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Frontier Analysis of Aquaculture Farms in the Southern Sector of Ghana

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Abstract: This study applies the single-stage modelling stochastic frontier approach to examine technical efficiency and its determinants of aquaculture farms and extends the scope of the analysis to explore interactive effects of farm specific variables on efficiency of production. The data consists of a cross-section of 150 farms collected from 15 districts in the southern sector of Ghana. Findings demonstrate that expected elasticities of mean output with respect to all input variables considered are positive and significant. Computed return to scale reveals that aquaculture farms in the southern sector of Ghana are characterised by technology with increasing return to scale. The combined effects of operational and farm specific factors are found to influence efficiency. The study further reveals that inclusion of interaction between some exogenous factors and input variables in the inefficiency model are significant in explaining the variation in efficiency. Comparison of mean technical efficiency according to regions did not show any significant variation. Overall mean technical efficiency is estimated to be nearly 80.8%.

Key words: Productivity · Technical efficiency · Stochastic frontier · Elasticity · Return to scale

INTRODUCTION

The fisheries sector plays a crucial role in human welfare and economic growth in many countries. The nutritional benefits of fish foods especially as a source of protein, fatty acids and minerals are well recognised [1]. In Ghana, the fisheries industry contributes 5% of the nation's agricultural gross domestic product (GDP) and provides employment to about 2 million people of which approximately 27% are directly employed in the sector [2]. Consumption of fish in the country ranges from 20 to 30 kg per capita with an average per capita consumption of 27.2 kg per annum, making Ghana one of the highest fish-consuming countries in Africa [3].

Despite these benefits, the growth of the fishery industry faces several challenges. The main concern is the low catches from the traditional marine and inland fisheries (about 435,000 tonnes per annum), whilst demand for fish exceeds 600,000 tonnes annually [2]. It is noted that the nation spends over 125 million US dollar ($) out of its scarce foreign exchange annually on importation of frozen fish only to mitigate the short fall.

Among the various mechanisms such as sustainable fisheries through managed exploitation and importation of fish products to supplement domestic production, aquaculture[1] is often cited as a major means of efficiently increasing fish production. This made the development of aquaculture very important to the government of Ghana as a strategy to bridge the gap between domestic demand and supply of fish and to produce surpluses for export. In view of this point, banks were directed to enhance finance for pond construction at subsidised interest rate in the 1980s. This attracted a number of farmers into the industry which resulted in the increase use of agricultural lands for aquaculture in the country. Awity [3] notes that production of aquaculture is expected to expand in the future, requiring the allocation of even more land at the expense of the limited agricultural lands for food and cash crop cultivation. Moreover, since its inception, the aquaculture industry has not seen any major technological improvement in the form of modern facilities to boost production due to inadequate resources [4]. It is important that in an economy where resources are scarce and opportunities for new technologies are lacking, efficiency study is paramount to raise productivity by improving output without increasing the resource base or developing new technologies.

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[1]Aquaculture is predominantly fish farming in Ghana

A variety of frontier techniques have been adopted to examine the issues of technical efficiency across the globe in many countries. Earlier approaches were designed to estimate technical efficiency without considering its determinants [5]. Critiques of this approach point out that the formulation does not explain variation in efficiency in order to distil important policy implication. Based on this argument, a two-stage frontier technique is proposed where the predicted technical efficiency effects from the first stage are regressed on various farm specific attributes to examine the determinants of inefficiency [6]. Kumbhakar *et al.* [7]; Huang and Liu [8]; Battese and Coelli [9] and other authors criticised this two-step modelling approach on the ground that the specification of the second-stage model violates the assumption of identically distributed technical inefficiency effects in the stochastic frontier and propose a single-stage modelling method in which parameters in the frontier and inefficiency models are estimated simultaneously. Application of this methodology in the fisheries and the aquaculture production is outlined by Kirkley *et al.* [10]. Iinuma *et al.* [11]. Dey *et al.* [12] and Chiang *et al.* [13]. However, these studies fail to account for interactive effects of the exogenous variables on efficiency.

Following Huang and Liu [8] and Battese and Coelli [9], the present study applies the single-stage modelling stochastic frontier approach to examine technical efficiency and its determinants of aquaculture farms in Ghana and extends the scope of the analysis by exploring the issues of interactive effects of some exogenous variables on efficiency of production. In addition, the study adopts a model by Battese and Broca [14]; Ngwenya *et al.* [15] and Lundvall and Battese [16] to examine output elasticity with respect to the various inputs used to assess how changes in such input resources could boost productivity.

The Status of Aquaculture: The history of the development of aquaculture in Ghana is well outlined by Awity [3] and MacPherson *et al.* [4]. It is estimated that about 50,000 hectares (ha) of area in brackish and fresh water environments is suitable for pond base aquaculture. Kapetsky *et al.* [17] also note that at first glance, about 193,000 km^2 of land in Ghana can be developed for aquaculture. Mensah *et al.* [18] reveal that the industry became widespread in Ghana especially in the Ashanti, Central, Eastern, Western and Greater Accra regions in the early 1980s and attracted both male and female individuals, farm families and cooperative groups who considered aquaculture as a major occupation or as a part time business. These farmers either converted their agricultural lands into fish ponds or rented lands from unrelated individuals or traditional chiefs for pond construction. Although majority of the farmers entered the industry with little or no technical knowledge and skills, most of them rely on government extension agents or family members with formal aquaculture education (FAE) for technical advice. Formal aquaculture education in Ghana include: degree programs at the four main government Universities and training programs at agricultural Colleges and some commercial farms.

The system of operation at various levels of intensification includes pond (earthen and concrete), pen, cage and raceway systems [19]. However, due to economic constraints in terms of cost of construction and feeding and seasonal fluctuation of fresh-water bodies in the country, the pen, cage and raceway systems are not commonly practiced [3]. Production systems range from extensive, intensive and semi-intensive with the latter accounting for over 60% of total production [20]. Most of the aquaculture farmers in Ghana rely on production of live feed by fertilization to achieve their production. In addition, they consider various types of supplementary agro-industrial by-products (cereal bran, fishmeal and groundnut husk) and high protein commercial diet (Dizengoff and Ranaan) for their farming activities. Family and hired labour are the sources of labour for aquaculture production.

The principal species that are in extensive culture are tilapia and catfish. Tilapia (mainly *Oreochromis niloticus*) is the most predominant and constitutes about 88% of the total aquaculture production. Catfish (*Clarias gariepinus* and *Heterobranchus longifilis*) records about 10% with the remaining 2% consisting of the other species such as *Heterotis niloticus* [20]. Without disaggregating into species, Wijkstrom *et al.* [19] note that tilapia and catfish production accounted for about 5% of inland fish production in the 1990s. However, Mensah *et al.* [18] reveal that most of the reported figures of aquaculture production are underestimated. They record estimated values of 7500 tones and 6000 tones in 2000 and 2001, respectively for aquaculture production. Awity [3] observes that total size of production by small-scale operators is estimated at 2.5 tones per hectare per year, whilst production from large commercial farms is estimated at 200 tones per hectare per year.

Notwithstanding: The priority given to aquaculture production by the government of Ghana, the industry is still constrained by a number of challenges. These include: the current high interest rate of bank loans for farmers, inadequate and weak extension support, poorly organised market, problem of poaching and high cost of commercial pelleted feed [3, 4]. MacPherson *et al.* [4] further state that the existing agro-industrial by-products are not sufficiently available at the required low cost to form the basis of any major development in aquaculture. Awity [3] also notes inadequate supply of improved seed and fingerling transportation problem as critical constraints affecting the development of aquaculture in the country. These constraints in addition to other factors hinder the optimum production from the industry. Thus, examination of technical efficiency of aquaculture farms in the study area and the underlying factors based on available inputs and technology is undoubtedly a valuable exercise to provide policy recommendations.

MATERIALS AND METHODS

The Stochastic Frontier and Inefficiency Models: The stochastic frontier production function specify output variability by a two-part (composed) error term in which one of the error terms is associated with noise effect and the other to account for technical inefficiency in production [5, 21]. A comprehensive survey on the frontier technique is outlined by Bauer [22] and Kumbhakar and Lovell [23].

Based on specification advantages key of which include flexibility, this study assumes the translog frontier production function as specified in (1) to be the appropriate model for analysing the data on aquaculture farms in the study area.

$$\ln Y_i = \beta_0 + \sum_{j=1}^{5} \beta_j \ln X_{ji} + 0.5 \sum_{j=1}^{5} \sum_{k=1}^{5} \beta_{jk} \ln X_{ji} \ln X_{ki} + (v_i - u_i) \quad (1)$$

Where :

*i*and *in* are the *ith* farmer and logarithm to base *e* respectively.

(Y) Output, is expressed as quantity of fish harvested in kilograms;

(X_1) Labour, represents total number of labour by family members and hired labour, measured in man-days[2];

(X_2) Feed, represents cost of feed in Ghana Cedi (GHC);

(X_3) Seed, indicates quantity of fingerlings (fry), measured in kilograms;

(X_4) Land, is the total area of pond(s) operated, measured in hectares.

(X_5) Other cost, denotes cost of intermediate inputs in GHC. It includes: cost of chemicals, fertilizer, fuel, electricity, farm rent, maintenance cost, depreciation cost.

(v) Represents a stochastic error term (e.g. measurement errors, extreme weather, industrial action, poaching and other noise errors such as misspecification problems);

(u) Denotes a non-negative random variable associated with farm-specific factors which contribute to farms not achieving maximum efficiency.

v_i's are commonly assumed to be independently, identically and normally distributed with zero mean and constant variance, σ^2_v, $\left[v_i \sim N(0,\sigma_v^2)\right]$. Different distributions namely half-normal, truncated, exponential and gamma distributions have been assumed with varied specifications for u_i in the literature. However Greene [26] and Coelli *et al.* [27] observe robustness to all four preceding one-sided distributions on the basis of predicted mean efficiencies and estimated frontier and inefficiency parameters. This study considers a model by Battese and Coelli [9] which assume that u_i is distributed as a truncation of the normal distribution with mean μ_i and variance[3] σ^2_u, $\left[u_i \sim N(\mu_i,\sigma_u^2)\right]$ such that the mean is defined as:

$$\mu_i = Z_i \delta \quad (2)$$

Where:

Z^*_i is a vassociated with the technical inefficiency effects which could include socioeconomic and farm management characteristics. δ^* is a vector of unknown parameters to be estimated. Huang and Liu [8] also purport the non-neutral stochastic frontier model defined as:

$$\mu_i = Z_i \delta + Z_i^* \delta^* \quad (3)$$

Where:

$Z^{''}_i$ is a vector of values of interactions between farm specific factors and input variables and is a vector of unknown parameters. Their model implies that a shift in the frontier for different farms depend on the level of the input variables, whilst elasticities of the mean output for different farms are functions of the particular farm specific

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[2] Man-days are computed according to the rule that one adult male, one adult female and one child (≤ years) working for one day (8 hours) equal 1 man day; 0.75 man days; and 0.50 man days respectively. These ratios have also been used by Battese *et al.* [24] and Coelli and Battese [25].

[3] Caudill and Ford [28] parameterise the variance of the pre-truncated distribution of the inefficiency term u_i as a function of exogenous variables in an attempt to address the problem of heteroskedasticity. However, earlier check by the study for heteroskedasticity in the residual using Breusch-Pagan test is revealed to be negative.

variables involved in the vector of explanatory variables. When the coefficients in the vector $\delta^*$are zero, this model reduces to model (2) of Battese and Coelli [9]. However, this study adopts a modificaton of the models by Huang and Liu [8] and Battese and Coelli [9] and specifies μ_i as:

$$\mu_i = Z_i^{*}\delta_i \qquad (4)$$

Where :

Z^{*}_i involve operational and farm specific variables (Z_i) and appropriate interactions (I_i)and some input variables (L_i) This idea is exemplified by Battese and Broca [14]. gwenya *et al.* [14] and Coelli and Battese [25]. Considering this specification, the present study defines the inefficiency model as;

$$\mu_i = \varphi_0 + \sum_{m=1}^{6}\delta_m Z_{mi} + \sum_{n=1}^{3}\omega_n I_{ni} + \psi L_i \qquad (5)$$

Where:

(Z_1) Gender dummy; has the value of 1, if farm decision maker is a male or 0, for a female;

(Z_2) Cultural system dummy; has the value of 1, if monoculture is practiced or 0, ifpolyculture is the adopted practice;

(Z_3) Age; represents the age of the primary decision maker;

(Z_4) Education; represents the maximum level of formal schooling[4] for a member of the household;

(Z_5) Eastern region dummy; has the value of 1, if farm is located in Eastern region or 0, if otherwise.

(Z_6) Ashanti region dummy; has the value of 1, if farm is located in Ashanti region or 0, if otherwise. Greater Accra region is considered as the base. Region-specific dummy variables are included to capture regional influence on technical efficiency of production.

(I_1) AgeExp; represents the interaction of age and experience of primary decision maker.

(I_2) AgeEv; represents the interaction of age of primary decision maker and extension visit.

(I_3) EduFAE; represnts the interaction of maximum level of formal schooling and formal aquaculture education for a member of the household.

(L) Land input; is total pond area and it is used as a proxy to capture size effect.

$\varphi_0\delta$,'s,ω's and Ψ are unknown parameters to be estimated. μ is the pre-truncated mean of u and it is parameterized as a function of Z in order to relate Z to the distribution of the inefficiency (u).

Elasticities: Considering the translog stochastic frontier production function as specified in (1), the estimated coefficients do not have straight forward interpretation. This is because, for a translog production function, the output elasticities with respect to the inputs are functions of the first-order and the second-order coefficients together with the level of inputs. Further, since the input variable land in this study is a factor involved in both the stochastic frontier model (1) and the inefficiency model (5), the output elasticity with respect to this input variable is a function of the value of the input in both the frontier and the inefficiency models. Following Battese and Broca [14], Ngwenya *et al.* [15] and Lundvall and Battese [16], elasticities of mean output with respect to the different inputs are derived by:

$$\frac{\partial \ln E(Y_i)}{\partial \ln X_{ji}} = \left\{\beta_j + \beta_{jj}\ln X_{ji} + \sum_{k\neq j}\beta_{jk}\ln X_{ki}\right\} - C_i\left\{\frac{\partial \mu_i}{\partial X_{ji}}\right\} \qquad (6)$$

Where:

$$C_i = 1 - \frac{1}{\sigma}\left\{\frac{\phi(\mu_i/\sigma - \sigma)}{\Phi(\mu_i/\sigma - \sigma)} - \frac{\phi(\mu_i/\sigma)}{\Phi(\mu_i/\sigma)}\right\} \qquad (7)$$

μ_i is defined by model (5), (ϕ) and (Φ) are density and distribution functions of the standard normal variables, respectively. The first component of model (6) is referred to as the elasticity of frontier output and the second part is called elasticity of technical efficiency. Though the second component $-C_i\left(\frac{\partial\mu_i}{\partial X_{ji}}\right)$ is zero in the frontier model by Battese and Coelli [9], implying that the output elasticities for labour, feed, seed and other cost do not involve the elasticity of technical efficiency, the derivative of the inefficiency model (5) with respect to land input, ($\partial\mu i / \partial Land$) is non-zero. Thus, the elasticity for land is defined by both components on the right-hand side of model (6). The sum total of the output elasticities is the estimated scale elasticity (ε). When, (ε)>1 ⇒ increasing return to scale (*IRS*), (ε)>1 ⇒ decreasing return to scale *(DRS)*and (ε)>1 ⇒ constant return to scale *(CRS)*.

The maximum likelihood estimates of the parameters involved in the frontier and inefficiency models are obtained using the Ox version 4.10 (windows) (C) J. A. Doornik, specifically, the SFAMB package [29]. The variance parameters are estimated in terms of $\sigma^2=\sigma^2_v+\sigma^2_u$ and $\gamma = \sigma^2_u / \sigma^2$.

[4]Ranking of level of formal schooling in Ghana is outlined as: None→0; Primary level→1; Junior Secondary/Middle School level→2; Senior Secondary level→3; Technical School level→4; Polytechnic level→5; University (bachelor) level→5; and University (graduate or above) level→7.

Table 1: Summary of variables in the frontier and inefficiency models

Variable	Minimum	Mean	Maximum	Standard deviation
Output	138	7929	73446	10666
Labour	180	468.80	1620	262.30
Feed	159.42	3493.10	39554	5267.60
Seed	29	471.51	4356	691.02
Land	0.04	0.75	7	1.10
Other cost	141.98	2277.90	36233	4194
Gender	0	0.91	1	0.29
Cultural system	0	0.08	1	0.27
Age	28	49.84	71	9.32
Education	0	4.24	7	1.29
Eastern region	0	0.33	1	0.47
Ashanti region	0	0.33	1	0.47
AgeExp[a]	58	382.92	1475	260.62
AgeEv[b]	0	9.53	60	18.71
EduFAE[c]	0	0.46	7	1.43
Land	0.04	0.75	7	1.10

[a] = interaction between age and experience of primary decision maker, [b] = interaction between formal schooling and formal aquaculture education, [c] = interaction between age of primary decision maker and extension visit.

Table 2: Hypothesis test for model specification and statistical assumption

Null hypothesis	Test statistics (λ)	Critical value ($\lambda^2_{0.001}$)	Decision
1. $H_0 : \beta_{ij} = 0$	183.90	37.70	Reject H_0
2. $H_0 : \gamma = \varphi_0 = \delta_i$	103.87[a]	32.20	Reject H_0
3. $H_0 : \gamma = 0$	17.07[a]	9.50	Reject H_0
4. $H_0 : \varphi_i = \delta_1 = \omega_i = \Psi = 0$	87.26	31.26	Reject H_0
5. $H_0 : \delta_i = \omega_i = \Psi = 0$	70.54	29.59	Reject H_0
6. H_0 $\omega_1 = \omega_2 = \omega_3 = \Psi = 0$	29.22	18.47	Reject H_0
7.$H_0 : \delta_5 = \delta_6 = 0$	0.32	5.99[b]	Accept H_0

[a] = test of one sided error from the Ox output. [b] = critical value at 0.05 level The correct critical values for the hypotheses involving γ are obtained from [31].

Hypotheses Test: A number of hypotheses are tested to examine the adequacy of the specified models, presence of inefficiency and relevance of variables in explaining inefficiency (Table 2). These tests are investigated using the generalised likelihood-ratio statistic *(LR)* which is given by: $LR = -2\left[\ln\{L(H_0)\} - \ln\{L(H_1)\}\right]$, where $L(H_0)$ and $L(H_1)$ are values of likelihood function under the null (H_0) and alternative (H_1) hypotheses, respectively. *LR* has approximately a Chi-square (or mixed Chi-square) distribution if the given null hypothesis is true with a degree of freedom equal to the number of parameters assumed to be zero in (H_0). Coelli [30] proposes that all critical values can be obtained from appropriate Chi-square distribution. However, if the test of hypothesis involves $\gamma=0$, then the asymptotic distribution necessitates mixed Chi-square distribution [31].

Data and Sampling Technique: The study is conducted in three out of five geographical regions of the southern sector of Ghana namely: Greater Accra, Ashanti and Eastern regions. Consideration of these regions for the study is based on concentration of aquaculture farms. A total of five sub-districts from each region were randomly selected. Consequently, the selected sub-districts represent the average condition of the respective regions fairly well. Ten aquaculture farms from each sub-district were chosen for detailed data collection. The overall sample for analysis is 150 farms from the three regions. During the data collection, a well structured questionnaire designed to obtain relevant socioeconomic characteristics, farming practices, output, inputs and price data is employed. Summary statistics of data collected through the survey are provided in Table 1.

RESULTS AND DISCUSSION

Hypotheses Test and Frontier Model Estimates: The first hypothesis which specifies that the coefficients of the second-order variables in the translog model are zero, meaning that the Cobb-Douglas frontier is an adequate representation for the data is strongly rejected. Thus, the specification for the translog stochastic frontier production function is more suitable to derive conclusions in the data. Both the test for the absence of inefficiency effects and that inefficiency effects are not stochastic in the second and third null hypotheses, respectively are strongly rejected as confirmed by the high value of gamma (γ=0.93) which is statistically different from zero. Hence, the traditional average response *(OLS)* function is not an adequate representation for the data. The fourth hypothesis that the intercept and the coefficients associated with farm-specific variables in the technical inefficiency model are zero (that the technical inefficiency effects have a traditional half-normal distribution with mean zero) is strongly rejected. Further, the fifth hypothesis which states that all coefficients, except the constant term of the inefficiency model are zero (hence the technical inefficiency effects have the same truncated-normal distribution with mean equal to δ_0) is also rejected. This reveals that the combined effects of factors involved in the technical inefficiency model are important in explaining the variation in production of fish farms in Ghana, although individual effects of some variables may not be significant. Given the specification of model (5), the sixth hypothesis that model (2) is an adequate representation of the data i.e. $\omega_1=\omega_2=\omega_3=\Psi=0$, is rejected. This implies that inclusion of the interactions between age and experience of the primary decision maker; age and extension visit to farms; formal schooling and formal aquaculture education for a member of the household; and total pond area in the inefficiency model are significant in explaining variation in efficiency. The last null hypothesis $(\delta_5=\delta_6=0)$ that there is no regional effect on technical efficiency of production is accepted.

In this study, the parameter estimates of the stochastic production frontier model (1) are discussed in terms of output elasticities evaluated at the mean values with respect to the various inputs (Table 3). The expected elasticities of mean output with respect to the five input variables: labour, land, feed, seed and other cost are all are positive and significant. Land is found to have the highest elasticity of 0.48, indicating that a 1% increase of pond size will increase production by 0.48%.

Table 3: Elasticities of mean output

Elasticities with respect to				
Labour	Feed	Seed	Land[a]	Other cost
0.10***	0.08**	0.15**	0.48***	0.23**
(0.03)	(0.04)	(0.06)	(0.13)	(0.07)

, * = statistically significant at levels of 0.05 and 0.01, respectively. Values in brackets below the estimated parameters are their corresponding standard errors. [a] = since the coefficient of land in the inefficiency model is positive, there is a negative contribution of the elasticity of technical efficiency in obtaining the elasticity of mean output for land.

The computed return to scale is revealed to be 1.04 (0.042) and it is statistically different from 1. The return to scale, defined as the percentage change in output from 1% change of all input factors is more than one implying that aquaculture farms in the southern sector of Ghana are characterised by technology with increasing return to scale. This means that if the industry increases all factor inputs by 1%, aquaculture farm output in the study area would increase by 1.04%.

Inefficiency Model Estimates: The estimates of the inefficiency model are of particular interest in this study (Table 4). The estimated gender dummy coefficient is significantly negative, indicating that farm decision makers who are males operate more efficiently than their female counterparts. Aquaculture involves fairly continuous labour input for grueling work and coupled with division of labour that assigns domestic role to women in Ghana as notes by Assibey-Mensah [32], which allows little time to be spent on aquaculture farms impedes efficiency of production. The coefficient of the cultural system dummy is revealed to be negative, implying that specialised aquaculture farms tend to be more technically efficient than farms growing several types of fish. However, the relationship is weak.

The coefficient of age is estimated to be positive and significant, indicating that older farmers are technically less efficient than the younger ones who are progressive and willing to implement new production systems. Further analysis reveals that estimated coefficient for older farmers who have greater number of years of experience in aquaculture (AgeExp) demonstrate a significant positive effect on technical efficiency of production. Although many years practice may infer adhering to old methods of production which may be technically less efficient, it is demonstrated by the current studies that the source of technical knowledge gained by the older farmers over the period in the business may be due to years of contacts with advisory services through

Table 4: Inefficiency model estimates

Variables	Parameters	Coefficients	Standard error
Constant	φ_0	-1.903**	0.731
Gender	δ_1	-0.399***	0.135
Cultural system	δ_2	-0.082	0.205
Age	δ_3	0.025**	0.011
Education	δ_4	0.086**	0.032
Eastern region	δ_5	0.021	0.042
Ashanti region	δ_6	0.013	0.029
AgeExp[a]	ω_1	-0.014**	0.005
AgeEv[b]	ω_2	-0.010**	0.004
EduFAE[c]	ω_3	-0.063**	0.033
Land	Ψ	0.140**	0.051

*, **, *** Statistically significant at levels of 0.10, 0.05 and 0.01, respectively. [a] = interaction between age and experience of primary decision maker, [b]= interaction between age of primary decision maker and extension visit, [c] = interaction between formal schooling and formal aquaculture education.

Table 5: Distribution of technical efficiency by location of farm

	All farms		Farms in Greater Accra		Farms in Ashanti Region		Farms in Eastern Region	
Technical efficiency Interval	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)
0.30-0.39	3	2	0	0	1	2	2	4
0.40-0.49	4	2.7	3	6	0	0	1	2
0.50-0.59	11	7.3	1	2	6	12	4	8
0.60-0.69	13	8.7	5	10	3	6	5	10
0.70-0.79	30	20	6	12	11	22	13	26
0.80-0.89	39	26	17	34	9	18	13	26
0.90-0.99	50	33.3	18	36	20	40	12	24
Total	150	100	50	100	50	100	50	100
Mean	0.808	0.830	0.812	0.782				
Standard deviation	0.149	0.144	0.153	0.148				

extension personnel. This revelation is confirmed by the coefficient of the interaction between age and extension visit (AgeEv) which is estimated to be significantly negative. Many studies have shown that contact with advisory service is a positive factor in increasing agricultural productivity.

Battese *et al.* [24] report a positive relationship between maximum years of formal schooling for a member of household and technical efficiency. In this study, the coefficient of education is estimated to be positive and significant, indicating that households with high level of formal schooling are less technically efficient. Aquaculture requires proper technical know-how for higher productivity [33]. Thus, when interaction of household with formal schooling and formal aquaculture education (EduFAE) is modelled to assess their effect on efficiency, the study demonstrates a positive impact. This means that formal education which enlightens farmers about the technical aspect of aquaculture production is more important in Ghana to enhance efficiency in the industry.

A varied relationship between farm size and technical efficiency in the developing countries using the frontier production function has been established [16]. The coefficient of land in this study is estimated to be significantly positive, implying that larger farms suffer from an oversize problem, resulting in larger measures of technical inefficiency (at the mean) than comparably smaller farms. This finding is consistent with Chiang *et al.* [13] who observe in Taiwan that smaller farms that produce 20-50 MT per hectare of milkfish operate close to the efficient frontier compared to big producers (> 50 MT per hectare). However, a contrary observation is revealed by Iinuma *et al.* [11] in carp pond culture in Peninsula Malaysia and Dey *et al.* [12] in grow-out pond operations in the Philippines.

Technical Efficiency: Table 5 reports the distribution of technical efficiencies of the farms by regions. The overall level of efficiency ranges from 34.3% to 98.4% with a sample mean technical efficiency of 80.8%. The frontier is built up by 50 farms (33.3%) found to be operating at efficiency levels of 90% or above. Only 7 farms (4.7%) belong to the least efficient category (30-49%). Majority of the farms (62%) operate with technical efficiency index between 0.50 and 0.89. When the study classifies location of farms by regions, no substantial variation in terms of mean technical efficiency is observed. On average, farms in Greater Accra region are observed to be about 1.8% more efficient than farms in Ashanti region and 4.8 % more than farms in Eastern region. However, these differences are not statistically significant, confirming the acceptance of the null hypothesis $(\delta_5=\delta_6=0)$ that there is no regional effect on technical efficiency of production. This finding may imply that differences in the quality of inputs used, level of advisory services and support from government aquaculture offices etc. within the respective regions do not influence technical efficiency of production. Given the results obtained, it is possible for farms to improve their performance by adopting the best practised technology. Farms on average can increase their level of output by 19.2% using the current level of inputs, or given the level of output, farms can reduce the input usage correspondingly.

CONCLUSION

This study adopts the single-stage modelling stochastic frontier approach to examine technical efficiency and its determinants of aquaculture farms in the southern sector of Ghana. It extends this model to explore the issues of interactive effects of some farm specific variables on efficiency of production. The study finds that output elasticities with respect to all the inputs (labour, land, feed, seed and other cost) are significant and have the expected positive signs. The estimate of return to scale is more than one implying that aquaculture farms in the study area are characterised by technology with increasing return to scale. The combined effects of operational and farm specific factors are found to influence efficiency. Further, the study reveals that inclusion of interaction between some exogenous factors and input variables in the inefficiency model are significant in explaining the variation in efficiency. Specifically, it is demonstrated that aquaculture farms in the study area suffer from oversize problems whilst extension advice plays a major role in efficiency of production. The overall mean technical efficiency is estimated to be nearly 80.8%. However, when location of farms are categorised by regions, the study did not observe any significant variation in terms of mean technical efficiency.

The findings indicate that it is possible for the farms in our sample to improve their performance by using the best practised technology. Allocation of resources to improve the level of formal aquaculture education and extension services will play an important role in this respect. Formation of aquaculture association should be encouraged to enhance coordination between young and old farmers. It will also be important to advice large farms on how to take advantage of economics of scale to improve efficiency. This study is pertinent since the Ghanaian economy appears to offer several challenges to increasing output directly, thus gains from reducing inefficient behaviour appear to be a viable option to increase output from the aquaculture farms.

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