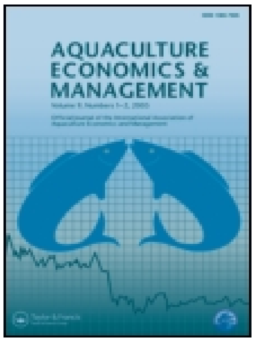

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EFFICIENCY OF RESOURCE USE AMONG POND FISH FARMERS IN CENTRAL UGANDA: A STOCHASTIC FRONTIER PRODUCTION FUNCTION APPROACH

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☐ *This article presents the use of a stochastic frontier production function to examine the efficiency of resource utilization in pond fish farming in Uganda. The study draws on data from a field survey administered to 200 small-scale fish farmers in three major fish farming districts in Central Uganda: Mukono, Mpigi and Wakiso. The districts were part of a large aquaculture development project funded by the United States Agency for International Development-Aquaculture and Fisheries Collaborative Research Support Program. Productive efficiency was analyzed using stochastic frontier analysis with a translog production function while assuming a truncated-normal distribution for the inefficiency term. The output variable was total quantity of fish produced, while input variables were quantity or value of inputs used in the production process, namely labor, pond size, stocking density, capital and feeds. The estimated index of resource-use efficiency revealed that small-scale farmers were inefficient in resource allocation by over-utilizing labor with an estimated allocative efficiency index of -0.94 and grossly under-utilized pond size, feeds and fingerlings with allocative efficient indices of 1.15, 1.64, 3.71, respectively. The results suggest that there is considerable scope to expand output and also productivity by increasing production efficiency at the relatively inefficient farms and sustaining the efficiency of those operating at or closer to the frontier.*

Keywords allocative efficiency index, production function analysis, small-scale fish farming, stochastic frontier approach, Uganda

INTRODUCTION

There is considerable agreement among scholars that an effective economic development strategy in the agricultural sector depends critically on promoting productivity and output growth (Squires & Tabor, 1991; Bravo-Ureta &

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Pinheiro, 2003; Idiong, 2007; Kalu & Mbanasor, 2008; Khai et al., 2008; Okoruwa et al., 2009; Do-Hoon et al., 2011). In support of this assertion, Ali and Chaudhry (1990), Kalu and Mbanasor (2008), Idiong (2007) and Tolga and Erkan (2006) have stressed the importance of efficiency in developing agricultural economies where resources are meager and opportunities for developing and adopting better technologies lately started dwindling. Indeed as Khai et al. (2008) have noted, the presence of shortfalls in efficiency means that output can be increased without requiring additional conventional inputs.

This suggests that empirical measures of efficiency are necessary in order to determine the magnitude of the gains that could be obtained by improving performance in agricultural production with a given technology. To this end, several studies around the world including Dey et al. (2000), Esmaeili and Omrani (2007), Chowdhury et al. (2010), Do-Hoon et al. (2011) and Pascoe et al. (2011) have studied production efficiency applying either the parametric stochastic frontier analysis (SFA) or the non-parametric data envelopment analysis (DEA).

In the African context, particularly in Sub-Saharan Africa, several studies have estimated production and allocative efficiency among aquaculture producers in Nigeria (Emokaro & Ekunwe, 2008; Kareem et al., 2008; Ogundari & Akinbogun, 2010), Ghana (Onumah et al., 2009; Onumah & Acquah, 2010; Asamoaha et al., 2012), Cote d'Ivoire (Adesina & Djato, 1997), and Tanzania (Sesabo & Tol, 2006). However, there have been no such studies conducted in Uganda, although the country has become one of the major aquaculture producers in Sub-Saharan Africa (FAO, 2009). The absence of production efficiency studies on Uganda's aquaculture sector, which is dominated by small and medium size enterprises, is troubling given that improvement in productive efficiency would provide opportunities for smallholder farmers to produce more, which in turn could lead to a rise in the welfare levels of rural farming families, *ceteris paribus*.

Thus, our main contribution is to fill this gap in knowledge by estimating and trying to explain the changes in performance of aquaculture production at the farm-level. The main objective is thus to assess productivity gains in small-scale pond fish farming through efficient resource utilization. The article also examines the factors that affect farm-level technical efficiency. The rest of the article is organized into six additional sections starting with background information on Uganda's fisheries sector followed by a brief review of the theoretical literature on production efficiency measures, the study area, a description of the data, empirical analysis, results, and conclusions.

Uganda's Fisheries Sector

Uganda's fisheries sector has been recognized for its vital contribution to the food and nutritional security of over 20 million people and for providing income for millions of households engaged in fish production, processing and trade (MAAIF, 2012). The sector is comprised of both capture and culture (aquaculture) fisheries with the former contributing most of the total production (FAO, 2011; MAAIF, 2012). Capture fishery is basically artisanal while aquaculture, which was first introduced in the country in the 1950s, is primarily practiced by farmers as one of the many farming activities (FAO, 1996; NARO/MAAIF, 2000; Rutaisire, 2007). Until recently, the technology has not flourished. The reasons for its mediocre performance have largely been socio-economic at both the macro and micro levels (Isyagi, 2007). The recent renewed interest is partly attributed to the advances in North African catfish (*Clarias gariepinus*) culture. Due to its desired qualities, the African catfish has become one of the key aquaculture species in Uganda and is likely to become the main contributor to aquaculture production both in terms of volume and value (Rutaisire, 2007; FAO, 2009).

Recent data on aquaculture production in Sub-Saharan Africa shows Uganda as the second major aquaculture producer in the region (FAO, 2008), contributing 22% in quantity and 18% in value to the region's total foodfish production (Figure 1). Uganda's success is attributed to the promotion of a private sector-led strategy accompanied with increases in expansion and productivity driven by significant improvements in farm management, as well as government policies in favor of the sector, for example divesting redundant and undeliverable services (Satia, 2011).

Furthermore, with improved market prices for fish, government intervention for increased production and stagnating supply from capture fisheries, aquaculture has begun to attract entrepreneurial farmers seeking to

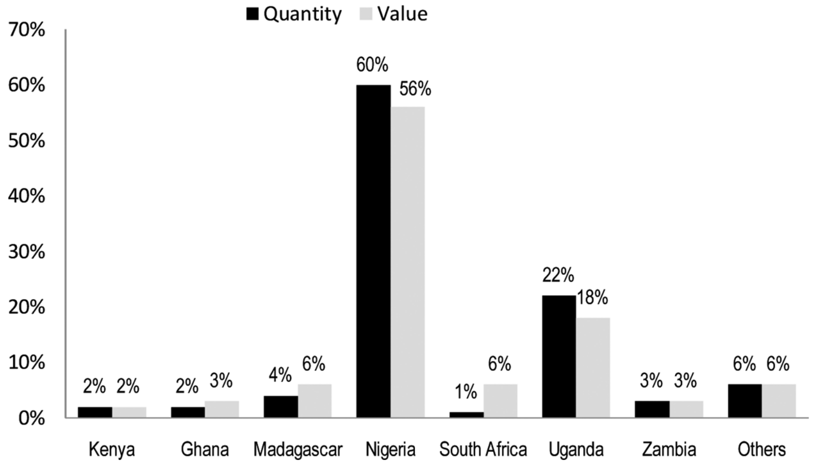

FIGURE 1 Major aquaculture producers by quantity and value in Sub-Saharan Africa (2008). Created by authors using data from FAO Fisheries and Aquaculture as reported in Satia (2011).

exploit the business opportunity provided by the prevailing demand for fish (Rutaisire, 2007; MAAIF, 2010, 2012). It is estimated that there are 2,000 such farmers who own nearly 5,000 ponds, with an average pond size of 1,500 m^2/pond (MAAIF, 2010, 2012). Production ranges between 1,500 kg/ha/yr for subsistence farmers to 15,000 kg/ha/yr for emerging commercial fish farmers (MAAIF, 2010; FAO, 2011; MAAIF, 2012). The recent expansion has also resulted in the transformation of 20% to 30% of the smallholder subsistence ponds into profitable small-scale production units through developments in management, as well as scale of production (FAO, 2012).

The most common production systems are extensive and semi-intensive pond based aquaculture systems (FAO, 2012). Nile Tilapia (*Oreochromis niloticus*) was the principal species in extensive culture, but recent data show that North African catfish has overtaken Nile tilapia as the most popular cultured species in Uganda (FAO, 2012). The main characteristics that have made the North African catfish more desirable are its fast growth and ability to literally feed on anything organic available at household level (Rutaisire, 2007; FAO, 2012). This has been a plus given that one of the major challenges faced by aquaculture farmers in Uganda

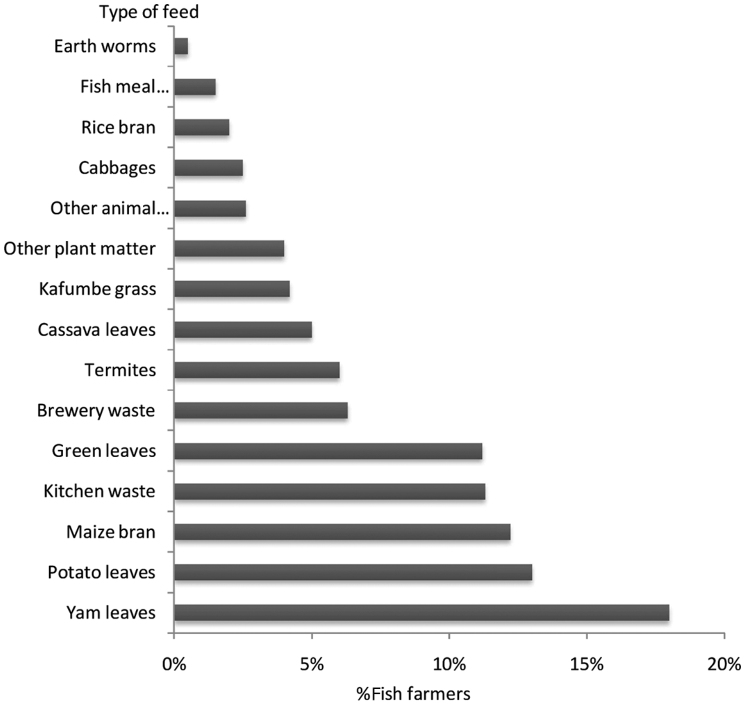

FIGURE 2 The proportional use of different types of feeds by Ugandan fish farmers. Created by authors using data from Rutaisire (2007) as reported in FAO Fisheries Technical Paper #497.

is the lack of cost-effective and efficient feeds. As illustrated in Figure 2, the majority of small-scale subsistence farmers rely on a multitude of ingredients as fish feeds.

Other challenges to the aquaculture sector include lack of prerequisite information, affordable credit facilities, inadequate supply of quality fish seed, extension support, lack of capacity to explore market forces, as well as the presence of technical inefficiency (Rutaisire, 2007; FAO, 2012). Particularly, the level of efficiency or inefficiency of utilization of available resources for fish farming has remained an unanswered question in the quest for increased fish production. It is against this background that the present study was undertaken to examine the efficiency of resource utilization in pond fish farming. Given that efficient farms either produce more output than others for a given set of inputs or produce a given output with minimum level of inputs (Singh et al., 2009); a study of the levels and determinants of production efficiency can provide some of the information needed by farmers and policymakers to improve productivity of aquaculture in Uganda, especially when searching for the primary causes of inefficiency and improvement potentials which have been stressed in the literature (Ogundari & Amos, 2011).

LITERATURE REVIEW

The theoretical literature on efficiency measurement begins with Farrell (1957), who drew upon the work of Debreu (1951). He distinguished three types of efficiency as technical efficiency, price or allocative efficiency and economic efficiency (combination of the first two). Technical efficiency is an engineering concept referring to the input-output relationship. A firm is said to be efficient if it is operating on the production frontier (Ali & Byerlee, 1991). On the other hand, a firm is said to be technically inefficient when it fails to achieve the maximum output from the given inputs, or fails to operate on the production frontier. By building on the foundation set by Debreu (1951) and extended by Farrell (1957), a growing body of literature on technical efficiency has emerged over the years.

In terms of measurement, the literature suggests several alternative approaches to measuring productive efficiency, grouped into non-parametric frontiers and parametric frontiers. Non-parametric frontiers do not impose a functional form on the production frontiers and do not make assumptions about the error term. The most popular non-parametric approach has been the DEA (Coelli, 1996). Parametric frontier approaches impose a functional form on the production function and make assumptions about the data. The most common functional forms include the Cobb-Douglas, constant elasticity of substitution and translog production functions. The other distinction is between deterministic and stochastic frontiers. Deterministic frontiers assume that all the deviations from the frontier are a result of firms' inefficiency, while stochastic frontiers assume that part of the deviations from the frontier are due to random events (reflecting measurement errors and statistical noise) and part is due to firm specific inefficiency (Forsund et al., 1980; Battese, 1992; Coelli et al., 1998).

The SFA, unlike the other parametric frontier measures, makes allowance for stochastic errors, due to statistical noise or measurement errors. The stochastic frontier model decomposes the error term into a two-sided random error that captures the random effects outside the control of the firm (the decision-making unit) and the one-sided efficiency component (Kalu & Mbanasor, 2008). The model was first proposed by Aigner et al. (1977) and Meeusen and van den Broeck (1977). Assuming a suitable production function, the stochastic production frontier is defined as:

$$\ln(y_j) = f(x_{ij}, \beta) + \varepsilon_j \tag{1}$$

where y is the level of output on the jth fish farm, x is the value of input i used on fish farm j, $\varepsilon_j = v_j - u_j$ is the composed error term, and v_j is the two-sided error term, yet u_j is the one-sided error term. The components of the composed error term are governed by different assumptions about their distribution. The random (symmetric) component v_j is assumed to be identically and independently distributed as $N(0, \sigma_v^2)$ and is also independent of u_j The random error represents random variations in the economic environment facing the production units, reflecting luck, weather, machine breakdown and variable input quality; measurement errors and omitted variables from the functional form (Aigner et al., 1977).

The distribution of the inefficiency component can take many forms, but is distributed asymmetrically. However, there is no *a priori* argument that suggests that one form of distribution is superior to another, although different assumptions yield different efficiency levels (Meeusen & van den Broeck, 1977; Greene, 1980; Stevenson, 1980; Battese & Coelli, 1995). The inefficiency component represents a variety of features that reflect inefficiency such as firm-specific knowledge; the will, skills, and effort of management and employees; work stoppages, material bottlenecks, and other disruptions to production (Aigner et al., 1977; Lee & Tyler, 1978). Meeusen and van den Broeck (1977) and Aigner et al. (1977) assume that u_j has an exponential and a half-normal distribution, respectively. Both distributions have a mode of zero. Other proposed specifications of the distribution of u_j include a truncated normal distribution—$N(\mu, \sigma_u^2)$ (Stevenson, 1980) and the gamma density (Greene, 1980).

The stochastic model can be estimated by corrected ordinary least squares method or the maximum likelihood method, which is used in this article. The maximum likelihood (ML) estimates of the production function in Equation (1) can be obtained from the following log likelihood function (Battese & Corra, 1977; Battese & Coelli, 1988, 1995):

$$lnL = \frac{N}{2}\ln\left(\frac{\pi}{2}\right) - \frac{N}{2}ln\sigma^2 + \sum_{j=1}^{N} ln\left[1 - F\left(\frac{\varepsilon_j\sqrt{\gamma}}{\sigma\sqrt{1-\gamma}}\right)\right] - \frac{1}{2\sigma^2}\sum_{j=1}^{N}\varepsilon_j^2 \qquad (2)$$

where ε_j are residuals based on ML estimates, N is the number of observations, F(.) is the standard normal distribution function $\sigma^2 = \sigma_u^2 + \sigma_v^2$, and $\gamma = \sigma_u^2/\sigma^2$. Assuming a half-normal distribution of "u", the mean technical efficiency is measured by

$$E\left[\exp(-u_j)\right] = 2\left[\exp\left(-\frac{\gamma\sigma^2}{2}\right)\right][1 - F(\sigma\sqrt{\gamma}] \qquad (3)$$

where F is the standard normal distribution function. Measurement of farm-level inefficiency requires the estimation of non-negative error "u." Given the assumptions on the distribution of v and u, Jondrow et al. (1982) first derived the conditional mean of u given ε. Battese and Coelli (1988) derive the best predictor of the technical efficiency of farm "j" $TE_j = \exp(-u_j)$ as

$$E\left[\exp(-u_j|\varepsilon_j)\right] = \left[\frac{1 - F\left(\sigma_A + \frac{\gamma\varepsilon_j}{\sigma_A}\right)}{1 - F\left(\frac{\gamma\varepsilon_j}{\sigma_A}\right)}\right]\exp\left(\gamma\varepsilon_j + \frac{\sigma_A^2}{2}\right) \qquad (4)$$

where $\sigma_A = \sqrt{\gamma(1-\gamma)\sigma^2}$.

In the empirical literature, numerous studies have used the SFA to examine efficiency aspects of fisheries. Notable studies include Do-Hoon et al. (2011), who uses SFA to study productivity efficiency of sandfish (*Scincus scincus*) coastal gillnet fishery on the east coast of Korea. Utilizing a translog production function with trip production quantity as the output variable and physical production factors directly related to the fishing activities of vessels as input variables, average productive efficiency was estimated at 0.59. Similarly, Pascoe et al. (2011) estimated a restricted profit function to determine the optimal vessel characteristics and output levels in the Australia's Northern Prawn fishery. Vessels were found to be currently close to their optimal size given average historic prices and current stock conditions.

Chowdhury et al. (2010) examined the effectiveness of different management tools, particularly input and quality controls on Bangladesh's industrial trawl fishery and concluded that over the period shrimp vessels were technically more efficient than fish vessels. Squires et al. (2002)

measured technical efficiency in the Malaysian gillnet artisanal fishery. Their estimated mean efficiency scores were 84% for east coast of Peninsular Malaysia and 88% for the west coast, while Singh et al. (2009) assessed the level of technical efficiency and the determinants of small-scale fish production in India. The technical efficiency ranged between 0.21 and 0.96 with mean of 0.66 and median of 0.71.

In the African context, Kareem et al. (2008) estimates technical, allocative and economic efficiency among farmers using concrete and earthen pond systems in Nigeria. The results of economic efficiency revealed an average of 76% in concrete pond system and 84% in the earthen pond system. The mean technical efficiency was estimated at 88% for concrete pond system and 89% in the earthen pond system. Similarly, allocative efficiency results were 79% for concrete pond system and 85% or the earthen pond system. SFA models revealed that pond area, quantity of lime used, and number of labor used were the significant factors that contributed to the technical efficiency of concrete pond system, while pond size, quantity of feed and labor were the significant factors in earthen pond system. Emokaro and Ekunwe (2008) analyzed the efficiency of resource-use and elasticity of production among catfish farmers in Kaduna, Nigeria. They established that catfish farmers in the study area were not efficient in their use of production inputs, based on allocative efficiency ratios that ranged from −426.71 for catfish feed to 3.46 for labor.

Ogundari and Akinbogun (2010) modeled technical efficiency with production risk in inputs using data from 64 fish farms from Oyo State, Nigeria. The empirical findings showed that the mean fish output was significantly influenced by labor, fertilizer, and feed. Fertilizer and feed were found to be risk-increasing inputs, yet labor was revealed to be a risk-reducing input. Furthermore, it was revealed that labor, farming experience, education, and access to market significantly decreased the technical inefficiency of farmers. The estimated technical efficiency showed that the efficiency score was overstated when the production technology of the fish farms is modeled without the flexible risk component.

Onumah et al. (2009) examine the productivity of hired and family labor and determinants of technical inefficiency of fish farms in Ghana. The results reveal that family labor, hired labor, feed, seed, land, other cost and extension visit have reasserting influence on fish farm production. It was shown that the combined effects of operational and farm specific factors (age, experience, land, gender, pond type and education) influence technical inefficiency although individual effects of some variables were not significant. Mean technical efficiency was estimated to be 79%. Onumah and Acquah (2010) extended the scope of the analysis to explore interactive effects of farm specific variables on efficiency of production from 15 districts in southern Ghana. Findings demonstrated that expected elasticities of mean output with respect to all input variable considered were positive and significant. Computed return to scale revealed that aquaculture farms in the southern sector of Ghana are characterized by technology with increasing return to scale. The combined effects of operational and farm specific factors were found to influence efficiency.

The study further revealed that inclusion of interaction between some exogenous factors and input variables in the inefficiency model was significant in explaining the variation in efficiency. Comparison of mean technical efficiency according to regions did not show any significant variation. The overall mean technical efficiency was estimated to be nearly 80.8%. In a recent study, Asamoaha et al. (2012) used a Cobb–Douglas production function to analyze survey data from pond farmers selected from four regions of Ghana. The results showed stocking rate as the most significant input that affected production. Aquaculture exhibited increasing returns to scale over the period of the study. Estimates of the marginal physical productivity of the inputs indicated stocking rate should be increased while decreasing feed and labor use in order to increase productivity.

METHODOLOGY

Study Area and Data Description

The study was conducted in Central Uganda in Mukono, Mpigi and Wakiso Districts. The districts were purposively selected and the criteria for their selection included: suitability for fisheries and aquaculture development based on both natural and socio-economic factors (MAAIF, 2010; FAO, 2012); proximity to the National Fisheries Resources Research Institute (NaFIRRI); similarity with respect to types of fish farmed, percent of agricultural households involved in fish farming and number of stocked ponds (Table 1); and last, the districts were part of a broader study area defined for a large aquaculture development project funded by the United States Agency for International Development (AquaFish CRSP, 2009).

In these districts, agriculture is the key economic activity with cotton, tea, coffee, bananas and vanilla as major crops. However, the trend is changing as traditional cash crops are gradually replaced by food crops as a major source of household income, because of low market prices for the traditional cash crops. The major food and cash crops grown now include maize, beans, ground nuts, cassava, sweet potatoes, and vegetables (Zake et al., 2005). Livestock keeping is practiced at a low scale; the major livestock types are cattle, goats, pigs and poultry. Livestock breed types are predominantly local and are kept under traditional practices. However, some farmers are adapting improved intensive livestock management practices, especially integrating it with crops (Zake et al., 2005).

TABLE 1 Number of Households with Fish Ponds by Number of Ponds and by Species of Fish in Uganda

Variable Name	Units	Mpigi District	Mukono District	Wakiso District	Uganda
Population	Total	414,543	763,800	1,277,220	28,789,000
Agricultural households	Total	69,893	113,041	75,146	3,833,485
Agricultural households	Total	142	223	153	7152
with ponds	Percent	20%	20%	20%	19%
Number of fish ponds	Total	396	955	404	25,000
Number of ponds stocked with:	Tilapia	137	284	132	10,556
	Mirror carp	99	259	79	6,220
	African catfish	56	181	36	4,771
	Mixed species	74	165	73	5,248
Number of unstocked ponds	Total	30	66	84	3,204

Source: UBOS (2002) and MAAIF (2012).

Wakiso District is the most populous of the three districts with an estimated population of approximately 1,277,220. The district is made up of two counties (Kyaddondo and Busiro) which are further subdivided into 15 sub-counties, 6 urban councils and 2 municipality divisions. On the other hand, Mukono District has an estimated population of 763,800 and is made up of four counties (Buyikwe, Buvuma, Mukono and Nakifuma) which are further subdivided into 25 sub-counties and 3 town councils. The third district, Mpigi District, has an estimated population of 414, 543 and is made up of three counties namely, Butambala, Gomba and Mawokota, which are further divided into 16 rural sub-counties and 1 urban council (Republic of Uganda, 2010).

The data were collected using survey questionnaires administered to 200 fish farmers. The sampling technique followed a multi-stage sampling approach where six counties (Buyikwe, Mukono, Kyadondo, Busiro, Butambala and Gomba) were randomly selected from the three districts. Using a constant sampling fraction of 45%, six sub-counties were randomly selected from Wakiso District, 11 sub-counties from Mukono District and seven sub-counties from Mpigi District. Then, lists of registered fish farmers were received from extension staff at NaFIRRI and Walimi Fish Farmers' Cooperative Society (WAFICOS). From these lists, farmers located in the selected sub-counties were compiled into a master list for this study. From this list, farmers were randomly selected until the estimated sample size of 200 was obtained from a population of 356 registered fish farmers in the study area. Overall, 69 fish farmers were selected from Mpigi District, 68 from Wakiso District and 63 from Mukono District.

Data collection started June 14, 2010 and ended July 15, 2010. Prior to administering the questionnaire, the instrument was pre-tested at five fish farms in Wakiso District. Responses from the pre-test were used to develop the final questionnaire. The pre-survey activities included reconnaissance for the pilot survey, revision of survey instrument and preparation of the sampling frame. The interviews, lasting about two hours, solicited information on number of years in the aquaculture business, allied industries, types of operation, species, product forms, marketing strategies and income generated from aquaculture. Other information collected included: production cycle, credit accessibility, group linkages, record-keeping and access to extension services.

Theoretical Considerations and Empirical Model

Stochastic production function frontier can be estimated by either econometric method or by mathematical programming (DEA). According to Sharma and Leung (2003), DEA is proven to be a superior approach in situations involving multiple inputs and multiple outputs. Econometric approach is better in this study because it is not considering multiple outputs (either tilapia or African catfish). Furthermore, it has been noted (Dey et al., 2005; Singh et al., 2009) that SFA is more appropriate for determining efficiency in developing countries, where data are often heavily influenced by measurement errors and other stochastic factors (such as weather conditions, diseases, etc.). Some recent notable studies that have applied SFA for determining efficiency in aquaculture in developing countries include: Bimbao et al. (2000), Dey et al. (2000), Sharma and Leung (2000), Sharma and Leung (2003), Singh (2008) and Onumah et al. (2009); and thus, based on the literature and statistical tests, the analysis was conducted using the SFA approach.

Generally, the production frontier can be viewed as composed of those parts of the firm's production functions that yield maximum output for a given set of inputs. Hence, it is possible that a fish farm with its scale of operation may not be able to reach the frontier, which is the production function for the industry. On the other hand, there may be farms whose outputs are closer to the frontier, given their levels of inputs. The notion of how close the individual production plans are to the maximum levels, as defined by the frontier, given inputs levels, is the measure of technical efficiency for each farm operation. Following Battese and Coelli (1995) the following production function is estimated using LIMDEP software package (Greene, 1995):

$$lny_j = \alpha + \sum_{i=1}^{m} \beta_i lnx_{ij} + \frac{1}{2}\sum_{i=1}^{m}\sum_{k=1}^{m} \gamma_{ik} lnx_{ij} \times lnx_{ij} + v_j - u_j \qquad (5)$$

where for farm j, y is the total quantity of fish produced, x is the quantity or value of input i used in the production process including labor, pond size,

TABLE 2 Summary Statistics of Variables in the Analysis

Variables	Units	Minimum	Maximum	Mean	Std. Dev.
Output	kg	25	8,423	1,114	1,521
Pond size	m^2	15	1,000	459	299
Stocking density	per pond	100	9,000	1,746	2,473
Feed cost	UG Shs.	8,000	8,400,000	505,919	1,006,650
Labor	Man days	23	1,123	129	121
Hired manager	yes = 1; otherwise = 0	0	1	0.335	0.473
Farmers group	member = 1; otherwise = 0	0	1	0.245	0.431
Extension services	access = 1; otherwise = 0	0	1	0.505	0.501
Record keeping	yes = 1; otherwise = 0	0	1	0.480	0.501
Credit	access = 1; otherwise = 0	0	1	0.400	0.491

capital and feeds, v_j is the two-sided error term and u_j is the one-sided error term (technical inefficiency effects). Output is measured as the total quantity of fish harvested in kilograms, pond size is measured in square meters, labor is estimated as man-days worked and capital is measured by a dummy variable representing access to credit needed for other inputs such as transportation and harvesting nets. The one-sided error term (the technical inefficiency effect) u_j is specified as:

$$u_j = f(z) \tag{6}$$

where z is a vector of farmer/farm characteristics. The farmer/farm level characteristics modeled in the inefficiency effect using the two-step procedure include pond size, use of hired manager, membership to a farmer's group/association, access to credit, access to extension services and keeping farm records. Table 2 shows the summary statistics of the variables used in the analysis.

Model Specification Tests

The selection of the functional form and distribution of the inefficiency term was based on the generalized likelihood ratio tests, with the relevant test statistics given by:

$$LR = -2\{ln[L(H_0)] - ln[L(H_1)]\} \tag{7}$$

where $L(H_0)$ and $L(H_1)$ are the values of the likelihood function under the null and alternative hypotheses. Hypothesis testing begins with determining the correct functional form of the stochastic production frontier (Equation (5)). The null hypothesis (H_0: $\beta = \beta_5 = \ldots = \beta_{14} = 0$) is tested against the alternative hypothesis that the translog is the most appropriate functional form for the existence of a frontier (the presence of technical inefficiency). To determine whether or not the technical efficiency effects have a half normal distribution $u \sim \left[N(0,\sigma_u^2)\right]$ or a truncated normal distribution $u \sim \left[N(\mu,\sigma_u^2)\right]$, we tested H_0: $u=0$ since the former is a special case of the latter. The last test was to determine whether or not the inefficiency deviations (u) are non-stochastic and equal to zero. The null hypothesis of no technical inefficiencies of production is equivalent to $H_0 : \sigma_u^2 = 0$ and the critical values of the test are obtained from Kodde and Palm (1986). Failure to reject the null hypothesis of no technical inefficiency in the data implies that the production frontier is identical to a standard production function (Forsund et al., 1980; Battese, 1992; Coelli et al., 1998).

Allocative Efficiency

In order to ascertain whether resources were efficiently utilized, allocative efficiency is examined using the marginal physical product, per unit price of fish, and per unit cost of each input utilized as follows:

$$AL_{ef} = \frac{MPP_{x_i} * P_{opt}}{P_{x_i}} \tag{8}$$

where AL_{ef} is an index of allocative efficiency in pond fish culture; MPP_{x_i} is the marginal physical product of the i-th input—which is the change in output due to a per unit change in the specified input, obtained as the first derivative of the production function equation; P_{opt} is the price per unit of fish and is obtained by dividing total revenue by the quantity of fish produced; and P_{x_i} is the cost per unit of the ith input employed in the production process, obtained by dividing the total cost of the ith input by the quantity of such input utilized. But, $MPP_{x_i} * P_{opt} = MVP$, and $P_{x_i} = MFC$; therefore, allocative efficiency can be expressed as:

$$AL_{ef} = \frac{MVP}{MFC} = \frac{\text{Marginal Value Product}}{\text{Marginal Factor Cost}} \tag{9}$$

Because a given resource is optimally allocated when there is no divergence between its MVP and its MFC, the literature suggests three possible scenarios (Agbamu & Fabusoro, 2001; Fasasi, 2006; Oladeebo et al., 2006):

$$\frac{MVP_{x_i}}{MFC_{x_i}} = 1, \text{ indicates that resource } \mathrm{X_i} \text{ is optimally utilized} \tag{10}$$

$$\frac{MVP_{x_i}}{MFC_{x_i}} < 1, \text{ indicates that resource } \mathrm{X_i} \text{ is over-utilized} \tag{11}$$

$$\frac{MVP_{x_i}}{MFC_{x_i}} > 1, \text{ indicates that resource } X_i \text{ is under-utilized} \qquad (12)$$

RESULTS AND DISCUSSIONS

Socio-Demographic Characteristics

Based on the 200 fish farmers who responded to the questionnaire, over 70% were new entrants with less than 10 years of fish farming experience. More farms cultured Nile tilapia and catfish compared with any other fish species. When asked to indicate the species grown for their previous harvest, the majority (82%) reported tilapia. Most farmers (70%) produced fish for family consumption, but often sold off surpluses at local markets. The majority (61%) of the farms surveyed solicited additional labor (hired 1 to 5 people) during harvest. The harvested fish size ranged between 500 and 1,000 grams. This appeared to be related to fish species, pond size and the target market. A good number of the respondents fed their fish with maize bran (47%), followed by feeds manufactured by Ugachic (24%), but a sizeable proportion (about 8%) also used crop leaves and pellets. A high number of farmers (64%) owned between 1 and 2 ponds and used rented harvesting nets.

The day-to-day management of the ponds on 67% of the surveyed farms was under family members with an average pond size of approximately 500 m^2. The stocking density of fingerlings ranged between 100 and 9,000/pond (between 7 and 9 fingerlings/m^2) depending on pond size and desired market, with an average stocking density for the 200 surveyed farms of 1,746 fingerlings/pond (4 fingerings/m^2). Survey responses reveal that most small-scale fish farmers in the region used fingerlings from a variety of sources with the most common source being Kajjansi Fisheries Institute (58%), followed by Mpigi and Umoja fish farm. Only 45% of the farms surveyed reported making a profit from the previous completed harvest.

Although many farmers regarded fish farming as a source of income, it was not considered as important as other income sources, but rather one that could be used sporadically. The majority of the farms (60%) sold live fish and over 90% of the farms used personal funds to finance their production enterprises. The majority (75%) of the respondents were not associated with any farmer's organization. Only 48% of the farms kept some form of written records, related mainly to production costs. Half of the respondents (50%) reported using extension specialists with the other half relying on their own experience or advice from other farmers. The length of the production cycle (from stocking to harvest) ranged between 6 and 9 months for the majority (60%) of the farms surveyed.

Model Specification Tests and Frontier Model Estimates

The hypothesis that the coefficients of the second-order variables in the translog model were zero, implying that the Cobb–Douglas frontier should be selected for the function form was rejected (Table 3), implying that the specification of the translog statistical frontier production function was more suitable. Similarly, the null hypothesis that the half-normal distribution is an adequate representation of the distribution of the inefficiency effects was rejected, implying that the truncated-normal distribution adequately represented the distribution of the inefficiency effects. Lastly, the generalized likelihood ratio test of the one-sided error term indicated that technical inefficiency was significant.

Table 4 presents the stochastic production frontier estimates obtained through maximum likelihood (ML) procedures, where the ML function is based on a joint density function for the composite error term. The estimated gamma (γ) parameter was statistically significant at $\alpha = 0.01$, implying that much of the variation of the observed output from the frontier output was due to random stochastic effects. The estimated value of $\gamma = 0.76$ suggested that 76% of the variation in fish output in Central Uganda was attributed to technical inefficiency. Similarly, the significant value of σ^2 (0.292) indicated the support for the specified assumption of the composite error term.

Turning to the estimated parameters for the explanatory variables, all four coefficients were statistically significant at $\alpha = 0.05$. The results suggest that a 1% increases in pond size given the set of inputs—feeds, stocking density and labor—will correspond to an increase (decrease) in fish output with 0.340%, 0.146%, 0.396% and −0.157%, respectively. The small magnitude of the coefficients suggests that fish yield in Central Uganda is inelastic to the inputs used in the production process. The positive and significant effect of the independent variables implies a direct relation between the variables and fish yield. Specifically, as pond size increases given other inputs, fish output will increase. This is because the pond is one critical variable upon which output in fish farming depends. As noted by Inoni (2007), if other inputs are available to expand production, the farmer will have to expand the size of his ponds if existing ponds are

TABLE 3 Model Specification Tests

Null Hypothesis	Test Statistic	Critical Value (5%)	Decision
$H_0: \beta = \beta_5 = \ldots = \beta_{14} = 0$	20.11	18.31	Reject H_0
$H_0 : \sigma_u^2 = 0.$	59.51	29.93*	Reject H_0
$H_0: \mu = 0$	13.05	7.814	Reject H_0

*The correct critical value is obtained from Kodde and Palm (1986).

TABLE 4 Elasticity of Production for Small-Scale Fish Producers in Central Uganda

Variables	Coefficients	Std. Error	t-ratio	P-value
Intercept	−0.514	1.040	−0.495	0.621
Pond size	0.340*	0.163	2.079	0.038
Feed cost	0.146**	0.015	9.754	0.000
Stocking density	0.396**	0.021	18.980	0.000
Labor	−0.157**	0.060	−2.609	0.009
γ	−0.762**	0.014	−55.656	0.000
σ^2	0.292**	0.015	19.212	0.000
Log-L	−408.13			
Sample size	200			

**and *are significant levels at 1% and 5%, respectively.

stocked to their optimum capacity. The response of fish yield to pond size was quite high as a 10% increase in pond size will result in a 3.4% increase in fish output. These results are supported by previous studies (Khan, 1986; Islam, 1987; Inoni & Chukwuji, 2000; Emokaro & Ekunwe, 2009).

In order for fish to reach marketable size in satisfactory time, an adequate feeding regime must be adopted (Inoni, 2007). Thus as the quantity and quality of feed (as measured by feed cost) utilized increase, fish production is bound to increase, *ceteris paribus*. This has been the case in the study area with increasing use of commercial feed, particularly from UgaChic feed company. Although relatively low, compared to pond size, the elasticity of output with respect to fish feed shows that a 10% increase in feed utilization will raise fish yield by 1.5%. Stocking density was another independent variable that exerted a positive and statistically significant influence on pond fish farming.

Improving yield requires fast-growing fingerlings of economically viable fish species, if the farmer is to maximize profit (Inonio, 2007). Thus the positive response of fish production to increased stocking density may be attributable to a farmer's goal to realize optimal benefits from the resources employed in production. As indicated in Table 4, a 10% increase in stocking density will cause fish yield to rise by 4%. Previous studies have noted that since increased stocking density may not necessarily translate into increased fish yield, its effect is tied to adequate feeding regime and efficient management. Comparable results were reported by Inoni (2007), Hatch et al. (1995), Khan (1986), and Merola and Pagan-Font (1988).

The contribution of labor is also accentuated by the regression results. Although unlike other factor inputs, its influence was negative but statistically significant. The negative sign implies that an increase in labor utilization will cause a reduction in fish output. The implication of the result is that optimum levels of labor utilization under the current scale of pond fish production in Central Uganda have been reached. Therefore further additions to labor will exert a depressing effect on yield. The inverse relationship between labor and fish output found in the study is supported by the literature (Inoni, 2007; Inoni & Chukwuji, 2000; Nyrkowski, 1988) and may be attributed to this situation.

Determinants of Inefficiency in Fish Farming

The estimated coefficients for the inefficiency model are presented in Table 5. The results show that three out of the six variables included in the model are statistically significant at $\alpha = 0.05$ or higher. It should be noted though that the explanatory variables in Equation (6) are included as inefficiency variables; thus a negative coefficient means an increase in efficiency and thus a positive effect on productivity. The estimated coefficients for access to extension services, record keeping, and access to credit have the expected signs.

The negative and significant coefficient for access to extension services indicate that information gained from extension agents is an important factor in enhancing fish yield and thus efficiency of resource use. This result is consistent with the findings of Feeder et al. (2004), Binam et al. (2004), and Rahman (2003). Also, the negative effect of credit availability is not surprising. Similar results have been reported by Ali et al. (1996) and Binam et al. (2004), implying a positive effect on fish yield and resource utilization. Although not statistically significant, the estimated parameter for the variables pond size and presence of a hired farm manager are negative, implying a positive effect on fish yield and efficiency of resource usage. Membership to a farmer's group, though not statistically significant, was the only variable with a positive coefficient, implying that membership to

TABLE 5 MLE Estimates of Determinants of Technical Inefficiency for Fish Farmers in Central Uganda

Variables	Coefficients	Std. Error	t-ratio	*P*-value
Intercept	2.120**	0.783	2.706	0.007
Pond size	−0.049	0.114	−0.426	0.670
Hired manager	−0.249	0.241	−1.034	0.301
Farmers group	0.281	0.276	1.016	0.310
Extension services	−0.576**	0.237	−2.429	0.015
Record keeping	−0.500*	0.226	−2.209	0.027
Credit	−0.447*	0.196	−2.282	0.022
σ^2	0.537**	0.077	20.000	0.000
Log-L	−170.498			
Sample size	200			

**and *are significant levels at 1% and 5%, respectively.

TABLE 6 Indices of Allocative Efficiency of Resource Utilization in Central Uganda

	MPP	MVP Ush.	MFC Ush.	Allocative Efficiency	Remarks
Pond size	0.340	1190	1037.79	1.15	Under-utilization
Feed cost	0.146	511	311.24	1.64	Under-utilization
Fingerlings	0.396	1386	373.78	3.71	Under-utilization
Labor	−0.157	−550.3	583.64	−0.94	Over-utilization

Farm gate fish price = Ush. 3500.

a farmer's group increases inefficiency in resource use among fish farmers in the study area. This is a surprising result given that farmers' groups are being promoted in the country as a vehicle to improve efficiency through access to credit, bulky buying and marketing.

Allocative Efficiency

Following Inoni (2007), the estimation of whether the average farmer over utilized, underutilized or optimally utilized the level of inputs so as to improve the present level of production required the determination of parameters such as marginal physical product (MPP), marginal factor cost (MFC), and marginal value product (MVP). The MFC of each input was determined as the average farm cost of an input per unit output. As shown in Table 6, the MVP of all resources were greater than their prices (MVP <MFC), with the exception of labor usage. Allocative efficiency of production resources employed in fish farming was estimated at 1.15, 1.64, 3.71 and −0.94 for pond size, feed resources, fingerlings usage and labor, respectively. The indices indicate that with the exception of labor, all resources were under-utilized, contributing less to fish yield in Central Uganda.

Like in other Sub-Saharan Africa countries, technical knowledge among small-scale fish farmers is somewhat low in Central Uganda. For example, recommended stocking rates range from two to six fingerlings/m^2, depending on the level of management. However, the majority of small-scale farmers in the study area stocked rates between 351 and 550 fingerlings/pond (roughly between one and two fingerings/m^2), far less than the recommended rates. Some ponds generally were overstocked while others were under stocked. There is no doubt that this situation may have contributed to the gross under-utilization of productive resources.

For labor, the poor performance can be attributed to the fact that like in many other Sub-Saharan Africa countries (Agbamu & Fabusoro, 2001; Akanni & Adeokun, 2004; Inoni, 2007), labor (particularly family labor) in Uganda is readily available. Another plausible explanation is that much of fish farming in the study area is being carried out by retired individuals whose opportunity cost for labor is low in an operation of this scale. Thus the gross inefficiency and over-utilization of labor found in the study may be attributed to these conditions. Comparable results of over-utilization of labor in small-scale agricultural production and processing in Sub-Saharan Africa have been reported in other studies (Akanni & Adeokun, 2004; Olarinde & Kuponiyi, 2004; Oladeebo et al., 2006).

CONCLUSIONS

The primary objective of this article was to examine the efficiency of resource utilization in pond fish farming in Central Uganda. This is achieved by determining the efficiency of small-scale pond fish farmers and identifying the determinants of inefficiency. The research in this article used a stochastic frontier production function, employing field survey data collected in June–July 2010 on 200 fish farms in three major fish farming districts: Mukono, Mpigi and Wakiso. The results obtained from the stochastic frontier estimation showed that inefficiency is present in pond fish production. Sufficient evidence of positive relationship between fish productivity and higher use of intermediate materials such as fingerings, labor and feeds is present. The results of efficiency analysis showed that small-scale fish farmers were not only producing at a lower level, but were also operating relatively farther from the production frontier. Thus there is considerable scope to expand output and also productivity by increasing production efficiency at the relatively inefficient farms and sustaining the efficiency of those operating at or closer to the frontier.

The finding that technical efficiency is positively associated with access to extension services, record keeping and access to credit implies that policies targeting these variables among others might have a positive impact on small-scale fish farmers' production and productivity. Furthermore, this finding indicates that improvement in provision of agricultural credit along with extension services are likely to lead to improved technical efficiency. There is a need therefore, to review, Uganda's agricultural policy with regard to renewed public support for increasing the capacity of the nation's agricultural extension system, which is grossly underfunded.

In closing, although the findings of this study highlight some significant variables in determining the efficiency of resource utilization in small-scale pond fish farming, some limitations must be considered. Particularly, we have examined an industry which is prevalent with market imperfections at the production and harvesting levels. The small sample size of our data sets warrant some caution when drawing broader conclusions from the results. Also, the inefficiency model is estimated in a two stage process using LIMDEP software package. This may create bias as the distribution of the inefficiency estimates is pre-determined through the distributional assumptions used in its generation. Amidst these limitations, aquaculture has gradually gained recognition and is currently being promoted as a sector to provide, employment, food security and for the eradication of poverty. Because of this recognition, it has become imperative to provide empirical data to guide policy makers in making informed decisions.

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