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Abstract

Lake Victoria fisheries are important to Tanzanian food security, employment, and foreign exchange, but they are experiencing declining performance largely due to overfishing. This paper studies technical efficiency and skipper skill using Tanzanian fishery data for the two major species, Nile perch and dagaa. The relative level of efficiency is high in both fisheries, and several observable variables linked to skipper skill significantly explain the efficiency level.

Key Words: Incentives, Lake Victoria, remuneration, skipper skill, stochastic frontier, technical efficiency

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Introduction

Lake Victoria is the world’s second largest, and Africa’s largest, fresh water body. The lake has faced major problems in the late 20th century manifested by loss of fish species and decline in catch per unit effort. The open access of the lake fisheries combined with rapid population growth, lack of employment opportunities, and the lucrative nature of fishing connected to the Nile perch boom have led to an increasing number of fishers and depletion of fish stocks (Ikiara 1999). This decline affects one-third of the populations (about 30 million people) in Kenya, Tanzania, and Uganda which are supported by the lake basin (LVFO 1999).

The lake fisheries contribute significantly to the Tanzanian economy in terms of food supply, foreign exchange, and employment opportunities. The contribution to gross domestic product has grown from 0.4 percent in 1993 to 1.8 percent in 1998, and the Nile perch export-value share of total export values has risen from 1.4 percent to 12.7 percent during the same period (Kulindwa 2001). To secure the livelihoods of the people and to render possible a sustainable management of the lake fisheries, the pressing issues of open access and overcapacity need to be rigorously addressed.

Limiting the number of boats can cap fishing capacity, but capacity will most likely be expanded by other means and will continue to place pressure on fish stocks and dissipate rents. Fishing capacity can increase by expansion in unregulated inputs (Wilen 1979; Dupont 1990) via productivity growth (Squires 1992) or by changes in inputs that are hard to observe and control, such as fishing skill (Hilborn and Ledbetter 1985; Kuperan et al. 2001). Skipper skill basically

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comprises all knowledge that influences the productivity of a fishing vessel and has been highlighted in a number of recent studies (Kirkley et al. 1998; Kirkley and Squires 1999; Eggert 2001; Pascoe and Coglan 2002; Squires et al. 2003). In general, skipper skill is an unobservable "input" in the production process, which means that empirical studies have to search for proxy variables, such as education and fishing experience. Technical efficiency studies in developing countries are scarce and there are mixed results concerning the usefulness of these particular proxy variables in explaining the role of skipper skills. Kuperan et al. (2001) and Squires et al. (2003) found the variables to be insignificant and signaled a need for other indicators that can be proxies for skipper skill and can be managed and regulated. Other indicators reflecting motivation or good management of the skipper have been proposed in the literature (see Mundlak 1961; Kuperan et al. 2001; Squires et al. 2003), but empirical applications are still lacking.

This paper presents a study of technical efficiency and skipper skill using Tanzanian fishery data for the two artisanal fisheries targeting either Nile perch or dagaa in Lake Victoria. The objective is to analyze the relative level of efficiency and to explore potential proxies for skipper skill. The effects of skipper skill are included in technical inefficiency and assess it through simultaneous estimation of a stochastic production (both neutral and non-neutral), frontier functions, and an inefficiency function. The results suggest that the Tanzanian artisanal fishers of Lake Victoria are relatively technically efficient and that skipper skill does play a role in the efficiency of the boat. For the Nile perch fishery, efficiency increased when the skipper had more experience. The two factors of skippers owning their vessels and revenues being shared after cost deduction imply increased efficiency. For the dagaa fishery, efficiency increased with the skippers' education. In both fisheries, efficiency increased if the owner shared 50-50 with the crew. A particularly interesting finding for both fisheries was that the local management (beach management units, or BMUs) led to improved efficiency. Development of the BMUs could potentially contribute to necessary limitations of capacity, which would make sustainable efficiency improvements for the Tanzanian fishers of Lake Victoria possible.

2. Lake Victoria Fisheries

Lake Victoria is a shared resource of three East African countries: Kenya, Uganda, and Tanzania. The Tanzanian section is the largest of the three, encompassing 49 percent of the lake's surface; Uganda has 45 percent, and Kenya 6 percent. To enhance the fisheries of Lake Victoria, an exotic species, the Nile perch (*Lates niloticus*), was introduced to Lake Victoria in the 1950s and experienced an explosive growth in population in the late 1970s (Brundy and

Pitcher 1995). During the 1980s, the Nile perch provided a new source of inexpensive protein for people around the Tanzanian shoreline. Tanzanian fishers christened the Nile perch the “savior” (Reynolds and Gréboval 1988). Although it is understandable why they viewed the Nile perch this way, the species has also led to the destruction of the lake’s ecosystem and the disappearance of the native biodiversity. The biological diversity of the lake has declined from an estimated 350–400 species of fish in the earlier years of the 20th century, to less than 200 species at present (Brundy and Pitcher 1995). Today there are only three commercially important species: Nile perch (*Lates niloticus*), the sardine-like dagaa (*Rastrineobola argentea*), and the Nile tilapia (*Oreochromis niloticus*), which is also a non-native species. Recent estimates show that Nile perch, dagaa, and Nile tilapia constitute 60 percent, 20 percent, and 10 percent, respectively, of Tanzania’s total Lake Victoria landings (Ssentongo and Jlhuliya 2000).

The Nile perch is a large, white, meaty fish that is exported to Europe, Asia, and North America. Processing and export industries were established in Kenya and Uganda during the 1980s, and in Tanzania in the early 1990s (Reynolds et al. 1992). The fish is exported as frozen fillets from processing plants that have been built onshore. Export demand has driven up the price of Nile perch and has led to an increase in capital investments in fish-harvesting equipment. The degree to which this demand is felt varies at different parts of the lake, but there is swift expansion in capacity for collecting fish by boat rather than truck, which ensures penetration to beaches in even the more remote areas.

Dagaa, on the other hand, is a sardine-like species, which largely is processed domestically for household consumption and animal feed (fishmeal). In addition to local consumption, there is substantial long-distance trade in dagaa. It is shipped to major Tanzanian cities, including Dar es Salaam, and to neighboring countries, such as Burundi, Rwanda, Zambia, and the Democratic Republic of Congo.

Small-scale fishing units generate almost all of the fishing effort on the lake. These fishers use boats or canoes that are fitted with outboard motors or sails and paddles and carry a total crew of two to six people, including the skipper. There are generally four major types of fishing gear used on the lake: Nile perch and tilapia gill nets, long lines, hook and lines, and dagaa nets. Nile perch is fished with gill nets as well as with multi-hook long lines. The focus of this study is on gill-net fishers, who tend to move further offshore and use reduced mesh sizes in order to maintain their catches. Nets are placed in the late afternoon and retrieved in the morning. Because of concerns with theft, fishers often stay out with their nets, sleeping in their boats.

Dagaa is fished at night when the moon is dark, using pressure lamps to attract the fish. Several types of gear are used, but short purse seines and mosquito nets are the most common. In many of the areas surveyed, wind and weather are the main constraints on the dagaa fishers because lamps are easily lost in rough conditions. Hence, the fishers are more dependent on more sheltered environments and their choices of where to fish are thus more limited to fishing areas they can reach from a particular beach. In other words, dagaa fishers have to fish off beaches fairly close to one another.

Boat owners are sometimes involved in the actual fishing, either as skippers or as ordinary crewmembers of their own boats. The crew, including the skipper, usually is paid based on a share of the catch. There are various kinds of remuneration systems used in the Lake Victoria fisheries, which we divided into two major categories. The first category is when the share is allotted *before* daily operating costs of the boat are deducted. (Fuel is a large component.) This share can be 70:30 or 80:20 for owner and crew, respectively. The second category is when the crew gets its share *after* operating costs are deducted. This is generally 60:40 or 50:50 for owner and crew (including the skipper), respectively. These share arrangements provide different incentives to the skippers and are therefore expected to influence the productivity of the skipper. The most striking difference between the two systems is that crew members (including skippers) who receive their share of revenues after running costs are deducted risk receiving no income at all. In addition to the variation in sharing mechanisms, some skippers receive an extra bonus, which is unknown in size. (To capture its potential effect, we used a dummy variable.)

3. Stochastic Production Frontier

Aigner et al. (1977) and Meeusen and van den Broeck (1977) simultaneously introduced the stochastic production frontier models. The approach used to obtain measure of technical efficiency is to estimate a stochastic frontier (Kumbhakar and Lovell 2000), where technical inefficiency is measured as the deviation of an individual boat's production from the best-practice production frontier. In this approach, production is assumed to be stochastic because fishing is sensitive to random factors, such as weather, resource availability, and environmental influences.

The potential for the misspecification of functional form, resulting in biased estimates of technical inefficiency, is considered to be a weakness of the stochastic frontier approach relative to non-parametric approaches, such as data envelopment analysis (DEA). Another disadvantage of stochastic frontier is that the selection of a distributional form for the inefficiency effects may be arbitrary (Coelli 1995). However, the disadvantages of DEA relative to stochastic frontier modelling are that it is not stochastic and, hence, it is not possible to isolate technical efficiency from random noise (Lovell 1993). Given the inherent stochasticity involved in harvesting a natural resource, such as fisheries, the stochastic frontier approach appears to offer the best method for assessing the efficiency of firms in the fishing industry (Kirkley et al. 1995). Stochastic frontier also allows examination of the proximity of observations relative to the frontier or the extent of technical inefficiency. Furthermore, under the stochastic frontier approach, technical inefficiency is found after removing the effects of random fluctuations—influences outside the control of the firm which could reduce or increase productivity but which should not be included in the inefficiency measure. This is important when examining the performance of fishing fleets, since random fluctuation due to environmental influences on recruitment (and due to the movement of fish stocks) introduces a large random component to success rate (Campbell and Hand 1998). It is also possible to perform tests of hypotheses regarding the existence of inefficiency and regarding the structure of the production technology in a stochastic frontier analysis. Further, in a situation in developing countries like the case under study and, in particular, the artisanal fisheries, the data are heavily influenced by the measurement error and the effects of weather, disease, etc., making the use of stochastic frontier more appropriate for the analysis.

3.1 Specification of the Stochastic Frontier

Fishers use inputs $x = (x_1, x_2, \dots x_J)$ to produce a single output Y, using a technology described by a well-behaved production function $f(x)$. All fishers may not be technically efficient, $Y \leq f(x)$, which can be expressed as $Y = f(x)TE(x;z)$, where $z = (z_1, z_2, \dots, z_M)$ is a vector of firm-specific characteristics and $TE(x;z)$ is the output-oriented measure of technical inefficiency defined over the range (0,1). If we approximate $f(x)$ by the translog function, the stochastic production frontier $Y = f(x;\beta) \exp(e)$ can be expressed in a general form as:

$$\ln Y_{it} = \sum_{j=1}^{J} \beta_j \ln x_{jit} + \frac{1}{2} \sum_{j=1}^{J} \sum_{k=1}^{K} \beta_{jk} \ln x_{jit} \ln x_{kit} + e_{it}\,, \tag{1}$$

with symmetry imposed by $\beta_{jk} = \beta_{kj}$. When $\beta_{jk} = 0$ for all j and k, this would imply a Cobb-Douglas production function. The error term e_{it} in equation (1) is defined as $e_{it} = V_{it} - U_{it}$, where $V_{it} \sim N(0, \sigma_v^2)$, and U_i is a one-sided error term. The noise component V_{it} is assumed to be independent and identically distributed and symmetrically distributed independent of U_{it}. The term V_{it} allows random variation of the production function across firms and captures the effects of statistical noise, measurement error, and exogenous shocks beyond the control of the firm. In modeling U_{it}, it is assumed that the mean of the pre-truncated distribution depends on both input use and firm-specific characteristics. These assumptions result in a non-neutral production frontier model (Battese and Brocca 1997; Karagiannis and Tzouvelekas 2005; Omer et al. 2007):

$$\mu_{it} = \delta_0 + \sum_{j=1}^{J} \delta_j \ln x_{jit} + \sum_{m=1}^{M} \delta_m z_{mit} \ , \qquad (2)$$

where δ is a vector of parameters to be estimated.

The specification in (2) is fairly general and encompasses the non-neutral stochastic production frontier model originally proposed by Huang and Liu (1994). If $\delta_j = 0$ (for all j), then (2) is reduced to the neutral technical inefficiency effect model by Battese and Coelli (1995). Further, if $\delta_j = \delta_m = 0$ (for all j and m), we get the Stevenson (1980) model. Finally, if $\delta_j = \delta_m = \delta_0 = 0$, we obtain the original model by Aigner et al. (1977). The U_{it} are non-negative random variables associated with technical inefficiency in production, which are assumed to arise from a normal distribution with mean $\mu_i = Z_{it}\delta$ and variance σ_u^2, which is truncated at zero (i.e., $U_{it} \sim (Z_{it}\delta, \sigma_u^2)$). The one-sided, non-negative random variable, U_{it}, representing output-oriented technical inefficiency, must be non-negative, so that no firm can perform better than the best-practice frontier. Z_{it} defines a (1 x M) vector of explanatory variables associated with the technical inefficiency function (Battese and Coelli 1995).

Technical inefficiency for each firm i, $U_{it,}$ is defined as the ratio of actual output to the potential frontier output. U_{it} is not directly observable: Jondrow et al. (1982) found its expected value conditional on the value of $\varepsilon_{it} = V_{it} - U_{it}$, that is, $E[U_{it}, | \varepsilon_{it}]$. Technical efficiency (TE) for each firm is obtained as $TE_i = {Y}/{f(x;\beta) * \exp(v)}$, where $Y = f(x;\beta) * exp(v) * exp(-u)$; hence, we can define $TE_i = exp(-u)$; *exp* is the exponential operator (Battese and Coelli 1988). If $U_{it} = 0$, then $\varepsilon_{it} = V_{it}$, suggesting that production lies on the frontier and production is said to be technically efficient. If $U_{it} > 0$, production lies below the frontier and thus there is evidence of inefficiency. The maximum likelihood estimation of equation (1) provides the estimators for βs and variance parameters $\sigma^2 = \sigma^2_v + \sigma^2_u$ and $\gamma = \sigma^2_u / \sigma^2$.

This study employed the neutral production frontier approach by Battese and Coelli (1995) and the non-neutral production frontier approach by Huang and Liu (1994) to analyze the relationship between technical efficiency and input variables, such as crew size, net length, and hours fished. The empirical frontier model is stochastic since fishing is sensitive to random factors, such as weather, resource availability, and environmental influences (Kirkley et al. 1995). The two main commercially important species are fished using different techniques, and we estimated separate models for Nile perch and dagaa. A frontier model with output-oriented technical inefficiency[1] is specified as follows:

$$LnY_{it}=\beta_0+\beta_1 lnL_{it}+\beta_2 lnN_{it}+\beta_3 lnH_{it}+\beta_{11}(lnL_{it})^2+\beta_{22}(lnN_{it})^2+\beta_{33}(lnH_{it})^2+\beta_{12}lnL_{it}lnN_{it}$$

$$+\beta_{13}lnL_{it}lnH_{it}+\beta_{23}lnN_{it}lnH_{it}+\beta_4 lnDS_{it}+\beta_5 Motor_{it}+\beta_6 Mwanza_{it}+\beta_7 Mara_{it}+\beta_8 Peak_{it}+\beta_9 Normal_{it}+\varepsilon_{it} \tag{3}$$

Inputs are L, N, and H. Total output (catch) in kilograms (kg) is denoted by Y, which is the catch representing two species, Nile perch and dagaa, that currently dominate the Lake Victoria fisheries' daily landings. Crew size (L) is the number of crew members employed per vessel per trip, including the skipper, and the gill-net capital stock (N) is measured by its length in meters multiplied by the number of hauls of the gill nets per day. Hours fished (H) measures the length of time gill nets were left active in the water. Distance from the shore to the fishing ground is approximated by hours traveled (DS), and in this case is considered an environmental variable beyond the control of the fishers. It provides for differences in resource conditions that vary by distance from shore and by water depth. We used a motor dummy, ($Motor=1/0$), to capture the effects of boats with and without motors. The regional dummies capture the variation in stock abundance, where $Mwanza$ and $Mara$ are dummies for the Mwanza and Mara regions, respectively. To avoid a dummy variable trap, Kagera is the reference region. The seasonal dummies, where $Peak$ is the peak season and $Normal$ is the normal season, capture seasonal variation. Off-season is the reference category.

Stock abundance is expected to be a major determinant of harvest across the different sections of the lake. However, for a short panel study like this, it was not possible to have the stock abundance be variable at each point. Stock abundance can vary consistently across fishing grounds and over seasons (or different time periods). We thus used the variable distance from shore to fishing ground (DS), and regional and seasonal dummies to capture the spatial difference in stock abundance.

In specifying the inefficiency function, there is no a general rule of thumb as to which variables appear in each equation, and it is worth thinking hard about which are explanatory variables that belong in the stochastic frontier equation and the inefficiency equation (Campbell and Hand 1998). Khumbakar and Lovell (2000) discussed external inefficiency effects as

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[1] An input-conserving approach (Kumbhakar and Lovell 2000) was also possible, but given the lack of any constraint on catch or effort, efficiency improvement was likely to imply output expansion.

features of the production environment beyond the control of the managers, but held that these should also be included in the stochastic production frontier if they influence the production process itself. In our context, that was an argument for including seasonality and distance in both equations.

The critique that the traditional two-stage process violates the inherent assumption of equal distribution for the inefficiency effects in both stages was overcome by expressing the inefficiency effects as an explicit function of firm-specific variables and a random term by Battese and Coelli (1995).[2] Huang and Liu (1994) used firm-specific variables in the inefficiency model of their non-neutral model, but also included the inputs. In a small boat fishery, it is quite possible that, for instance, crew size may also affect the relative efficiency due to congestion or free-riding problems. Hence, in the inefficiency effects as defined by equation (3), we both included firm-specific variables, such as skipper experience, net age, education of skipper, etc., and the inputs, such as crew size, net length, and hours of fishing, plus distance to the fishing ground and seasonality. The input levels were included in the inefficiency model to account for the relationships between scale of operation and the level of technical inefficiency (Tveteras and Battese 2006).

Using our specific *Z*-variables hypothesized to affect the technical efficiency of boats and the inputs used in the frontier model, the inefficient model can be specified as follows:

$$\mu_{it}=\delta_0+\delta_1 lnCrewsize_{it}+\delta_2 lnNetlength_{it}+\delta_3 lnHours_{it}+\delta_4 lnDistance_{it}+\delta_5 lnNetage_{it}$$

$$+\delta_6 lnSkipExp_{it}+\delta_7 lnEduc_{it}+\delta_8 Motor_{it}+\delta_9 Peak_{it}+\delta_{10} Normal_{it}+\delta_{11} CrewShare_{it}+\delta_{12} Ownerpcr_{it}$$

$$+\delta_{13} Ownerop_{it}+\delta_{14} Remun_{it}+\delta_{15} ExB_{it}+\delta_{16BMU_{it}} \qquad (4)$$

where δs are parameters to be estimated. If the coefficients of the inputs are not significantly different from zero, i.e., $\delta_{1\text{-}5} = 0$, changes in the frontier are independent of changes in the input use and are neutral. Hence, the non-neutral specification by Huang and Liu (1994) formulation is

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[2] Previously, it was common to proceed in a two-step approach in estimating the determinants of efficiency differences in equation (1): extracting the efficiency scores in first stage and then running these scores against the exogenous variables in the second stage (equation 2). Kumbhakar, Ghosh, and McGuckin (1991) and Reifschneider and Stevenson (1991) first noted the inconsistency between inefficiency effect when two independent and separate regressions are performed. In the first stage of a two-stage estimation, the error is assumed to be independently and identically distributed, but the predicted inefficiency effects in the second stage are specified as a function of a number of firm specific factors implying the errors are not identically distributed. For this reason, and as described in detail in Coelli, Rao, and Battese (1998), we estimated both (1) and (2) jointly using the maximum likelihood estimation.

more general than Battese and Coelli's (1995) neutral specification (Karagiannis and Tzouvelekas 2005). Further, the marginal products and elasticities of the mean production for different firms are functions of the particular firm specific variables, specified in the vector of explanatory variables Z_{it}.

SkipExp is the number of years as crew leader. We also included the share taken by the crew, including the skipper (*CrewS*), age of the gill net in years (n*etage*), education of the skipper in years (*educ*), and a number of dummy variables to capture some immeasurable skipper and gear attributes. These include dummy variables for the ownership of the boats (*ownerprc=1*/0); owner as the skipper (*ownerop*=1/0); remuneration system used in the unit (*remun=1/0*); and extra bonus (*ExB=1/0*). We also had a dummy variable that captured the effect of local management measures on the efficiency of the vessel (i.e., beach management units, *BMU*s=1/0).

3.2 Elasticities and Returns to Scale

We provided estimates of the elasticity of mean output with respect to the different explanatory variables. The elasticity of mean output was decomposed into the *frontier elasticity* and the *elasticity of technical efficiency* (see Battese and Broca 1997) as follows:

$$\frac{\partial \ln E(Y)}{\partial x_k} = \frac{\partial f(\cdot)}{\partial x_k} + C_{it}\frac{\partial \mu}{\partial x_k} , \tag{5}$$

where *f*(.) is given by equation (3), μ is given by equation (4), and

$$C_{it} = 1 - \frac{1}{\sigma}\left\{\frac{\phi\left(\frac{\mu_{it}}{\sigma} - \sigma\right)}{\Phi\left(\frac{\mu_{it}}{\sigma} - \sigma\right)} - \frac{\phi\left(\frac{\mu_{it}}{\sigma}\right)}{\Phi\left(\frac{\mu_{it}}{\sigma}\right)}\right\} .$$

ϕ and Φ represent the density and distribution functions of the standard normal random variable, respectively. It follows from Battese and Broca (1997) that the elasticity of *frontier output* with respect to the *k*th input $\partial f(\cdot) / \partial x_k$ is different from the elasticity of TE with respect to the *k*th input $C_{it}\frac{\partial \mu}{\partial x_k}$. Thus, the *elasticity of technical efficiency* is zero for the neutral stochastic frontier model, but non-zero for the non-neutral model.

Table 1 Description of Input and Skipper-Specific Variables

Variables	Description
Input (X-variables)	
Crew size (L)	Total number of crewmembers in the boat, including the skipper
Net length (N)	Net length (in meters) multiplied by the number of gill nets hauled per trip
Hours fished (H)	Total number of hours spent fishing each trip
Distance travelled (DS)	Distance traveled from the shore to the fishing ground, measured in hours
Motor	Value1 if the boat is outboard-motor propelled. 0 otherwise
Mwanza	Value 1 for Mwanza region
Mara	Value 1 for Mara region
Peak season	Value 1 for peak season
Normal season	Value 1 for normal season
Boat gear and skipper-specific variables (Z-variables)	
Skipper experience (SkipExp)	Number of years the skipper has captained a boat
Years of schooling (educ)	Number of years skipper spent in school
Age of net (netage)	The average age of gill nets in years
Crew share (CrewS)	Value 1 if the crew gets a share equal to the owner's. Value 0 if the owner gets more than half.
Owner on board, part of crew (ownerprc)	Value 1 if owner is part of crew, but not a skipper. Value 0 otherwise.
Owner-operated (ownerop)	Value 1 if boat is operated by the owner. Value 0 otherwise.
Remuneration method (remun)	Value1 if the sharing of the proceeds is after costs are deducted. Value 0 if gross revenues are shared.
Extra bonus (ExB)	Value 1 if the skipper gets extra payment for his role. Value 0 otherwise.
Local management (BMU)	Value 1 if the beach has active beach management unit. Value 0 otherwise.

Table 1 provides the description of the variables used in the analysis. Several hypotheses about the model can be tested using generalized likelihood ratio tests. We tested these hypotheses both for the neutral and the non-neutral model specifications and finally tested the neutral versus the non-neutral specification. The first null hypothesis is whether or not technical efficiency effects were absent, i.e., $\sigma_u^2 = 0$. This null hypothesis is specified as $\gamma = 0$, where $\gamma = \sigma^2$

$/ (\sigma 2v + \sigma^2)$ was tested. If the null hypothesis is accepted, this would indicate that σ^2 is zero and, hence, that the U_{it} term should be removed from the model described by equation (1) (Battese and Coelli 1995)—which implies that there were no inefficiency effects in the model and that the model could be efficiently estimated using OLS.[3] The second null hypothesis is whether or not the functional form of the stochastic production frontier, equation (1), was Cobb-Douglas form. This null hypothesis, which was tested against the full translog form, is H_o: $\beta_{ij} = 0$, for all $i \leq j=1,2,3$, in equation (1); in other words, all of the input interaction and second-order terms equal 0. The third null hypothesis is whether or not the technical inefficiency function, equation (3), was influenced by the level of explanatory variables. Under the assumption that the inefficiency effects were distributed as a truncated normal, the hypothesis is that the matrix of parameters, excluding the intercept term δ_0, was null, such that, H_o: $\delta_6 = \ldots = \delta_{16} = 0$. The test of the non-neutral versus the neutral model is given by the null hypothesis H_0: $\delta_1 = \delta_2 \ldots = \delta_5 = 0$.

3.3 Data

Data were collected between November 2002 and September 2003, from 22 randomly selected fish landing sites (referred to as beaches throughout the rest of the paper), on the Tanzanian section of Lake Victoria. A total of 500 skippers were interviewed over the three fishing seasons, creating a sample size of 1500 observations.[4] We gathered the data by administering questionnaires. Face-to-face interviews were conducted in collaboration with the staff of the Tanzania Fisheries Research Institute (TAFIRI) in Mwanza, which has extensive work experience in the field and has regular contact with fishers around the lake. The survey was carried out in three regions bordering the lake: Mwanza, Mara, and Kagera.

The data was collected by randomly sampling the beaches and the fishermen. The sampling of beaches was done with the help of district fishery officers. Summary statistics of the data are given in table 2. The average skipper had a primary education of 6–7 years in school and also had relatively few years of experience as a skipper: four years in Nile perch fishing and five years in dagaa fishing. On average, Nile perch boats carried three crew members, including the

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[3] A value of γ zero indicated that the deviation from the frontier was due entirely to noise, while a value of 1 would indicate that all deviations were due to technical inefficiency. Hence, $0 < \gamma < 1$ indicated that the deviation from the frontier was both due to data noise and technical inefficiency.

[4] In some of the seasons, some of the skippers observed in the first round were not available for the second round. Thus, the panel is not balanced. The final analysis consisted of 1313 observations in the Nile perch fishery and 179 observations in the dagaa fishery.

skipper, while dagaa boats tended to carry a larger crew per trip. (The average size of the crew was four.) Both fisheries had indicated nearly identical fishing hours.

Table 2 Summary Statistics of the Variables

Variable	Units or value	Nile perch fishery		Dagaa fishery	
		Mean	***Std. dev.***	***Mean***	***Std. dev.***
Average catch / day trip	Kg	70.07	61.05	48.95	37.87
No. of crew in boat / day trip	No.	3.09	0.80	3.79	0.66
Net length / day trip	Meters	3767	2329.5	1495	1636
Hours fished / day trip	Hours	5.96	3.27	5.37	3.48
Education of the skipper (educ)	Years	6.46	2.25	6.60	2.25
Number of years as a skipper (SkipExp)	Years	4.43	4.29	5.20	5.77
BMU (local management)	(1 or 0)	0.49	0.50	0.34	0.48
Mara region	(1 or 0)	0.32	0.47	0.26	0.44
Mwanza	(1 or 0)	0.48	0.58	0.33	0.47
Motor	(1 or 0)	0.44	0.50	0.58	0.49
Crew share (CrewS)	(1 or 0)	0.23	0.42	0.37	0.49
Owner is part of crew (ownerprc)	(1 or 0)	0.24	0.34	0.31	0.40
Owner is the skipper (ownerop)	(1 or 0)	0.45	0.49	0.57	0.37
Remuneration system (remun)	(1 or 0)	0.38	0.49	0.60	0.40
Extra bonus to skipper (ExB)	(1 or 0)	0.43	0.50	0.40	0.49

Std. dev. = standard deviation

4. Empirical Results

The parameters of the stochastic production frontier model, equation (1), and those for the technical inefficiency model, equation (2), were estimated simultaneously using the maximum-likelihood estimation (MLE) program, FRONTIER 4.1 (Coelli 1996). We reported hypotheses testing concerning model specifications in table 3.

We found that all formulated null hypotheses could be rejected at the 5-percent level, irrespective whether a neutral or a non-neutral specification was preferred. Hence, for both the neutral and the non-neutral models, the stochastic production frontier was appropriate for the sample data (i.e., H_0: $\gamma = 0$ was rejected). Similarly, the second null hypothesis—that the Cobb-

Douglas production function was an adequate representation for the Lake Victoria fisheries data (H_0: $\beta_{ij} = 0$, for all $i \le j=1,2,3$)—could be rejected, suggesting that the translog production

Table 3 Hypothesis Testing of Model Specification

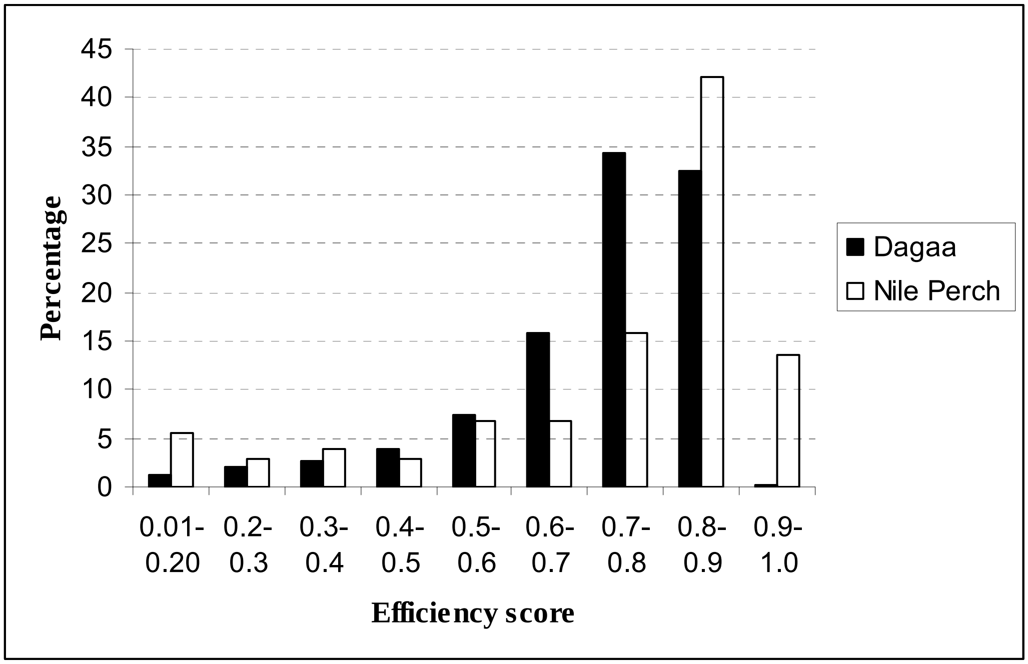
Null hypothesis	Log-likelihood	LR statistics	Critical $\chi^2_{v.\ 0.95}$	Decision
Neutral model specification				
1. H_0: γ =0				
Nile perch fishery	-1421.39	56.60	Mixed $\chi^2_{2.\ 0.95}$ = 5.14	Reject H_0
Dagaa fishery	-192.23	57.35	Mixed $\chi^2_{2.\ 0.95}$ = 5.13	Reject H_0
2. H_0: β_{ij} = 0 for all i ≤ j=1.2. (Cobb-Douglas frontier)				
Nile perch fishery	-1940.73	810.50	$\chi^2_{6\ .\ 0.95}$ =12.59	Reject H_0
Dagaa fishery	-193.64	24.33	$\chi^2_{6\ .\ 0.95}$ =12.59	Reject H_0
3. H_0: δ_{ij}= 0. i.j. =1…=9 (No tech. inefficient frontier)				
Nile perch fishery	-1516.07	813.24	$\chi^2_{9.\ 0.95}$ = 16.92	Reject H_0
Dagaa fishery	-207.42	32.34	$\chi^2_{9.\ 0.95}$ = 16.92	Reject *Ho*
Non-neutral model specification				
1. H_0: γ =0				
Nile perch fishery	-1521.94	46.45	Mixed $\chi^2_{2.\ 0.95}$ = 5.14	Rejected
Dagaa fishery	-205.55	310.13	Mixed $\chi^2_{2.\ 0.95}$ = 5.13	Rejected
2. H_0: β_{ij} = 0 for all i ≤ j=1.2.3 (Cobb-Douglas frontier)				
Nile perch fishery	-1967.85	838.24	$\chi^2_{6\ .\ 0.95}$ =12.59	Rejected
Dagaa fishery	-184.43	36.63	$\chi^2_{6\ .\ 0.95}$ =12.59	Rejected
3. H_0: δ_{ij}=0. i. j = 1….9 (No tech. inefficient frontier)				
Nile perch fishery	-1535.23	38.32	$\chi^2_{9.\ 0.95}$ = 16.92	Reject H_0
Dagaa fishery	-270.83	126.83	$\chi^2_{9.\ 0.95}$ = 16.92	Reject H_o
Neutral vs. non-neutral				
1. H_0: δ_{6i}=…=δ_{i6}=0. i =1….6				
Nile perch fishery	-1514.52	34.48	$\chi^2_{9\ .\ 0.95}$ =16.92	Rejected
Dagaa fishery	-184.43.	21.14	$\chi^2_{9\ .\ 0.95}$ =16.92	Rejected

Note: Mixed $\chi^2_{v,0.95}$ values are taken from Kodde and Palm (1986), table 1, 1246.

function was the preferred model specification. The hypothesis that the parameters of the inefficiency effects were absent (i.e., H_0: $\delta_6 = \ldots \delta_{16} = 0$) was also rejected by the data. This indicated that the majority of skippers in the sample operated below the output-oriented technical inefficiency frontier. This also suggested that the traditional average production function did not adequately represent the production structure of the fishers in the sample. Finally, the null hypothesis H_0: $\delta_1 = \ldots \delta_5 = 0$ was rejected and provided evidence in favor of the non-neutral specification and that there existed a significant relationship between scale of operation and the level of technical inefficiency. Hence, the results indicated that the more general non-neutral translog stochastic frontier model was an adequate representation of our data. Therefore, the results presented in figures 1–3 and tables 4–5 corresponded to non-neutral model.

Figure 1 shows the distribution of efficiency scores for Nile perch and dagaa fisheries. Our results indicated that more than 72 percent of the fishers in the sample had efficiency scores greater than 70 percent for Nile perch fishery, while for dagaa fisheries about 65 percent of the samples had efficiency scores over 70 percent. Similarly about 12 percent of the fishers were operating below 50 percent of the efficiency level in Nile perch fishery, while about 14 percent of the dagaa fishers were operating below the 50 percent efficiency level.

Figure 1 Technical Efficiency Scores for Nile Perch and Dagaa Fisheries

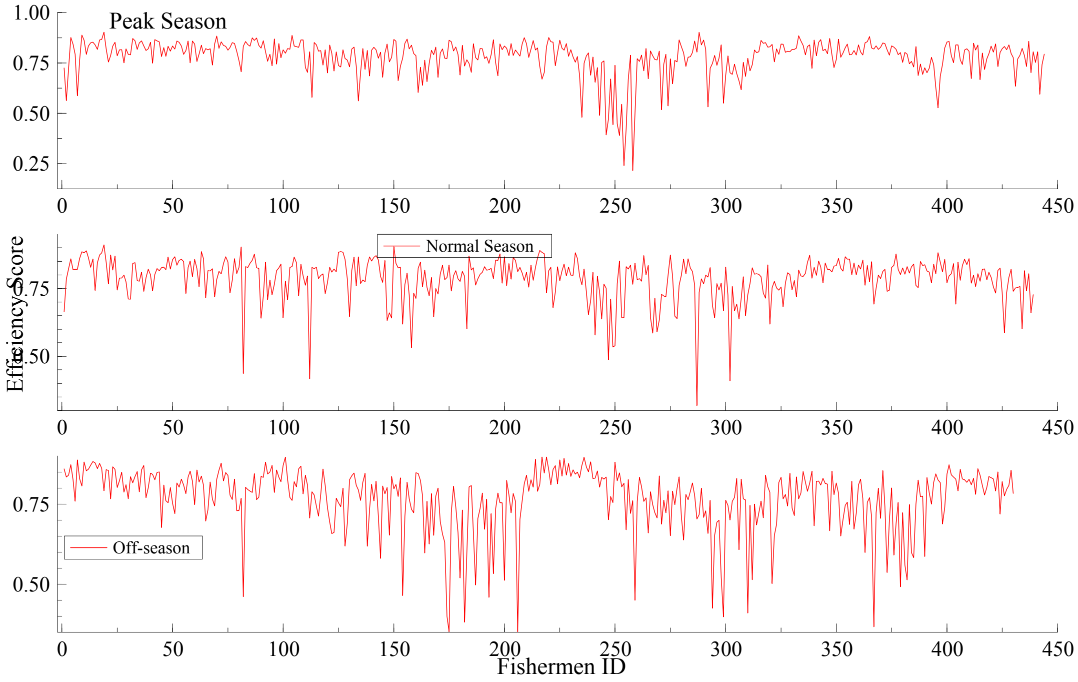


A limited number of boats displayed substantially lower levels of technical efficiency in both fisheries. The arithmetic means of the individual efficiency scores were 0.75 for Nile perch and 0.70 for dagaa fishery. These results compared well with Squires et al. (2003) for the Malaysian gill-net fleets of artisan fishers, but were comparatively higher than those found in Kuperan et al. (2001) in the Malaysian trawl fishery. This comparatively high efficiency score was consistent with Schultz's (1964) thesis of "poor and efficient" smallholders and peasant farmers in developing country agriculture.

The results suggested that the variance of the one-sided component was 0.52 and 0.53 for Nile perch and dagaa fisheries, respectively, indicating that output-oriented technical inefficiency is important in explaining the total variability of the fish harvest.

The seasonal variables, *Peak* and *Normal*, were included in the frontier model and the inefficiency models to capture the variations in stock abundance. The elasticity of mean output with respect to the seasonal dummies varied in the two fisheries. The effect of *Peak* season in the Nile perch fishery was significantly negative, compared to the reference season, while *Normal* was not different from the low season. For dagaa, the seasonal effects were as expected, *Peak* had a positive effect, as did the *Normal*, compared with the reference low season. Analyzing the efficiency score over season, we found that the mean efficiency was distributed as follows: 0.79, 0.78, and 0.77 for peak, normal and off-seasons, respectively, for the Nile perch fishery. This implied that most vessels targeting Nile perch in the sample were technically efficient at around 0.77 in all seasons (figure 2). This showed that there might not be any significant variation in Nile perch availability at different times of the year, contrary to what fishers claim. This lack of significant variation could also be explained by the stock being so overfished that there was no

Figure 2 Technical Efficiency over Season for Nile Perch Fishery



longer any clear variation in catch over season. The dagaa stock, on the other hand, was in better shape (Balirwa et al. 2003), with confirmed expected seasonal effects. Generally in the Nile perch fishery, high efficiency scores dominate for all seasons. These results contrasted with those found by Kuperan et al. (2001) for the Malaysian trawl fishery, where the lower efficiency scores dominated the high scores in normal and off-season.

The existence of seasonal effects in dagaa fishery was also confirmed by a plot on individual vessels basis (figure 3). In the dagaa fishery, the peak season was dominated by high efficiency values and to some extent the same applies for the normal, while the low-season was dominated by relatively low efficiency values.

Figure 3 Technical Efficiency over Season for Dagaa Fishery

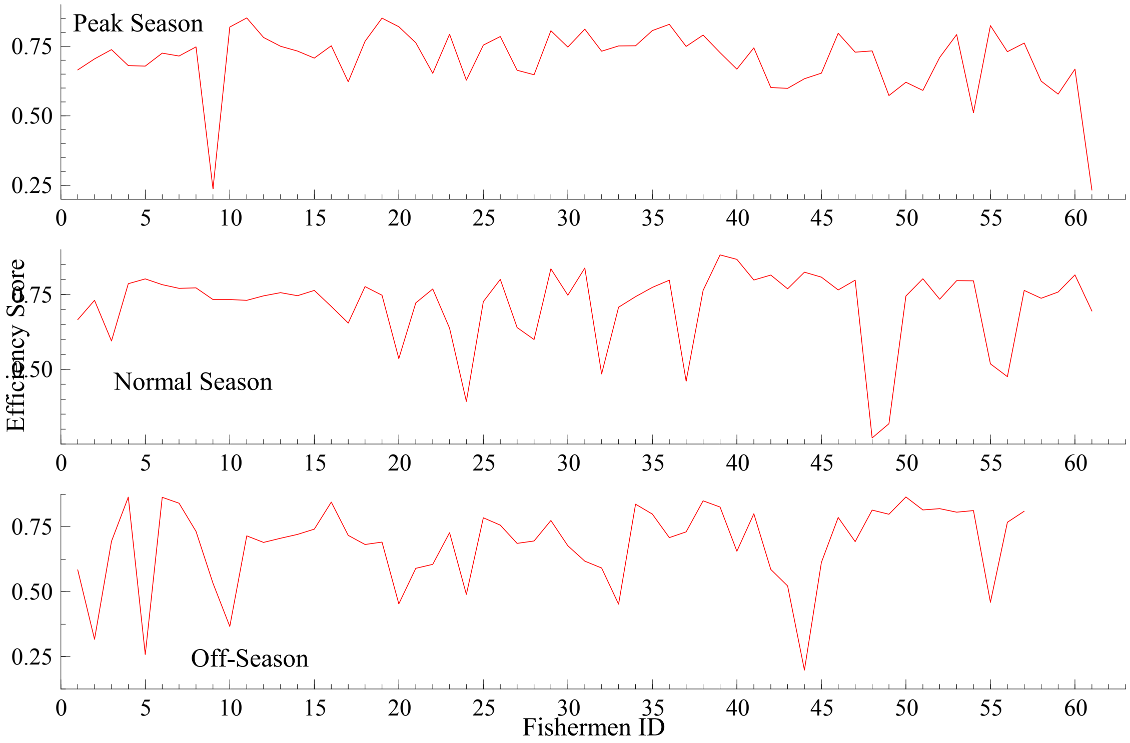


Table 4 reports the results of the frontier model (top panel) and the inefficiency model (bottom panel) for non-neutral specifications for both Nile Perch and dagaa. Interpretation of the individual parameters of a translog specification may not be particularly meaningful, and we focused our discussions more on the output elasticities, which are reported in table 5. The effect of an outboard motor was positive for the dagaa fishery, suggesting that outboard motors improved output relative to those boats using paddles or sails. Outboard motors appeared to have no effect in the Nile perch fishery, as parameters were not significantly different from zero.

Table 4 Parameter Estimates of Stochastic Production Frontier: Nile Perch

Variables	Non-neutral—Nile perch		Non-neutral—Dagaa	
	Coefficient	*t-ratio*	*Coefficient*	*t-ratio*
Constant	1.98***	3.53	3.86**	2.16
Ln (crew size)	0.20*	1.74	-1.98*	-1.69
Ln (net length)	1.01***	7.61	-0.40	-0.71
Ln (hours)	1.00***	3.02	2.31***	2.69
Ln (crew size) x *Ln* (crew size)	-0.02***	-5.18	-0.46	-0.64
Ln (net length) x *Ln* (net length)	-0.04***	-3.51	0.03	1.03
Ln (hours) X *Ln* (hours)	-0.17**	-2.37	-0.11	-0.57
Ln (crew size) X *Ln* (net length)	-0.04***	-3.86	0.45	1.41
Ln (crew size) X *Ln* (hours)	0.02	1.18	0.48	0.77
Ln (net length) X *Ln* (hours)	0.00	-0.47	-0.35***	-3.89
Ln (distance)	0.10**	2.09	0.07	0.66
Motor	0.05	0.70	0.35**	2.12
Mwanza	0.16***	3.27	-7.36***	-8.48
Mara	-0.01	-0.17	-8.11***	-10.54
Peak season	-0.38**	-2.16	1.08***	3.37
Normal season	-0.15	-0.90	0.95**	2.40
Age of net (netage)	-0.13*	-1.91	0.52**	2.36
Variance parameters				
σ^2	1.00***	2.69	0.77***	2.75
γ	0.52**	2.50	0.53**	2.10
Constant	-3.31*	-1.90	-2.09	-0.80
Ln (crew size)	0.19	0.53	-1.66	-1.33
Ln (net length)	-0.31***	-3.22	-0.71**	-2.35
Ln (hours)	0.95*	1.79	1.55**	2.42
Ln (distance)	-0.56**	-2.35	0.27	0.81
Ln (skipper experience)	-0.09	-1.07	1.31	1.53
Ln (education)	-0.13	-0.98	-0.77*	-1.64

	Non-neutral—Nile perch		**Non-neutral—Dagaa**	
Variables	***Coefficient***	***t-ratio***	***Coefficient***	***t-ratio***
Dummy variables				
Motor	-0.34	-0.90	1.46**	1.97
Peak season	-1.10**	-1.98	1.18*	1.70
Normal season	-0.49	-1.24	-0.07	-0.05
Age of net (netage)	-0.56*	-1.74	1.49	1.24
Crew share (CrewS)	-0.38*	-1.66	-3.70***	-2.98
Owner part crew (ownerpcr)	0.25	1.08	-0.80	-0.87
Owner operated (ownerop)	-0.15	-1.07	-0.07	-0.12
Remuneration (remun)	-0.26*	-1.84	0.40	0.41
Extra bonus (ExB)	-0.54**	-2.02	0.82*	1.64
Local management (BMU)	-0.60*	-1.85	-1.48*	-1.65
Log likelihood		-1514.53	-184.42	
Mean efficiency		0.75	0.70	
No. of observations		1313	179	

Notes: t-statistics in brackets

*** Significant at 1% level; ** significant at 5% level; * significant at 10% level

However, the dummy for the Mwanza region was also positive and significant, implying that vessels in Mwanza were performing better, relative to those in Mara and Kagera regions. The market potential in Mwanza, compared to the other two regions, could be a possible explanation. Of about 13 processing factories, 10 were located in Mwanza region, 3 in the Mara region, and none in Kagera. Seasonal dummy variables were significant and positive in dagaa fishery, suggesting that fishers targeting dagaa species were performing better in peak and normal seasons, compared to off-season. This should be expected since stock abundance was relatively higher in these two seasons.

The technical inefficiency function has the technical inefficiency dependent variable so that a negative sign will indicate an increase in technical efficiency or a decrease in technical inefficiency. A majority of the variables in the technical inefficiency function were significant, especially in Nile perch fishery. It was interesting to find that some of the input variables in the inefficiency model turned out to be significant in both Nile perch and dagaa specifications. Net length was negative and significant, suggesting increasing efficiency in both fisheries, while hours spent fishing was positive and significant, implying decreasing efficiency with long hours fishing. The variable crew size was insignificant in both fisheries.

A skipper's fishing skill is often considered to be an important determinant of a boat's catch and efficiency. Among the skipper's attributes, we expected fishing experience to imply better knowledge of fish location, weather patterns, currents and tides, bottom conditions, and how to best catch the fish. However, we found that it was the experience as a skipper that mattered, while previous experience as a regular crewmember was insignificant.[5] The result indicated that efficiency increased with skipper experience. In addition to fishing experience, long experience as a skipper generally implied experience working with different crews and thereby better skills in finding the best crew for a boat.

To capture the efficiency effects of incentives given to the skipper, we included dummy variables for an extra bonus given to the skipper, a dummy variable indicating whether owner took an equal share as the crew, and the mode of remuneration, i.e., whether the share was calculated after or before deducting the daily running cost. The results indicated that an extra bonus to the skipper led to increased efficiency in both fisheries, and that efficiency increased if the owner shared 50-50 with the crew. We also found that sharing after deducting operating costs led to increased efficiency in the Nile perch fishery. A potential explanation is that the risk of receiving zero payment forced the crew to work harder, which was reflected as increased efficiency.

Ownership patterns, and particularly owner participation, in actual fishing can affect efficiency and incentives. The variable (*ownerop*) was significant, which indicated that skippers who owned their vessels were more efficient than hired skippers. An interesting result was that boat owners without skipper skills are better off hiring a skipper and staying ashore. The presence of an owner on board reduced efficiency; one reason for this is that the boat owner might interfere with the skills of the skipper.

Additional schooling can improve literacy and cognitive skills, which may be important in increasing efficiency by increasing the ability of skippers to adopt technical innovations. The number of years the skipper spent in school was found to be statistically significant, suggesting

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[5] The variable experience was included in the model in the initial analysis, but was found to be insignificant. Because of its high correlation coefficient with the number of years as a skipper, it was removed in the model.

that addition years of schooling or training could be important in increasing efficiency among the inefficient skippers in dagaa fishery.

In 1998, the Tanzanian government—through the Lake Victoria Environmental Management project (LVEMP)—introduced local management units, commonly known as beach management units (BMUs). These units were established to enhance community participation in the surveillance and management of the lake resources. Although the BMU leaders do not have legal power to arrest anyone, they can point out culprits to the enforcement officials. Their most important task, however, is to help prevent the use of destructive gear. The existence of BMUs has led to increased efficiency in both fisheries, which is possibly explained by fishermen exchanging information and learning from each other at the regular BMU meetings.

The production elasticities for the estimated model were evaluated at means of relevant data points defined by equation (5). As shown in equation (5), the elasticity of the mean frontier output, with respect to the *k*th input variable, has two components: (1) the elasticity of frontier output with respect to the *k*th input, given by the estimated β_k parameters, and (2) the elasticity of TE with respect to the *k*th input.[6] The mean frontier output, the efficiency elasticities, and the return to scale are presented in table 5. The elasticities were generally low and always below unity, suggesting the low responses of harvests to the scale of fishing inputs. We found that net length was consistently higher in all the fisheries in both frontier output and TE efficiency. Hours fished were higher in TE in both fisheries, but relatively low in frontier output. The elasticity of crew size was significant and negative for both fisheries in TE, which suggested that the mean vessel might be subject to input congestion and operated in Stage 3 of the production function where the isoquant had a positive slope (Kuperan et al. 2001). Skippers might have had more crew members than necessary on their vessels for social reasons or might not have adjusted to the given stock level.

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[6] As noted in Omer et al. (2007), we assumed that a firm's input decisions were not influenced by its productivity. Otherwise, estimating the stochastic production frontier regression without considering this kind of endogeneity would yield inconsistent coefficient estimates. The size of this inconsistency may depend on the slope parameters as well as the variance of the error terms. Hence, the model assumed that the choice of inputs used to maximize marketable output was only subject to human error, which in turn was uncorrelated with the error specification in the stochastic frontier model.

Table 5 Elasticity Parameter Estimates with Respect to All Inputs

	Nile perch		Dagaa	
Variable	***Frontier output elasticity***	***Technical efficiency elasticity***	***Frontier output elasticity***	***Technical efficiency elasticity***
Crew size	0.087 (0.212)	-0.462 (0.191)	0.307 (0.197)	-0.279 (0.222)
Net length	0.499 (0.218)	0.570 (0.123)	0.165 (0.096)	0.356 (0.176)
Hours	0.179 (0.129)	0.887 (0.259)	0.013 (0.152)	0.458 (0.299)
Returns to scale	0.765 (0.432)	0.995 (0.345)	0.485 (0.329)	0.535 (0.348)

The estimated returns to scale were 0.765 and 0.485 in the Nile perch and dagaa fisheries, respectively, for the frontier output elasticity, while TE elasticity was 0.995 and 0.535 in the Nile perch and Dagaa fisheries, respectively. The returns to scale for frontier output in Nile perch fisheries, and for all cases in dagaa fisheries, were generally decreasing, influenced mainly by the input congestion, suggesting that input reduction would help boats enjoy increasing returns to scale and some scale economies. This finding supported the finding by Kateregga (2005), who reported the results from a translog production function for Nile perch and Nile tilapia. Kateregga used data from the Ugandan section of Lake Victoria, where it was found that return to scale was decreasing in all fisheries. We did, however, notice that the return to scale was generally higher for the TE elasticity in the Nile perch fisheries, which was found not to be significantly different from unit.[7] Hence, we could generally say that harvests in the Nile perch fishery were subject to constant returns to scale. Returns to scale for the dagaa fishery however, was not statistically significant at the conventional level.

Decreasing returns to scale imply that the productivity of inputs declines with large fishing units. In these fisheries, which could be considered as regulated open access, return to scale might be expected because there were imperfections in both outputs and inputs markets. Furthermore, prices and harvests were highly subjected to uncertainty, especially due to the fact that fishers do not have storage facilities and that whatever is caught must be sold the same day.

One plausible argument could explain decreasing returns in these fisheries. In open access fishing where fluctuations in fisheries are expected to be higher, larger fishing units (presumably with higher incomes) are less risk averse (Eggert and Lokina 2007). The reduction

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[7] Using the estimated standard error and the coefficient of the return to scale, we tested the null hypothesis that the value of returns to scale of TE was 1and referred to a standard normal table (see Green 2003).

in their risk averseness enables them to use more effort even when production is jeopardized. This is in line with the Arrow-Pratt decreasing absolute risk aversion that has been widely used in explaining behavior under uncertainty (Block and Heinke 1973).

Furthermore, the market imperfections and a high level of unemployment within the lake regions and beyond may induce boat owners to hire more labor at low wages. Family-managed fishing units, especially among Dagaa fishers but also some Nile perch fishers, in some instances may hire household members as crew to keep them employed rather than aim for improved productivity. Thus, the crew size that a fishing unit opts for may be influenced by factors other than what it expects to reap from fishing.

5. Discussion and Conclusion

Lake Victoria fisheries can be regarded as open access with no regional or national restrictions on entry or total catch. There are no limits on effort, and the only measure for preventing stock depletion is a minimum mesh-size regulation, which is widely violated by the fishers (Lokina 2004). The lack of alternative employment opportunities, coupled with the open access of the fisheries, has led to a substantial overcapacity both in number of fishing vessels and number of fishers. This study focused on the Tanzanian section of Lake Victoria, but the results should also apply to the Kenyan and Ugandan sections, where fishers employ comparable technology and harvesting practices and operate under similar management. There is a tremendous need for the three governments sharing the lake to direct their policies toward resource conservation and support for sustainable livelihoods, including incentives for fishers to diversify into other professions.

The results of this study indicated variation in efficiency, but primarily that boats on average had a relatively high level of efficiency. (The majority was above 77 percent or more in Nile perch fishery and 71 percent in dagaa fishery.) The inefficiency models indicated possibilities for improving performance in both fisheries. For Nile perch fishery, efficiency increased with more years of skipper experience and with more years of education the skipper had. Furthermore, efficiency was found to increase with net length and distance covered by the fishers. Efficiency was also found to decrease with hours spent fishing. A number of significant dummy variables indicated increased efficiency when the skipper owned the vessel, if the crew was paid the same share as the owner, and if the revenues were shared after cost deduction. An extra bonus to the skipper increased efficiency, while owners (who were not skippers) joining the crew reduced efficiency.

For the dagaa fishery, efficiency increased with skipper experience, while efficiency decreased with average gill-net age. Efficiency also increased if the crew received an equal share and if the skipper was given an extra bonus. A common feature for both fisheries was that the existence of local management over fish resources, commonly known as beach management units (BMUs), led to improved efficiency. These BMUs were charged with eliminating destructive gear practices as their prime objective, but their repeated meetings with fishers may, for instance, implied an effect that the information sharing was accompanied by learning.

From the perspectives of equity and of distribution, improved efficiency is desirable. The results from the study offer some suggestions for policy. One such idea is that if the hired skippers in Nile perch fishery could buy their vessels, they would likely increase the rate of return. This suggests that better credit facilities with more access would improve efficiency in Lake Victoria fisheries. Probably for these reasons, the government quite recently removed all import duties and value added tax (VAT) on fishing gear and outboard motors to enable more fishers to own their vessels (URT 2004). This move by the government can be seen as an attempt to subsidize the fishing sector to maintain employment and make fishers technologically competitive in the face of declining stocks. But improving efficiency when neither effort nor catch is limited could lead to further depletion of stocks. Conclusions about efficiency are subject to biological limits. Given the stock conditions, it is not possible to increase the catch in the long-run by increasing fishing effort, since the practice would lead to depletion. Increased efficiency at the aggregate level is only possible if fishing effort is limited. One potential option would be to retire a number of boats, preferably least efficient ones. Improved efficiency could then lead to similar catch levels with a smaller number of boats and fishers. However, such a prescription is problematic for two reasons. First, it presupposes control at the aggregate level, which is currently not available. Second, it requires decommissioning a number of boats and the consequent unemployment of a number of fishers. Theory states that, in the long run, improved stocks and increased profits for the remaining fishers should in principle be sufficient to compensate those who are forced out of the industry, but there remain serious issues of distribution, enforcement, and monitoring.

In the absence of aggregate control of effort and the exit of less-efficient fishermen, we have a different situation. The existing variation in efficiency can be a problematic rather than constructive element. Potentially it contributes to hiding the problem of over-fishing; unsuccessful fishermen will compare themselves to successful fishermen and may see a difference of skill rather than stock decline. The results show that some of the variation in efficiency is due to differences in equipment, skill, and organizational variables, such as the structure of incentives and the relationship between the owner and the skipper. These tangible differences can be remedied, but the competition for increased efficiency may reinforce overcapacity. One example is that some boats use extremely long, fine-meshed nets and "stack" these nets on top of each other: there are already physical signs of such competition. If such a practice spreads across all of Lake Victoria, the stocks will be further depleted, and improved landings will only be a temporary phenomenon.

This is particularly destructive since the same amount of fish could have been caught if there were fewer fishermen and less capital. Overcapitalization is a heavy economic burden on very poor fishermen. At the same time, this might easily be an explanation for why we found low elasticity coefficient in most of the inputs. It suggests that Lake Victoria fisheries might be attracting more inputs than what is strictly necessary for the stock size.

Given the current situation with Lake Victoria fisheries, there is a need to curb overcapacity. From a theoretical perspective, a Warming landing tax is attractive (Warming 1911; Weitzman 2002); it would make fisheries less attractive to new entrants and limit the incentive schemes, which according to our results influence efficiency and potentially restore rents in the long run. However, for a fishery without landing records and with total allowable catches, such reform would face tremendous problems. Our results correspond to Squires et al. (2003), who found that development aid should focus on human and social capital rather than on vessel and gear upgrade. Pomeroy (1994) and Squires et al. (2003) held that strategies for cooperative and community management could help control fishing activity and promote sustainable fishing practices, while Christy (1999) suggested that limited entry could be beneficial for developing fisheries. In this case, BMUs could be a potential starting point for a limited entry policy. Almost half of the studied artisans fishing communities in Lake Victoria have BMUs. The current structure of these management units is quite disorganized, as evidenced by a lack of resources and lack of power to enforce the law. Still, these BMUs seem to have a positive effect on mesh-size compliance (Lokina 2004) and efficiency. An overall restructuring could be beneficial and enable the BMUs to play an effective role in fishery resource management. With such reform, the BMUs could potentially carry out a limited entry policy, which would make efficiency improvements and sustainable fisheries on Lake Victoria possible.

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