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Measurement of technical efficiency of smallholder fish production in Ghana: A stochastic frontier approach

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This paper examines the level and determinants of technical efficiency of smallholder fish production in seven of the ten regions of Ghana. We employ the single-stage stochastic frontier approach in this study. Regional location, feed, fingerlings and labour are found to influence technical efficiency positively and significantly. However, formal education, marital status, membership in fish farmer groups and contact with extension services negatively influence inefficiency. Finally, estimates from the study indicate that the average smallholder fish producer in Ghana is 73.88% technically efficient. We recommend a bottom-up participatory approach to policy formulation which involves grassroots participation as well as the inclusion of aquaculture management in the curriculum of schools.

Key words: Smallholder fish production, technical efficiency, stochastic frontier.

INTRODUCTION

Globally, the contribution of fish farming to national development, both from poverty alleviation and national economic development points of view poses some interesting concerns. These concerns may be attributable to the fact that fish is a significant component of the diet for many people around the world, providing essential nutrition for over one billion people, and fish production also provides livelihood for over 200 million people in developing countries (The WorldFish Centre, 2007). In terms of trade, over 37% (by volume) of world fish production is traded internationally, the value of this being the highest in international trade in all animal proteins (World Bank, 2011). It is therefore not surprising that aquaculture has recently been adopted as a means to increase or supplement other sources to meet the deficit in Ghana's fish supply. In 2003, for instance, Ghana produced about 52% of its fish requirements from its domestic sources; this contribution increased to 68% in 2004 (FAO, 2005).

In Ghana, there are generally six major sources of fish ranging from imports, the open sea or marine fisheries, lagoon fisheries, the Lake Volta, other inland water bodies and pond fish production. In fact, of all these sources most of Ghana’s fish supply comes from marine sources (Asmah, 2008), which contributed about 80% of the total quantum of domestic production between 1993 and 2000 (FAO, 2004). According to Braimah (2001) in Asmah (2008) Lake Volta is the single most important source of fish of all inland fisheries, supporting about 140 species of fish. Furthermore, the vast size of the Lake also lends itself to canoe fishing by fisher folk along its banks. It was estimated to have produced over 70,000 tonnes of fish in 2002 which is about 16% of total domestic production and 85% of inland fishery output

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(Asmah, 2008). Fishing along the lake is seasonal: the peak season spans the months of July and August, while the lean season is from January to February. It is necessary to mention that apart from the Volta Lake there are many other water bodies from which fish is obtained for consumption, of which include Bosomtwi, Weija, Barekese, Tano, Vea and Kpong; altogether covering approximately 1,000,000 ha, and over 50 lagoons covering 40,000 ha (ibid). It is generally argued that in terms of fish, Ghana as a country has a self-sufficiency ratio of 60% meaning that the demand of fish exceeds supply by some 40%. According to Adutwum (2001) in Asmah (2008) the nation has over the years tried to meet this deficit through the importation of frozen fish. This raises concern for especially the small holder fish farmer who cannot effectively compete on the basis of prices: the imported frozen fish is cheaper and has increasingly become an important part of the diet of low income urban and rural consumers. Per capita fish consumption in Ghana is between 20 and 25 kg, making it one of the highest in Africa. This is an indication of the availability of a market for fish and fish products.

In spite of the high demand pointed out above available data indicates that the contribution of small-scale pond fish production to total quantum of fish produced in Ghana for local consumption is less than 1% (Abban et al., 2009). This is an interesting discovery and one that calls for some consideration and action especially at a time when aquaculture is poised to fill the gap between dwindling supply from major capture fisheries and the ever-increasing demand for fish and fishery products in several peer countries. For aquaculture to succeed in Ghana and to play its role towards food security and livelihood both the government and private sector must work together. Plausible as the above may be, there is the inherent assumption that fish farmers need more inputs to reach their potential. However, it is known that increase in agricultural production, and by inference fish production, may be attained through improvement in productivity, which can be increased through one or a combination of factors namely, technology, the types and quantities of resources used and the efficiency with which the resources are used. Of the various determinants, improvement in the efficiency of the resources already available to the farmers is most important (Goyal et al., 2006); hence the objective of this study was to determine the level of technical efficiency of smallholder fish production. Taking the above into consideration, this paper measures and analyzes the performance of small-scale fish farming households in Ghana. The paper applies a stochastic production frontier model, which measures the relative technical efficiency in a consistent way while also shedding light on the factors associated with these efficiency differences.

Statement of hypotheses

In this study, three hypotheses are tested. These hypotheses are;

1. $H_0 = \beta_{ij} = 0$, The null hypothesis that identifies an appropriate functional form between the restrictive Cobb-Douglas and the translog production function.
2. $H_0 = U_i = 0$, The null hypothesis specifies that each smallholder fish farmer is technically efficient and that variations in actual fish output (harvest) are due to random effects.
3. $H_0: \gamma = \delta_0 \ldots \delta_6 = 0$, The null hypothesis that inefficiencies are absent from the model at every level.

METHODOLOGY

Theoretical framework

The estimation of technical efficiency has been carried out with many different approaches, but the Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) have been given the most consideration by researchers. The basic difference between these two approaches lies in the method of analysis: the former employs econometrics while the latter uses mathematical programming. The SFA takes cognizance of the presence of stochastic noise-random shocks affecting the production process-outside the control of the producer, as well as technical error and also permits inferences to be drawn from estimation results (Coelli et al., 2005). In fact, the inclusion of the measurement error makes the frontier stochastic, whence the name stochastic frontier model is derived (Koop, 2003). As a consequence the SFA technique is considered appropriate for this study as such factors are expected to abound in smallholder fish farming in Ghana, a developing economy. Coelli et al. (2005) specified, in this case, a Cobb-Douglas Stochastic frontier model as:

$$Y_i = exp(\boldsymbol{\beta_0} + \boldsymbol{\beta}_1 \ln x_{it}) \text{x } exp\,(v_{it}) \text{x } exp\,(\text{-}u_{it}) \tag{1}$$

Where: $exp(\boldsymbol{\beta_0} + \boldsymbol{\beta}_1 \ln x_{it})$ is the deterministic component; $exp\,(v_{it})$ is the noise component, and $exp\,(\text{-}u_{it})$ is inefficiency. Some assumptions have been associated with the noise term in the existing literature:

1. It is independently and identically distributed (*i.i.d.*)
2. It is symmetric and
3. It is distributed independently of (u_{it})

In the estimation of the effects of the exogenous variables on the technical efficiency of farms, the two main procedures are the one-step and the two-stage modelling. In the two-stage procedure the production function is first estimated and the estimates of the technical efficiency of each farm are obtained. These are then regressed on farm-specific variables known or hypothesised to influence the efficiency. Critics of the two-stage approach -including Kumbhakar et al. (1991) and Reifschneider and Stevenson (1991) argue that this procedure is inconsistent and some of the assumptions of the error term, such as independent distribution are violated in the second stage (Pascoe and Mardle, 2003), and hence it is biased (Wang and Schmidt, 2002) and not as efficient as the single-stage procedure (Reifschneider and Stevenson, 1991). In contrast to this approach is the single-step, which incorporates all the variables affecting either the production function or contributing to inefficiency. In essence the relation between μ_i and z_i is established by this procedure, using the maximum-likelihood estimation (Wang and Schmidt, 2002); hence in this study the one-step modelling procedure is adopted.

Determination of technical efficiency

The technical efficiency (TE) of a given firm is illustrated as the ratio of the output obtained from that firm in comparison to the output of the best producing (frontier) firm using the same technology, as:\

$$TE = \frac{yi}{exp(x_i\boldsymbol{\beta})} = \frac{exp(xi\boldsymbol{\beta} - u_i)}{exp(x_i\boldsymbol{\beta})} = exp(-u_i) \qquad (2)$$

Empirical models

In order to determine the effects of predetermined variables on the value of pond fish production, as well as the efficiency of resources used, the translog stochastic production function is estimated, being motivated by the fact that this functional form has been widely used in frontier production studies and it is also flexible to use (Onyenweaku and Okoye., 2007; Onumah and Acquah, 2010).

The following translog model is used in this study to arrive at the technical efficiency of the smallholder fish farmers in Ghana:

$$\begin{aligned}
\ln Q = {} & \boldsymbol{\beta}_0 + \boldsymbol{\beta}_1 \ln labour + \boldsymbol{\beta}_2 \ln capital + \boldsymbol{\beta}_3 \ln fingerlings + \boldsymbol{\beta}_4 \ln feed + \\
& \frac{1}{2}\boldsymbol{\beta}_5 (\ln labour)^2 + \frac{1}{2}\boldsymbol{\beta}_6 (\ln capital)^2 + \frac{1}{2}\boldsymbol{\beta}_7 (\ln fingerlings)^2 + \frac{1}{2}\boldsymbol{\beta}_8 (\ln feed)^2 + \\
& \boldsymbol{\beta}_9 \ln(labour) * \ln(capital) + \boldsymbol{\beta}_{10} \ln(labour) * \ln(fingerlings) + \\
& \boldsymbol{\beta}_{11} \ln(labour) * \ln(feed) + \boldsymbol{\beta}_{12} \ln(capital) * \ln(fingerlings) + \\
& \boldsymbol{\beta}_{13} \ln(capital) * \ln(feed) + \boldsymbol{\beta}_{14} \ln(capital) * \ln(\ln feed) + \\
& \boldsymbol{\beta}_{15} \ln(fingerling) * \ln(feed) + Reg + v_i - u_i
\end{aligned} \qquad (3)$$

Where: Q refers to the total output of fish harvested in kilograms; *labour* is labour (man-hours) employed during the production season *capital* is the area of all ponds used in production of fish in the production season in hectares; *feed* (in kilograms) is feed[1] fed to the fish during the production season; *fingerlings* count) is the number of fingerlings stocked at the start of the production season; *Reg* is a dummy, used as a proxy to capture regional effects on the efficiency of fish production by smallholder fish farmers in the different regions. Seven (7) dummies are constructed from this variable, where for a particular region, say Greater Accra the *Reg* takes on a value of 1, and zero for all other regions. In the estimation of the model, one of the dummy regional variables is excluded to conform to the n *-1* degree of freedom restriction when using dummy variables, and also to avoid the problem of perfect correlation among the dummies and the constant; β_is are regression parameters to be estimated and are as defined earlier.

The empirical technical inefficiency model

The model for various operational and farm-specific variables hypothesised to influence technical inefficiencies of fish farms in Ghana is defined as:

$$\begin{aligned}
Zi = {} & \boldsymbol{\delta}_0 + \boldsymbol{\delta}_1 land_i + \boldsymbol{\delta}_2 sex_i + \boldsymbol{\delta}_3 techad_i + \boldsymbol{\delta}_4 ffa_i + \\
& \boldsymbol{\delta}_5 edu_i + \boldsymbol{\delta}_6 maristat_i + W_i
\end{aligned} \qquad (4)$$

In this inefficiency model, *land* is a dummy, capturing the effect of land tenure on the efficiency of individual smallholder fish farmers. It has a value of 1 if freehold, otherwise 0; *sex* is a dummy, and has a value of 1 if decision maker is male, 0 otherwise; *techad* is a dummy variable and has a value of 1 if farmer was visited at least once by an extension officer, 0 otherwise; *ffa* is a dummy variable indicating whether the farmer/farm is a registered member of the local fish farmers' association. It has a value of 1 if yes, 0 otherwise; *edu* is the maximum level of formal schooling of the farm owner/manager; *maristat* is a dummy and is an indication of marital status of respondent; it takes a value of 1 if married, 0 otherwise; W is the 'error term' in the model; $\delta_0 - \delta_6$ are parameters to be estimated along with the variance parameters σ^2 and γ.

It must be noted that while the σ^2 is an indicator of how well the functional form specified fits the data and also the appropriateness of the assumption underlying the distributional form of the composed error term, the γ tests whether or not the dominant sources of errors are outside the deterministic part of the production function (Umoh, 2006).

Data description

The data set for this study is secondary and it comes from primary information on aquaculture development in Ghana obtained via questionnaires in 7 of the 10 regions, namely the Greater Accra, Eastern, Ashanti, Volta, Western, Central and Brong-Ahafo Regions. The list of smallholder fish farmers in each region was obtained from the Fisheries Directorate's regional offices. From the list respondents were then randomly sampled and interviewed with structured questionnaires. To facilitate data collection, questionnaires were completed with the farm owner or manager, whichever was available, at the time of visit. Where none was present, the farmers were traced to their homes where the data was gathered. Collection of data by phone was done only in one instance, which was to the owner of a commercial farm whose manager was not ready to give out any information. The surveys were conducted between June 2006 and December 2006. Primary data from134 fish farms were obtained, 124 of which are purposively selected (based on intensity of production) from seven of the ten regions (Greater Accra, Ashanti, Volta, Brong Ahafo, Central, Eastern and Western) for this study. This was motivated by the fact that the remaining three northern regions had no record of pond fish farms, and that these seven regions had 966 pond fish farms, spanning more than half of the entire country. Ecologically, the seven regions fairly represent the climatic conditions of the country.

A limitation to this secondary data set was the inconsistency in data entry and incomplete records (especially for costs and outputs). This may be due to the fact that the farmers did not know the basic booking-keeping methods or were afraid to release financial information for fear of taxation (Hiheglo, 2008).

RESULTS AND DISCUSSION

Summary statistics

This study was conducted to provide baseline information for subsequent monitoring of smallholder fish production efficiencies to assess the impacts of changes in the agricultural policy environment on selected socio-economic factors in the study area. Table 1 shows the summary statistics for the variables used in the stochastic frontier model. The mean harvest (output) per hectare was 266.10 kg. This was obtained by using: 0.39 ha of

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[1]Feed is a composite term for all food items given to the fish during the production season.

Table 1. Summary statistics of quantitative variables used in the Stochastic Frontier Model.

Variable description	Unit	Mean	Standard deviation
Harvest (Output)	Kg/ha	266.10	706.00
Pond area	ha	0.39	1.05
Fingerlings	Num/ha	1018.64	3629.32
Feed	Kg/ha	400.80	557.60
Labour	Man - hours	464.38	302.43
Years of education	Years	9.06	5.17

Source: Authors' Computation from FAO dataset (2005).

pond area, 1018 fingerlings, 400.8 kg of feed and 464.8 man -hours of labour, by fish farmers with an average of about 9 years of formal education.

In this study we adopted the single-stage modeling technique and Table 2 is a descriptive statistics of the demographic variables used in this study. There were more male fish farmers than female fish farmers. The result also indicates that about 71% of the sample were members of FFA, while more (89.52%) of them had contacts with extension agents. Having more males is no indication of male dominance in the industry as workers, but rather as the main decision makers and heads of family businesses. It is interesting to note that membership of FFAs is on the higher side, with more extension contacts. From the perspective of policy intervention, policy makers may have to consider reaching farmers with new innovations and better ways of improving efficiencies through their farmer associations using a participatory approach.

Technical efficiency measurement of smallholder fish production in Ghana

Table 3 shows the estimation of the maximum likelihood estimates for parameters of the general translog stochastic production frontier and technical inefficiency effect models for smallholder fish production in Ghana.

Whereas labour and capital had positive and significant coefficients at 1%, fingerlings had a positive and significant coefficient but at 10%. This is an indication that stocking a pond with fish does not necessarily determine the yield obtained but rather the optimum combination of other relevant input factors. Feed, however, had a negative and significant coefficient at 1%; hence excess feeding regime may have been detrimental to the growth and development of the fish stocked.

From the results in Table 3, the output of fish would increase by about 1.3 kg with every 10% increase in man-hours. A 1% increase in the number of fingerlings and capital will result in 18 and 62.75% respectively in the output of fish produced.

The input variable that should be of greatest interest to policy makers is feed. Optimum amounts of feed and the adoption of the most effective feeding regime during the production cycle would help improve output of fish and hence efficiency. Thus to improve productivity primary interest should be on research to determine the optimum amount of feed and the right combination of feed nutrients. Interaction between variables resulted in some important findings. Feed alone as an input had a negative significant effect on the output, but an interaction between feed and capital had a positive significant effect on output. On the other hand a combination of feed and labour as well as feed and fingerlings were significantly negative. This confirms the previous assertion that the right proportion and composition of feed had a very important role to play in the output of fish and hence the efficiency of fish production

Inefficiency model estimates

The estimates for the inefficiency model are reported in the lower section of Table 3. Estimated coefficients of formal education, gender, membership in ffa, technical advice and the dummies for the regions were all significantly negative. These imply that fish farmers who have formal education were more technically efficient than those who had none; female farmers/farm owners were more efficient; members of ffas were more efficient, and farmers in all the regions under consideration except the Brong Ahafo Region, were relatively more efficient than their counterparts in the Ashanti Region. Crentsil (2009), however, in his study concluded that the Ashanti Region was the best fish producing region in Ghana. The point to note here is that the output of a farm does not necessarily correlate with its efficiency, because technical efficiency simply relates the output to the input used. Onumah and Acquah (2010), however, found regional differences to be insignificant in the variation of technical efficiency among smallholder fish producers in Ghana. We therefore conclude that the right combination of inputs bear much more on the output and hence efficiency rather than the location of the farmer, even though the latter cannot be ignored as a determinant of the variation in efficiencies among respondents in this study.

Battese et al. (1996) also found a positive significant

Table 2. Descriptive statistics on other demographic features of the smallholder fish farmers.

Variable names	Frequency	Percentage
Gender (1 = Male; 0 = female)		
Male	93	75.00
Female	31	25.00
Marital status (1 = married; 0 = single)		
Married	108	82.10
Single	16	12.90
FFA membership (1 = member; 0 = non – member)		
Member	88	70.97
Non - member	36	29.03
Land tenure (1 = owner; 0 = tenant)		
Owner	82	66.13
Tenant	42	33.87
Access to technical advice (1 = yes; 0 = no)		
Yes	111	89.52
No	13	10.48
Western region (1 = yes; 0 = no)		
Yes	12	9.68
No	112	90.32
Eastern region (1 = yes; 0 = no)		
Yes	9	7.26
No	115	92.74
Central region (1 = yes; 0 = no)		
Yes	20	16.13
No	104	83.87
Brong Ahafo (1 = yes; 0 = no)		
Yes	26	20.97
No	98	79.03
Greater accra (1 = yes; 0 = no)		
Yes	3	2.42
No	121	97.58
Volta region (1 = yes; 0 = no)		
Yes	22	17.74
No	102	82.26

Source: Authors' Computation from FAO dataset (2005).

relationship between education and technical efficiencyof farmers. Chiang et al. (2004) and Onumah and Acquah (2010), on the contrary found a negative correlation between education and technical efficiency, but indicated that technical know-how had greater influence on productivity than general formal education. It was not surprising to discover that members of ffas were more efficient, because as indicated elsewhere in this study members of a group learn from each other and get assistance from other members of the team, hence could be expected to be more efficient than the non-member, generally.

Technical advice in Ghana takes various forms. It includes informal meeting with an extension agent by a single farmer or as a group of farmers to discuss issues regarding their operations. In this study farmers who had access to technical advice were generally more efficient than those who did not. This has policy implications, because by this outcome, therefore, it may be suggested that more contacts with extension agents could further increase the efficiency of smallholder fish farmers.

γ is a measure of level of the inefficiency in the variance parameter, it ranges between 0 and 1. For the translog model, γ is estimated at 0.7992. This is an indication that about 80% of the random variation in fish production is attributable to inefficiency and the remaining 20% to stochastic factors. In other words, the variation in the output of fish is attributable to factors under the control of farm units much more than stochastic factors. The implication of these findings is that in formulating policy to help boost productivity of farmers, policy makers should

Table 3. Maximum-likelihood estimates of parameters of the Translog Frontier production function for smallholder fish farmers in Ghana.

Variable	Coefficient	Std. Error	t – Value	P - Value
Stochastic Frontier				
Constant	0.4433	0.0613	7.23	0.000
lnlabour	0.1310***	0.0450	2.91	0.004
lncapital	0.6275***	0.1201	5.22	0.000
lnfingerlings	0.1790*	0.0993	1.80	0.071
lnfeed	-0.5077***	0.1445	-3.51	0.000
½(lnlabour)^2	-0.1848***	0.0392	-4.71	0.000
½(lncapital)^2	0.0966***	0.0278	3.47	0.001
½(lnfingerlings)^2	0.4008	0.4018	1.00	0.319
½(lnfeed)^2	0.1181	1.3679	0.09	0.931
ln(lab)*ln(cap)	0.0614	0.0407	1.51	0.132
ln(lab)*ln(fing)	0.1887*	0.1130	1.66	0.061
ln(lab)* ln(feed)	-0.0513***	0.0105	-4.89	0.000
ln(cap)* ln(fing)	-0.3099**	0.1410	-2.20	0.026
ln(cap)*ln(feed)	3.3906***	1.0899	3.11	0.002
ln(fing)*ln(feed)	-1.9822***	0.7342	-2.70	0.007
Inefficiency Model				
Constant	-4.1868	1.5033	-2.79	0.005
Formal education	-0.1251***	0.0251	-4.98	0.000
Gender	-0.4348***	0.1801	-2.41	0.007
Marital status	0.2688	0.6921	0.39	0.698
FFA membership	-0.8930***	0.3196	-2.79	0.006
Land tenure	0.2730	0.2682	1.02	0.309
Technical advice	-0.3396***	0.1208	-2.81	0.003
Western region	-1.8439**	0.7300	-2.53	0.012
Eastern region	-2.0078*	1.0453	-1.92	0.055
Central region	-2.1514**	1.0227	2.10	0.035
Brong Ahafo Reg.	0.6034	0.9764	0.62	0.537
Greater Accra Reg.	-0.8092*	0.4648	-1.74	0.052
Variance parameter				
Sigma squared	0.1803***	0.0292	6.17	0.000
Gamma	0.7992***	0.2508	3.19	0.000
Lambda	1.9949	0.4768		
Log likelihood	-56.24704			
Mean TE	73.88%			

***Significance at 1%; **significance at 5%; *significance at 10%.

not merely think about increasing inputs or making credit available but that a means should be found to conduct efficiency monitoring and evaluation at the farm level with the view to creating awareness about the causes of farm level inefficiency. This finding is also a major indicator of how future policy interventions should be formulated and implemented: not top-down but bottom-up by employing participatory methods. Thirdly, it suggests the need for a follow-up on qualitative research to seek to understand qualitative underpinnings for inefficiency in Ghanaian smallholder fish production in greater depths. The σ^2 value of 0.18, highly significant at 1% is an indication of quite a good fit of the translog model for the data.

Distribution of the technical efficiency of smallholder fish farmers in Ghana

The overall mean technical efficiency of the sample was 73.88%. Stating this figure alone without further analysis of the performance of individual farms could be misleading, to say the least. It may be seen from Table 4 that most farms (43.5%) had technical efficiency scores

Table 4. Distribution of the overall technical efficiency of smallholder fish farmers in Ghana.

T.E Class	No. of fish farmers	Percentage
≤0.50	43.5	54
0.51 - 0.60	11	8.8
0.61 - 0.70	17	13.7
0.71 - 0.80	14	11.4
0.81 - 0.90	21	16.9
0.91 - 1.00	7	5.7

Source: Author's computation.

Table 5. Regional technical efficiency distribution of smallholder fish farmers in Ghana.

T.E Class	WR (%)	ER (%)	CR (%)	BA (%)	GA (%)	VR (%)
≤0.50	74.0	33.1	55.0	21.9	0.0	50.0
0.51 - 0.60	0.0	0.0	10.0	11.5	0.0	13.5
0.61 - 0.70	9.3	22.2	5.0	7.7	0.0	4.5
0.71 - 0.80	0.0	44.7	10.0	15.4	33.1	9.2
0.81 - 0.90	16.7	0.0	20.0	26.1	66.9	18.2
0.91 - 1.00	0.0	0.0	0.0	17.4	0.0	4.6

Source: Author's computation. Number of Fish Farmers: WR = 12; ER = 9; CR = 20; BA = 26; GA = 3 and VR = 22; Mean TEs: WR = 49.5%; ER = 61.0%; CR = 55.4%; BA = 66.0%; GA = 81.2% and VR = 59.5%; TE ranges: WR = 0.1375279 to 0 .8998032; ER = 0.2428515 to 0.7899342; CR = 0.0911026 to 0.8977706; BA = 0.1799706 to 0.9317483; GA = 0.809598 to 0.8621432 and VR = 0.0777726 to 0 .933502

below 50%. However, about 6% of farmers operated on or very close to the frontier. The results also indicate that the least efficient farm needs to improve its technical efficiency by some 23.9% to attain the mean efficiency score and the average farmer needs to adopt the best technology of the frontier farmers to increase its efficiency score by at least 26%.

The outcome of this study also brings to the fore the fact that only a small percentage of farmers is near the frontier and therefore policies to improve efficiency need to critically identify the factors responsible for the discrepancy in technical efficiency among farmers. Could regional differences contribute to these differences? This is considered in Table 5.

Regional technical efficiency distribution of smallholder fish farmers in Ghana

In Table 4 it was concluded that most farms operated below the mean technical efficiency score. We therefore assessed the technical efficiency of the sample based on the region within which they operated. From Table 5 it may be seen that on average the Greater Accra and the Western Regions were the most and least technically efficient regions respectively. However, considering the frontier most farmers (17.4%) in the Brong-Ahafo for instance, operated closest to or on the frontier, though in the same region majority of farmers (21.9%) operated at efficiency levels below 50%. This is an indication that even within the same region variation in efficiency could be observed among farmers. Consequently, though regional differences could explain some of the differences in technical efficiency, much more importantly the operations of individual farmers are very critical in this distinction. Onumah and Acquah (2010) however, concluded that region of production played no significant role in explaining the differences in technical efficiency.

Technical efficiency distribution of smallholder fish farmers in Ghana by gender

On average female respondents were more technically efficient than their male counterparts; however about 4.8% of males had efficiency scores between 0.91 and 1.00 (Table 6), an indication that males operated closer to the frontier than females. In a similar study to measure technical efficiency of maize farmers in the Mfantseman Municipality in Ghana, Essilfie et al. (2011) discovered that female maize farmers were more technically efficient, stating that males were more likely to be involved primarily with the production of cash crops.

In their study of aquaculture in Southern Ghana, Onumah and Acquah (2010) also concluded that males were generally more technically efficient, citing the strenuous and laborious nature of fish farming as a reason. The implication of these varied findings is that

Table 6. Gender technical efficiency distribution of smallholder fish farmers in Ghana.

T.E Class	Male (%)	Female (%)
≤0.50	44.2	35.0
0.51 - 0.60	9.6	15.0
0.61 - 0.70	10.6	20.0
0.71 - 0.80	12.5	10.0
0.81 - 0.90	18.3	20.0
0.91 - 1.00	4.8	0.0

Source: Authors' Computation from FAO dataset (2005). Mean TE: Male = 56.9% and Female = 60.6%.

Table 7. Likelihood ratio tests.

Variable description	Chi^2	Df	P > | Z |	Decision
$H_0 = \beta_{ij} = 0$	42.01	17	0.000	Reject H_0
$H_0 = U_i = 0$	50.23	10	0.000	Reject H_0
$H_0: \gamma = \delta_0 ... \delta_6 = 0$	36.49	13	0.000	Reject H_0

Source: Authors' Computation from FAO dataset (2005).

gender may not be conclusive in explaining the variations in technical efficiency among smallholder fish farmers in Ghana.

Tests of hypotheses

As was indicated earlier in this paper, to ensure that the estimation procedure and thus the results obtained were as reliable as possible, we carried out tests on the hypotheses stated. For the first null hypothesis, a nested hypothesis test was performed to determine whether the Cobb-Douglas specification is an adequate representation of the frontier production function. This test uses the log Likelihood ratio test.

Table 7 outlines the results of the null hypothesis. The null hypothesis $H_0 = \beta_{ij} = 0$ is rejected in favour of the translog production function. The second null hypothesis explores the test that specifies each smallholder fish farmer is operating on the technically efficient frontier and that the systematic and random technical efficiency in the inefficiency effects are zero. This is rejected in favour of the presence of inefficiency effects. The final null hypothesis determines whether the variables included in the inefficiency effects model have no effect on the level of technical inefficiency. This is also rejected confirming that the combined effect of these variables on technical inefficiency is statistically significant.

Conclusion

The main objective of this paper was to determine the levels and the factors affecting the technical efficiency of smallholder fish production in Ghana. We started off on the premise that different farms would have different levels of technical efficiency owing to farm-specific factors such as the level of experience of the farm owner, the tenure of land, among others; hence these were incorporated in the stochastic frontier in a single-stage modeling procedure. The results of the study showed that the labour employed, the number of fingerlings stocked and the quantity of feed used were positive and significant determinants of technical efficiency among smallholder fish farmers.

Furthermore, interaction between some exogenous variables were found to have significant and positive effects on the endogenous variable and hence efficiency. For instance it was demonstrated that if pond area simultaneously increased with number of fingerlings feed and labour, *ceteris paribus*, the total output of fish would increase (Table 2). This indicates a holistic approach is needed to improve efficiency.The effect of geography on the efficiency of production as captured by the coefficients of the regions indicates that the region within which a farmer operates does have an effect on technical efficiency. On the average the most technically efficient region was the Greater Accra Region (81.2%); a further study to find out how farmers in this region attain such technical efficiency scores is recommended, to serve as the basis for improving the efficiencies of the other regions. The overall average technical efficiency among smallholder fish producers was estimated to be 73.88%. This means that there is the possibility of increasing the efficiency level by some 26.12% if the best practices of the frontier farmer could be emulated and the necessary support given by the government. The average efficiency scores are however, not very representative of the sample since the standard deviations are high and therefore the distribution of farmers according to efficiency indices is tabulated, from which it is concluded that inefficiency among the respondents does not lie only in over-utilization, but also underutilization of significant inputs.

These findings have very important policy implications. Since technical advice enhances efficiency, training members of fish farmer associations by extension agents could help reduce over-feeding and improve on the technical efficiency and hence output. Formal education should be encouraged in the study area, and where possible fish production should be included in the agriculture and integrated science syllabi in the primary and secondary schools, since this may help improve efficiency of fish production in the future. Increases in pond areas will result in the reduction of output, but membership in FFAs could improve output, therefore the formation of more fish farmer cooperative societies is hereby recommended so that the more highly educated and the less educated ones will have the opportunity to learn from each other and members should be encouraged to construct smaller ponds for easier management and hence improve efficiency. Furthermore, membership in fish farmers' associations is a very important determinant of technical efficiency and this medium could be used as the platform for discussing important innovations that could improve efficiency.

Involving fish farmers in the drafting of policies is a recommendation worth noting, especially because most of the variations in technical efficiency result from factors directly under the control of farmers rather than from stochastic factors. A participatory bottom-up - rather than the traditional top-down - approach to solicit the view of farmers before formulating policy interventions would help in the adoption of innovations and hence the sustainability of such interventions.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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