75) | 0.283**(2.36) | 0.146**(2.38) |
| *ℓn* costs of capital | $\beta_5$ | 0.387*(5.93) | 0.124**(1.97) | 0.142*(3.28) | 0.252**(2.04) |
| **Variance Parameters** | | | | | |
| Sigma square | $\sigma^2$ | 0.445*(3.46) | 0.319*(8.35) | 0.523*(3.96) | 0.464*(3.09) |
| Gamma | $\gamma$ | 0.821*(5.85) | 0.803*(3.07) | 0.941*(6.24) | 0.894**(2.36) |
| Log likelihood | LL | -47.954 | -68.251 | -60.298 | -55.892 |
| **Returns-to-scale (RTS)** | | **1.332** (2.49)** | **1.153*(5.07)** | **0.882*(2.86)** | **0.921*(3.17)** |
| **Technical Efficiency** | | | | | |
| Minimum | 0.581 | 0.295 | 0.246 | 0.127 | |
| Maximum | 0.982 | 0.927 | 0.811 | 0.763 | |
| Average | 0.892 | 0.816 | 0.784 | 0.565 | |
| Standard Deviation | | 0.013 | 0.028 | 0.017 | 0.035 |

*Figures in parentheses are t-ratio; * and ** estimates are significant at least 1% and 5% level of significance respectively*

of feed used, 893 hours of labor, 14,100 fingerlings stocked and ₦28,485.56 costs of materials.

## Resource-use efficiency of the inputs

Presented in Table 1 are the results of the point estimates of input elasticities of the farms across the states. All the estimated coefficients had positive signs that were significantly different from zero. The implication of this is that the production functions monotonically increased with input level for the farms across the states. The returns to scale (RTS) computed as the summation of the input elasticities, show that a joint increase in the inputs by one percent increased the output by 0.88 percent, 1.33 percent, 1.15 percent and 0.92 percent for farms in Ekiti, Ogun, Ondo and Osun, respectively. This implies that farms in Ogun and Ondo states exhibited increasing returns to scale, while farms in Ekiti and Osun exhibited decreasing returns to scale.

The results of the input specific allocative efficiency show that none of the farms across the states appeared to have efficiently allocated any of the variable inputs considered $(MVP_x = MFC_x)$. The results revealed that 90, 85, 60 and 70 percent of the farms in Ogun, Ondo, Ekiti, and Osun states, respectively, appeared to have underfed. At the same time 70, 78, 65, and 68 percent of the farms in Ogun, Ondo, Ekiti, and Osun states, respectively, appeared to have understocked their fingerlings. Ninety-three, 70, 88 and 55 percent of the farms in Ogun, Ondo, Ekiti, and Osun states, respectively, appeared to have over-used labor.

The economic implication of the results was that increased use of feeds, as well as numbers of fingerlings stocked for farms across the states will increase the output level of the farms. At the same time decreased use of labor will increase the farms output level across the states.

However, one possible reason for the observed allocative inefficiency across the farms can be attributed to financial constraints. This observation was pointed out to us by the farmers from the study areas as one of the most frequently identified problems.

That observation was similar to the findings of Liefert (2005) in his study of allocative efficiency of material inputs in Russian agriculture. He stressed the major influence of credit constraint on optimal input utilization and concluded that improving access of the farmers to credit would improve allocation of resources.

Another reason can be attributed to the availability of the inputs. The most affected of all the inputs considered for the analysis is number of fingerlings stocked. Except in Ogun and Ondo states, where there were numbers of hatcheries, other states have few and partially functioning hatcheries. Most hatcheries in Ogun state are privately owned, while most hatcheries in Ondo state were government owned. Farms in Osun state relied on hatcheries from their neighboring states, Oyo and Ogun, while farms in Ekiti relied on hatcheries in Ondo and Oyo. With hatcheries in Ogun and Ondo states supplying farms in their states and farms in the neighboring states, demand seems to outstrip the supply. That issue needs to be addressed. The farmers identified the fingerling supply as another important factor threatening their expansion across the region.

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Table 2. Allocative efficiencies of variable inputs by state.

| Inputs | Feeds | | Labor | | Fingerlings | |
|---|---|---|---|---|---|---|
| Decisions | Freq. | % | Freq. | % | Freq. | % |
| Ogun State | | | | | | |
| $MVP_x > MFC_x$ | 36 | 90 | 3 | 7 | 28 | 70 |
| $MVP_x < MFC_x$ | 4 | 10 | 37 | 93 | 12 | 30 |
| Ondo State | | | | | | |
| $MVP_x > MFC_x$ | 34 | 85 | 12 | 30 | 31 | 78 |
| $MVP_x < MFC_x$ | 6 | 15 | 28 | 70 | 9 | 22 |
| Ekiti State | | | | | | |
| $MVP_x > MFC_x$ | 24 | 60 | 5 | 12 | 26 | 65 |
| $MVP_x < MFC_x$ | 16 | 40 | 35 | 88 | 14 | 35 |
| Osun State | | | | | | |
| $MVP_x > MFC_x$ | 28 | 70 | 18 | 45 | 27 | 68 |
| $MVP_x < MFC_x$ | 12 | 30 | 22 | 55 | 13 | 32 |

# Farm-level Efficiency

*(Continued from page 19)*

### Technical efficiency analysis

The summary statistics of the point estimates of the technical efficiency scores for the farms are presented in the lower part of Table 2. The results show that an average farm in Ogun, Ondo, Ekiti and Osun obtained an average technical efficiency of 0.892, 0.816, 0.784 and 0.565, respectively.

In terms of resource-use efficiency, the results of the technical efficiency shows that an average farm in Ogun, Ondo, Ekiti and Osun states could scale up their present level of output by approximately 11, 18, 22 and 44 percent, respectively, to reach the frontier level of most efficient farm across individual states. Comparatively, it implies that, less than 20 percent of the current output of the farms in Ogun and Ondo states is forgone as a result of inefficiency as compared to more than 20 percent in Ekiti and Osun states.

## Conclusions and Policy Implications

The findings show that assessment of farm-level technical and input specific-allocative efficiencies provide the needed performance indicator of aquaculture farms in the country. While the results have implications to sustainable fish production in Nigeria, effort must be made to address inefficiencies inherent in aquaculture production in the country, as highlighted in the study. Therefore, any measure aimed at improving economic efficiency of cultured fish production in Nigeria should address allocative inefficiency as well as improve the current level of technical efficiency of the farms.

We suggest that policy options for improving the economic efficiency of the farms should follow closely the combination of the following approaches:

1. Expansion of the present fingerling production capacity across the states. A possible way to implement this suggestion is to embrace public-private partnerships that will lead to the establishment of more hatcheries across the states. Government should provide an enabling environment to encourage individuals and entrepreneurs to invest in fingerling production. This approach had been working well in other parts of the country.
2. Another option is to extend the provision of credit facility to the fish farmers as currently extended to the food crops farmers across the states. A credit delivery system without the bureaucratic bottlenecks will improve allocative, as well as technical efficiency of the farms.

Finally, the role of effective extension activities in fish production, preservation and processing cannot be ruled out if expansions of fish production, as well as its sustainability are crucial in fulfillment of the millennium development goal (MDG) of food security in the country.

## Notes

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[2]This assumption in economic theory holds in principle for functional forms other than Cobb-Douglas and Tans-log functional forms. While in case of Cobb- Douglas or Trans-Log, the slopes serve as a direct measure of elasticites.

[3]Cobb-Douglas functional form was chosen because it's widely used in farm efficiency for developing agriculture.

[4]Here, MP = $\beta_j$.AP, where AP = Y/X.

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## Asian-Pacific Chapter

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Agricultural Sciences and Natural Resources, Gorgan, Iran).

2. **2nd Prize — Binh Thanh Nguyen** for "The influence of marine polychaete exteracts on ovarian maturation of Kuruma shrimp (*Marsupenaeus japonicus*) brookstream," with coauthors Shougo Harakawa, Yasuki Hirakawa, Asda Laining, Jian Gao, Kyaw Kyaw, Abdul Md. Kader, Janice Ragza, Roger Mamauag, Saichiro Yokoyama, Manabu Ishikawa and Shunsuke Koshio (Science of Marine Resources, United Graduate School of Agricultural Sciences, Kagoshima University, 1-21-24 Korimoto, Kagoshima city 890-8580, Japan).
3. **3rd Prize — Omar Noraini** for "Induction if IgM production in tilapia by spray administration of *Streptococcus agalactiae*, with co-authors M. Y. Sabri, A. Siti-Zahrah and M. Zamri-Saad (Faculty of Veterinary Medicine, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia [UPM]).

### Next Meeting

We are now working hard on our first ever meeting to take place in India. A contract was signed in Malaysia for the Conference/Trade Show to take place in Kochi 17-20 January 2011. For details, see https://www.was.org/WasMeetings/meetings/Default.aspx?code=APA2011. Everyone is excited with the prospects for this event, so we look forward to seeing you in Hobart or Kochi.

*— Roy Palmer*

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