International Journal of Agriculture Innovations and Research
Volume 2, Issue 4, ISSN (Online) 2319-1473
Manuscript Processing Details (dd/mm/yyyy) :
Received : 27/12/2013 | Accepted on : 15/01/2014 | Published : 20/01/2014

Production Functions for Nile Perch and Tilapia Fisheries: A Case Study of Uganda's Section of Lake Victoria

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***Abstract* – In this study we seek to explain the determinants of catches for the Nile perch and tilapia fisheries of Uganda's section of Lake Victoria. Production functions are estimated from data collected from a survey of 100 boats engaged in fishing of Nile perch, and 150 boats fishing tilapia, in 3 districts along Lake Victoria. A restricted Translog production function specification without complementary terms was found to be the appropriate functional form for both fisheries. Results showed that the elasticities of catch with respect to the variable components of effort were quite small, and that fishing units were operating under decreasing returns to scale.**

***Keywords* – Elasticities of Catches With Respect To Fishing Effort, Nile Perch and Tilapia Production Function, Returns To Scale.**

I. Introduction

The introduction of alien species in Lake Victoria in the late 1960s, though now widely acknowledged as an arrangement that led to the destruction of the lake's ecosystem and thus the disappearance of the native biodiversity, can on the other hand be credited for having made the Lake's catch of more economic valuable[i]. The Nile Perch was introduced in Lake Victoria in the 1960s. However, intensive exploitation of these resources began only in the late 1980s. The reason being that for the period 1970 –1985, the Lake Victoria fishery was basically artisanal, constrained in production by the lack of inputs necessary to carry on fishing, particularly in offshore grounds [Ministry of Finance and Economic Planning, Uganda, 1989]. The enhancement of the fish market by the influx of fish processors whose supply goals were geared toward markets abroad in the early 1990s, further increased exploitation of the lake's resources, particularly as the search for Nile perch gained momentum in the Kenyan and Tanzanian sections of the lake [*Economic Policy Research Centre*, *1996*]. Consequently, catch from Lake Victoria emerged as the dominant proportion of total fisheries sector output in from 1990.

Nile perch, Tilapia, and *Rastrineobola Argentea* (locally known as *Mukene*) are the three species that dominate the commercial fisheries in the Uganda section of Lake Victoria. Over 70% of the Nile perch catch is processed for external markets, while Tilapia and *Mukene* catches are locally consumed. Before the fish ban of 1998, earnings from fish exports were second to coffee, the country's main foreign exchange earner [Ministry of Finance and Economic Planning, 1999]. Fish provides more than 60% of the country's protein requirements, and close to 50% of this comes from catches of Lake Victoria. Over 50% of employment in the fisheries sector is found here.

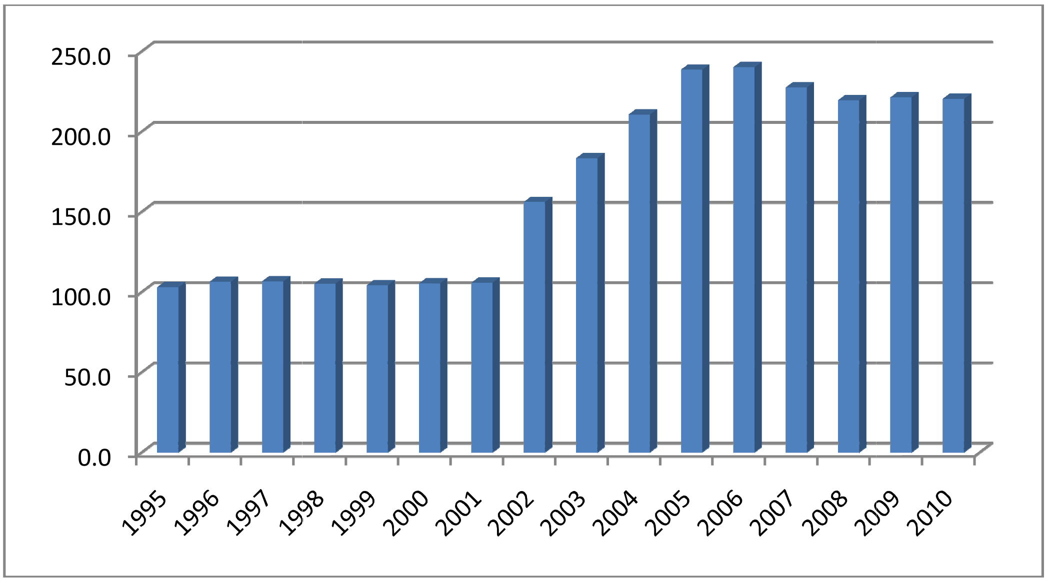

Fig.1. Catches in Ugandan Part of Lake Victoria 1995–2010
Source: National Fisheries Research Institute (NaFIFRI) 2011

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Catch levels of the various types species, and changes in types and quantities of types of fishing gears used in the Lake Victoria fisheries have been recorded along several landing sites in different time periods [Lake Victoria Fisheries Organisation (LVFO), 2008]. The trend in aggregate catches for the period 1995 – 2010 appears in figure 1. Catches from the lake steadily increase up to 2006 and thereafter the trend goes down. The decline in catch after 2006 may be explained by the declining Nile perch and Tilapia fisheries due persistently acknowledged high levels of both qualitative and quantitative over-fishing [LVFO, 2008].

This paper seeks to examine the determinants of fish catches in the Nile perch and tilapia fisheries of Uganda's section of Lake Victoria. The analysis in this paper is novel in that we seek to explore the structure of production in Lake Victoria fisheries by identifying the key determinants of catch in the Nile perch and tilapia fisheries. Elasticities of catch with respect to the variable components of effort, and the returns to scale are estimated. We estimate production functions for the Nile perch and tilapia fisheries, using cross-section data collected from a survey of 100 boats engaged in Nile perch fisheries, and 150 boats harvesting tilapia in the Ugandan section of Lake Victoria.

In the following section we present a literature survey on issues raised in the estimation of fisheries production functions and discuss how they relate to our study. Section 3 presents the empirical strategy behind the analysis. The survey and data characteristics are discussed in section 4. In section 5 we discuss the estimated results. Section 6 gives the conclusions from the study.

II. Issues Related to the Estimation of Fisheries Production Functions

In this section some issues that have been raised on the credibility of fishery production functions and on the estimation of production functions from cross section data are discussed. The traditional fishing effort approach to fisheries economics implies the existence of a production function in which fishing effort is combined with fish stock abundance to produce catch [Gordon, 1954]. Effort could be measured as the number of traps, nets, boats, man-days/hours spent in fishing, and in production function estimations these inputs may be controlled for various fisheries specific characteristics. These may include seasonal variations in the intensity of fishing, water temperature and hydrological characteristics of the aquatic systems, the differences in the productivity and knowledge of fishermen, among others [Wilson, 1990]. One of the important attributes of using a production function is that it allows the simultaneous measurement of as many parameters of fishing power as may be thought to be important in its determination. The assumed functional form of this production relationship has great implications for the fish stock growth function and its parameters [Hannesson, 1983]. As Berk (1979) notes, it is the shape of the production function, together with the fish demand function and the effort cost function that determine the viability of fish stocks exploited under a free access aquatic resource. Following the Schaefer model, the fish production function is normally assumed to take the form of Cobb-Douglas. Estimation of Cobb-Douglas type catch–effort functions have been conducted in several studies [Ikiara, 1999 among others]. The frequent application of this production function is due to its flexibility, in that it allows the researcher to capture the effects of the congestion and stock externalities in fish production, depicted by the catch elasticity parameters with respect to effort and stock.

Some critiques in the application of traditional analysis of fisheries production have been raised in Anderson (1976), Hannesson (1983), Wilson (1990), Holland and Sutinen (2000), among others. First, when nominal fishing effort is measured as a single index no guidelines can flow out of the analysis as to which aspect of fishing effort to regulate, since other than fishing time/power, many details of the various gears may not be incorporated in the estimations [Andersen, 1999]. It has also been noted that in some cases, effort that determines catch is found using catch data. This makes the procedure circular and renders fishing effort an inappropriate determinant of catch. Failure of the approach to make a clear distinction between fishing capacity and fishing effort is raised in Andersen (1999). To this effect there have been arguments in favour of estimating effort production functions instead. Hannesson (1983) and Pascoe and Robinson (1998) explore fisheries production by estimating effort production functions. Such a treatment of the fisheries requires data on the biomass of fish, which is unavailable for Lake Victoria.

Hilborn (1992) notes that the traditional approach treats fish populations as a single, spatially homogenous entity. Yet many fisheries are not spatially homogenous. Moreover, several studies have shown that production in fisheries, like same process in hunting, is guided by elements of "discovery and exploitation". Unless perfect information exchange is assumed to exist in the fishery, fishermen who by luck or otherwise manage to locate relatively more productive grounds, may intentionally fail to disclose such information to fellow competing units. In this regard, they are able to maintain catch levels at higher levels than others. Considerable variations in landings among vessels in a fishery could be eminent also because recruitment to various stocks is generally asynchronous [Sisswine et al., 1982]. This then raises the need to allow for spatial differences in fish densities in production function estimations. Such a treatment requires good knowledge of all year around distribution of stocks. This information was not available for our study. We however incorporate district dummies in our estimations to explain district specific variations in fish densities. This may not be the best method of capturing density differences. Since district bounds are not mutually exclusive, we had no alternative.

Multi-species fisheries pose yet another concern for the production and fish stock growth approaches to fisheries economics. Here the intricate biological interactions among the various species in the water body become

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crucial components of the stock function, and technological interrelationships in harvesting. The issue of by-catches, particularly where by-catch-ratios tend to be high and volatile, has attracted more attention in multi-specie fisheries both in terms of fish production and regulations admissibility. The indiscriminate harvesting nature of some fishing gears raises the need to account for the jointness in production in a multi-fisheries resource [Hannesson, 1993]. Squires (1987) tests the hypothesis of jointness of inputs a multi species fishery and finds that jointness in production could not be rejected at the 5% level of significance.

In the Uganda's Lake Victoria fisheries, gear restrictions in place ensure that juveniles of tilapia are not cropped out, however gear recommended for tilapia crops out juvenile Nile perch. While the former is a crime, the latter is an accident [Uganda Fisheries Department, 1992][ii]. And indeed, in our survey we found that several vessels whose main target was tilapia also crop out Nile perch though the mesh sizes used by the unit are tilapia type. Thus jointness in production for the two species could not be ruled out. This implies that data from the two fisheries may be pooled to estimate an aggregated production function. However poolability of the data is an issue that is determined by statistical tests such as the Likelihood ratio and F-tests on the assumed restrictions.

In our analysis of fisheries production in Uganda's section of Lake Victoria we impose restrictions on the Translog production function. We estimate the unrestricted and restricted specifications of the function, following the traditional fisheries modelling procedure. We conduct F-test to determine which specification best fits Nile perch and tilapia fisheries production in Uganda's section of Lake Victoria. The dependent variable is catch per day (the kilogram weight of harvests). Effort is the product of fishing time and fishing power. Fishing power is described by quantities and attributes of the various gear used in fishing. District dummies are used to capture the relative abundance of fish across the three districts. We make conclusions about the structure of production in the Nile perch and tilapia fisheries based on these results.

III. Empirical Strategy

In this section we present the formulation of the models to be estimated. We explore the possibility that the technologies used in the Nile perch and tilapia fisheries, subscribe to the Translog (Transcendental Logarithmic) specification. The Translog production function is a flexible specification, exhibits non-homothetic technology, and imposes no restrictions on the magnitude of the elasticity of substitution between inputs, or the returns to scale [Christensen, Jorgenson, and Lau, 1971]. Due to its flexibility, the Translog specification has been widely used in the study of input substitution [Berndt and Christensen, 1973], productive efficiency [Greene, 1980; Field, 1988; Kim, 1994], technical change and productivity growth [Xu, 2000]. The function has also been used to estimate cost share equations by imposing on it the condition of constant returns to scale, and assuming perfectly competitive input and output markets [Morgenstern et al., 1998].

The individual fishing unit's production function is assumed to be a function of the level of effort applied in the period, and the size of the fish stocks which is exogenously determined,

$$h_i = f\left(E_{ik}, F\right), \qquad (1)$$

where we assume:

$$\frac{\partial h}{\partial E} > 0, \frac{\partial h}{\partial F} > 0, \frac{\partial^2 h}{\partial E^2} < 0, \text{ and } \frac{\partial^2 h}{\partial F^2} < 0. \qquad (2)$$

h_i is the observed average catch per day in kilogram weight, for fishing unit i, E_{ik} is a vector of factor inputs k used by i ($E_{ik} > 0$), and F is the stock of fish in the lake in the period. For a pooled regression over all cross-sectional units, the Translog production function is:

$$\ln h_i = \beta_0 + \sum_{k=1} \beta_k \ln E_{ik} + \frac{1}{2}\left\{\sum_{k=1} \sum_{l=1} \beta_{kl} \ln E_{ik} \ln E_{il}\right\} + \delta_m + \cdots + \mu_i \qquad (3)$$

We assume symmetry of the cross product terms is assumed, that is $\beta_{kl} = \beta_{lk}$ [Greene, 1997]. u_i is a random error assumed to be $iid\left[0, \sigma_u^2\right]$.. Because Lake Victoria fisheries do not subscribe to schooling fisheries class, where CPUE is constant and independent of stocks [Bjϕrndal 1989], stock abundance is expected to be a major determinant of harvest across the different sections of the lake. Lack of data on stock density and distribution however prevented us from including the stock variable F in the production function specification in (3). We instead use district dummies to capture this effect. δ_m denotes the coefficient of the j^{th} dummy variable designed to capture the effects of fish stock distribution, vessel characteristics, crew and other gear specific attributes like, gear size, level of education and so forth, on the dependent variable. The elasticities of output with respect to the various components of effort E_k are calculated from (4) as:

$$\frac{\partial \ln h}{\partial \ln E_k} = \beta_k + \sum_l \beta_{kl} \ln E_l \qquad (4)$$

The returns to scale are given by the sum of these output elasticities, which equals:

$$\sum_k \frac{\partial \ln h}{\partial \ln E_k} = \sum_k \beta_k + \sum_k \sum_l \beta_{kl} \ln E_l \qquad (5)$$

Possible restrictions on the parameters of the function are imposed and tested in order to identify the specification that is appropriate for Uganda's Lake Victoria Tilapia and Nile perch fisheries. We use F-tests to determine the appropriate functions[iii]. Three types of restriction are explored. These are:

(i) $\beta_{kk} = \beta_{ll} = 0 \quad \forall\ k, l$

(ii) $\beta_{kl} = \beta_{lk} = 0 \quad \forall\ k, l$

(iii) $\beta_{kk} = \beta_{kl} = \beta_{lk} = 0 \quad \forall \quad k, l$. (6)

The differences in the working environment and management decisions could imply the estimated production functions coefficients may vary across fishing units. That is, the parameter β_0 and slope coefficients may vary across producers. We try to capture the effects of differences in working environment and other fishing unit specific characteristics by including dummy variables that capture boat, crew, and organisational specific attributes. These included type of boats type of fishing gear used, level of education of the skipper and remuneration modes. The mode of remuneration variable was expected to capture the effects of incentive programs on catch. We include the variable years spent in fishing and age of the boat to capture effect of fishing background (or experience) on catch. Further, the effects of compliance on mesh size and boat licence on catch are examined. We pool the observations on harvests per day in weight, and the levels and attributes of the different components of effort to estimate the production functions for Tilapia and Nile perch fisheries in Uganda's section of Lake Victoria in section 4.

IV. The Survey

In this section we discuss the survey design, and the data that was generated from the survey. We conducted a survey of 250 fishing boats engaged in the Nile perch and tilapia fisheries from 25 landing beaches in the districts of Masaka, Mpigi and Mukono. The time period was June to August 2012. By location, Mpigi and Mukono districts are closer to the country's capital city than Masaka is. Annual catches from these districts constitute more than 50% of the annual tonnage of catches from the lake [UFD, Statistics Department, Lake Victoria Fisheries survey, 2000]. Mukono district's catch contribution is the largest of the three. The number of landing beaches on the lake exceeds 700. Some beaches however do not operate all year around, particularly those where the main catch is *Rastrineobola Argentea* (*Mukene*, also known as *Dagaa*). *Rastrineobola Argentea* fishermen's migratory behaviour is the highest among the fisheries. They normally operate for only two weeks in a month, because their activities are controlled by moonlight. Moreover, unlike for many of other species, *Mukene* catches are generally marketed in dry weight form. Thus closeness to the market is not a major concern. For some periods of the year, fishermen in the *Mukene* fishery migrate to grounds further off shore, near the islands. They then accumulate catches of dry weight fish, and offload it to the landing beaches in lump sum. Consequently, it became impossible to keep track of their daily activities. Thus in our sample we had to omit boats engaged in *Mukene* fishing, and included only Nile perch and tilapia fishing boats. The sample sizes for both fisheries were arbitrarily determined. Sampled beaches were randomly selected after ruling out those where activity was temporary during the year. The latest catch data at the time of survey was for 1998.

In order to determine how many landings to select from each district, we used the percentage contribution of each district to total catch from the total of the three districts in 1998. This implied a selection of 11 beaches from Mukono, and 7 beaches each from Masaka and Mpigi districts. Selection of the villages to be included in the survey was based first on whether there were all year around operations on the respective beaches. Among the all year around landing sites, selection of those that were included in the survey was done by random selection[iv]. We then sampled 10 boats from each landing. The boat selection procedure used here was to include those boats whose positions were odd in the arrival sequence on the starting day (that is, the first, third, fifth, and so forth), subject upon the boat being engaged in the fishery that we were focusing on, and the cooperation of the boat crew.

Table 1: List and Definition of Variables

Variable	Definition
Size of Boat	The length of the boat in metres
Crew Head's Education	The highest level of formal Education attained by the skipper
Activity of Boat Owner	A dummy variable, which is 1 if the owner engages in fishing, and 0 if he/she is a supervisor.
Type of Boat	A dummy variable, with 1 if the boat is planked, 0 if a dugout canoe was used by the fishing unit.
Type of Gear	A dummy variable, with 1 is gillnets are used, 0 otherwise.
Mode of Proceed Sharing	Mode of sharing proceeds from fishing is a dummy variable with 1 if the crew receives a fixed monthly pay, and 0 otherwise.
Mode of Boat Propulsion	Mode of boat propulsion, which is dummy variable 1 if an outboard engine is used, and 0 otherwise.
License Compliance	A dummy variable, with 1 if the boat had a valid license at the time of the survey.
Catch Per Day	Total catch weight divided by the number of trips made during the period.
Boat Age	The life span of the boat since construction to date expressed in months.
Size of Crew	The number of people working on the boat.
Years Spent In Fishing	The number of years the skipper had been engaged in fishing.
Fishing Time	The number of days the boat was observed in fishing during the sample period.
Mesh Size Compliance	A dummy variable coded 1 if the boat's gill nets met the required legal standard.
Number of Gill Nets	The number of gill nets held by the boat

We collected data from the sampled boats, on catches by weight and numbers, per day for two months (June and August, 2000), on their effort structure and other issues. We define catch as the total kilogram weight of the main

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specie harvested by the boat over the sample period. The main species harvested implies here that over 80% of the observed catches harvested by the fishing unit was either Nile perch or Tilapia. Effort constitutes of boat by type, size and age, the number fishing gears by type, size and numbers, fishermen's experience as represented by the number of years spent in fishing, their level of education, and the mode of sharing proceeds from fishing (a motivational variable). A detailed definition of variables included in the estimations of production functions, is presented in table 1. The data descriptive statistics are reported in tables 2 and 3.

Table 2: Descriptive Statistics – Tilapia Fishery

Variable	Mean	Std. Dev.	Minimum	Maximum
Catch (in Kgs)	395.57	326.22	47.50	1887.00
Catch per day (in kgs)	8.02	5.39	1.63	32.53
Fishing time	47.10	7.74	17.00	60.00
Age of boat	17.13	12.63	1.00	60.00
Number of gill-nets	18.05	22.85	1.00	250.00
Size of Crew	1.87	0.64	1.00	4.00
Years spent in Fishing	7.62	5.01	1.00	32.00
Size of boat (metres)	5.33	1.84	3.00	12.00
Crew head's education	0.67	0.47	0.00	1.00
Activity of boat owner	0.88	0.32	0.00	1.00
Type of boat	0.44	0.50	0.00	1.00
Type of gear	0.80	0.40	0.00	1.00
Mode of sharing	0.78	0.41	0.00	1.00
Mesh size compliance	0.27	0.44	0.00	1.00
License compliance	0.43	0.50	0.00	1.00

Number of observations = 147

Table 3: Descriptive Statistics – Nile perch Fishery

Variable	Mean	Std. Dev.	Minimum	Maximum
Catch (in kgs)	2542.81	1607.46	286.00	7548.00
Catch per day (in kgs)	51.27	30.51	7.51	142.42
Fishing time	48.87	7.43	25.00	60.00
Age of boat	20.23	15.71	1.00	120.00
Number of gill-nets	57.61	40.77	1.00	160.00
Size of crew	2.33	0.65	1.00	5.00
Years spent in fishing	8.60	5.05	2.00	25.00
Size of boat (metres)	8.32	1.83	3.00	12.50
Crew head's education	0.74	0.44	0.00	1.00
Activity of boat owner	0.71	0.46	0.00	1.00
Type of boat	0.22	0.15	0.00	1.00
Type of gear	0.88	0.33	0.00	1.00
Mode of sharing	0.75	0.43	0.00	1.00
Mesh size compliance	0.38	0.49	0.00	1.00
Mode of propulsion	0.61	0.49	0.00	1.00
License compliance	0.72	0.45	0.00	1.00

Number of observations = 93

V. Hypotheses

In this section we discuss the expected signs on the coefficients of the explanatory variables included in the estimations. A summary is presented in table 4. The more time input the fishing unit engages in fishing, and the more intensive is the search, given that the "chance of discovery" exists, the more likely is the vessel's catch increased. Thus fishing units with higher input of fishing time are expected to have higher daily catches. Both the marginal product of catch and the elasticity of catch with respect to time should be positive. However in our estimation fishing time does not appear in the equations because the dependent variable is catch per day.

In the same vein the marginal product of catch and the elasticity with respect to labor is expected to be positive. Years spent in fishing, used here as a proxy for fishing experiences, and education of the crew head, are expected to have positive effects on catches. The coefficient on the dummy for activity of the boat owner (coded one if he is not part of the crew) is expected to be negative. A skipper who owns the boat is more likely to motivate himself to work rather than an employed skipper.

The effects of vessel size and age could be unpredictable. Several studies have found vessel size to be a crucial determinant of quantity of fish [Ikiara, 1999]. Others fail to trace the importance of the size of the boat, presumably because the boat only provides a platform of operations. Ikiara (1999) contends that vessel age is synonymous with progress in vessel building or technology. However, what seems to matter is boat maintenance. In the perspective of Ugandan Lake Victoria fisheries boat size does not only provides a platform but also determines how stable the boat is on the waters. Hence it also defines the scope of mobility of the vessel in the expanse of fishery grounds, particularly for the Nile perch fishery. Besides, size determines the vessel's load capacity. We thus expect boat size to have a positive effect on catch.

Table 4: Hypotheses

Elasticity of catch w.r.t the Variable factors	Expected Sign
ln boat age	(?)
ln gill-nets	(+)
ln crew size	(+)
ln years spent in fishing	(+)
ln boat size	(+)
The effect on Catch from	
Education of crew head	(+)
Activity of boat owner	(+)
Boat license compliance	(+)
Type of boat	(+)
Type of gear	(+)
Mode of proceed sharing	(-)
Mesh size compliance	(?)
Mode of boat propulsion	(+)

The type of boat variable is intended to capture the effect of the change in boat construction technology on catch. The dugout canoes were the first type boats used in the fisheries. Planked boats are the more recent ones. We expect the effect of the change in boat construction on catch to be positive. The effect of mesh sizes on catch is not obvious. Smaller nets have a "non-selective effect" that enables them to crop out more harvests. The selectivity of bigger meshes may imply lower catches, if smaller fish dominate the recruited individuals [Schnute, 1987]. However the effect may depend on the location where the nets are applied. In inshore grounds that are habitats for smaller fish small nets may have a positive effect on catches. In offshore grounds with larger fish, the effect of small size net on catch may be negative. Due to this complication, we do not *apriori* spell out the effect of mesh size on catch, however the number of gears (nets, or hooks) are expected to have a positive effect on harvests.

In addition to mesh size compliance, boat license compliance is explored by using a dummy (coded one if the boat held a valid license at the time of the survey). In general compliance is expected to have a negative effect on catch in the short-run. In this particular case, whether the sign on the coefficient of boat license is positive or negative may depend on effectiveness of regulation enforcement was at the time of the survey. If monitoring was quite regular, then unlicensed boats may be observed with less input of fishing time. No information of the effectiveness of regulation is available to us. We thus make no prediction on the sign of this coefficient.

There were two types of proceed sharing modes observed from the survey. Close to 50% of the boats surveyed in the Nile perch fishery were using a fixed monthly wage system to remunerate the crew, 28% had wages pegged to the amount harvested, while the rest seem to be governed by other factors including family based decisions, where the boat was managed by a household member. In the tilapia fishery, 37% of the boats were paying a fixed monthly wage to the crew, 21% pegged crew wages on the amount harvested, and the rest were family run fishing units. In order to capture the effect of remuneration on catch a dummy (coded one if the fishing unit uses a fixed monthly wage) is included in the estimations. The coefficient on this dummy is expected to be negative, as harvest-pegged wages are expected to motivate the crew to harvest more.

We had no information on the stock distribution in the lake. We however assume different distributions across districts and expect district dummies to capture this effect. District dummies may capture differences in spatial distribution of stocks, but they may also reveal differences in the productivities across fishing grounds in the three districts. No prediction on the signs of these dummies is made therefore.

VI. Estimation and Discussion of Results

This section outlines the procedure followed in identifying the appropriate production function specification in the Nile perch and tilapia fisheries. Further the estimated results are discussed.

6.1 Model Selection

In this section we discuss the approach followed in selecting the specification of the production functions that best explain production in both the Nile perch and tilapia fisheries. The dependent variable is average catch per day (in kilogram weight), and all variables are transformed in logarithmic form.

In the first stage we estimate unrestricted Translog functions for each fishery. One problem that has been commonly raised in the estimation of Translog production functions is the multicollinearity among the input variables [see e.g Bjϕrndal, 1989; Kim, 1992, among others]. Several of the coefficients in our unrestricted Translog functions were not significant at the conventional levels. This then raised the question of the possibility of dropping segments of the functions. Following the idea expressed in (3.5) above we impose restrictions and estimate three restricted functions. For each fishery results, statistical tests which were used to determine possible restrictions on the coefficients of the Translog production function. The results from tests of the imposed restriction are reported in table 5.

For both fisheries' production structure, a restricted form of the Translog production function in which there are no cross-product terms could not be rejected by the F-test. This thus rules out the complementarity of variable components of effort in the Nile perch and tilapia fisheries. The next task was to explore the possibility of running a pooled regression over observations in both fisheries. Joint-ness in production in multi-specie fisheries implies that production functions for one type of catch may not be mutually exclusive from the production of other species [Mercer, 1982].

Harvesting of Nile perch by units using gill net size recommended for Tilapia catch was observed in the sample period for some boats to be as high as 10% of total catch. We thus pooled observations in the two fisheries, and estimated generalized catch function. A test on the poolability of the data was then conducted. The calculated F-statistic was 16.87 ($F_{[21,189]}$). This is significant at the 5% level. We concluded that production structures in the two fisheries were significantly different. The results from the restricted Translog functions are reported in table 6 and are discussed below. The reported results were corrected for heteroscedasticity using White's (1980) heteroscedasticity consistent covariance estimator.

Table 5: Results from the Tests on Restrictions on the Translog Production Function

Restrictions	Test Statistic	Critical F Value (5%)	Result
Nile perch			
$\beta_{kk} = \beta_{kl} = \beta_{lk} = 0$	2.02**	1.84 $F_{(15,62)}$	reject
$\beta_{kk} = \beta_{ll} = 0$	2.51**	2.37 $F_{(5,62)}$	reject
$\beta_{kl} = \beta_{lk} = 0$	1.80	2.20 $F_{(10,62)}$	accept
Tilapia			
$\beta_{kk} = \beta_{kl} = \beta_{lk} = 0$	2.65**	1.77 $F_{(15,117)}$	reject
$\beta_{kk} = \beta_{ll} = 0$	2.86**	2.31 $F_{(5,117)}$	reject
$\beta_{kl} = \beta_{lk} = 0$	1.56	1.93 $F_{(10,117)}$	accept

** denotes significance at the 5% level

6.2 Discussion of Results

In table 6, the tilapia and Nile perch production functions are reported[v]. Let us start by discussing the results for tilapia. The results are as follows: Boat age appears to increase Tilapia catch. Moreover, the skipper's experience level (as measured by the number of years in fishing) also increases the catch. Together these two variables appear to suggest that the background and skill level of the boat and its captain are highly important. However, the effect is decreasing as suggested by the negative squared term for boat age.

On the other hand, formal education of the crew head appears unimportant. This suggests that it is fishing experience that is crucial, rather than formal schooling. Measures of scale such as crew size and boat size have significantly positive effects on the amount caught. These inputs have diminishing effects on catch as suggested by their negative squared coefficients. On the other hand, the number of nets per boat, mesh size, and the type of gear (coded one if gill nets were used) were not found to influence the amount caught. This suggests that the ability of the skipper and the crew, and where fishing takes place, are relatively more important than the number and type of nets.

The coefficient on the type of boat (where planked boat is coded with a dummy equal to one) is positive and significant for both fisheries, indicating that improvements in boat construction technology have a positive effect on catch. Incentive programmes also play a role for productivity. Mode of proceed sharing (a dummy coded one if the crew were receiving a fixed monthly income) is negative and significant, raising the possibility for boat owners to stimulate greater productivity of their crews. This suggests that boat owners using a fixed monthly wage are foregoing a potentially profit enhancing management tool. Without information on wages, no firm conclusion can be made however. On the other hand, whether the boat owner participates in fishing appears to be of no importance. Moreover, whether the boat had a valid license, and thus complies with existing regulations, has no significant effect.

Table 6: Production Functions for Tilapia and Nile Perch Fisheries

Variable	**Tilapia Fishery** Coefficient	t-statistic	**Nile perch Fishery** Coefficient	t-statistic
ln boat age	0.491***	4.67	0.400***	4.49
ln gill-nets	0.166	1.50	-0.044	-0.30
ln crew size	0.933*	2.04	2.237***	3.98
ln years spent in fishing	0.271*	1.70	-0.058	-1.18
ln boat size	0.362*	2.13	0.360*	1.81
$(\ln \text{boat age})^2$	-0.259***	-5.53	-0.158***	-3.72
$(\ln \text{gill-nets})^2$	-0.043	-0.97	0.042	0.81
$(\ln \text{crew size})^2$	-1.113*	-1.82	-2.099**	-2.99
$(\ln \text{years spent in fishing})^2$	-0.121	-1.25	0.065	0.43
$(\ln \text{boat size})^2$	-0.045*	-1.68	-0.038*	-1.73
Education of crew head	0.020	0.27	0.066	0.88
Activity of boat owner	-0.052	-0.59	-0.004	-0.15
Boat license compliance	0.03	0.47	0.075	-1.04
Type of boat	0.393**	3.38	1.308**	2.91

Type of gear	0.307	1.48	0.076*	1.85
Mode of proceed sharing	-0.110*	-1.68	-0.009*	-1.83
Mesh size compliance	0.221	1.27	0.162*	2.03
Mode of boat propulsion			0.603***	6.37
Constant	-0.845	-1.46	0.030	0.03
Mukono	0.378***	3.91	0.124*	1.77
Masaka	-0.147*	-1.71	0.209*	1.96
Adj. R^2	0.56		0.77	
Log likelihood function	-139.11		-92.62	
Breuch-Pagan Chi-squared	37.2124		19.70	
Sum of Squared Residuals	23.05		7.21	
Number of Observations	147		93	

*, **, *** represents significance of the parameter at the 10%, 5% and 1% respectively. Mukono and Masaka are district specific documents

Different districts have significantly different levels of productivity. Whereas fishing in Mukono is significantly more productive than Mpigi, Masaka exhibits a significantly lower productivity for tilapia but greater for Nile perch. One explanation for the latter finding may be that Masaka is specialised in Nile perch fishing. Mukono is more productive in both Tilapia and Nile perch fisheries. Finally, the fit of the regression is reasonable with an adjusted R^2 of 0.56.

The results for the Nile perch fishery are remarkably similar to the tilapia fisheries findings. One additional variable reaches significance at conventional levels. Mesh size (coded one if the size of gillnets used meet the legal standard) has a positive coefficient, suggesting that small mesh sizes are unsuitable for catching the relatively large Nile perch. In general compliance may have a negative effect on catches, since the reason for using illegal sizes derives from the expected higher gains. A positive effect from bigger mesh sizes in this case shows that fishing units which for some reasons were not able to buy and use gillnets of the required standard were reaping lower harvest of Nile perch. Note also that this regression includes an additional variable, the mode of boat propulsion. Consistent with the fact that Nile perch fishery involves further transportation away from the shore, the coefficient of this variable is positive and strongly significant.

Finally the size of some coefficients increase strongly compared to those in tilapia function, in particular for type of boat and crew size. This can be explained by the much larger average size for the Nile perch compared to Tilapia. Boat and crew size appear to yield greater returns in terms of the kilograms of fish caught when applied to Nile perch fishing.

6.3 Returns to Scale

Returns to scale refer to the benefits of operating at large scale, and are calculated as the sum of the elasticities with respect to the scale variables. Using the expressions in (3) and (4), and the means of the variable factors we calculate the elasticities of catch rates with respect to each of the scale factors. These are shown in table 7. The elasticities are generally low and always below unity, indicating the low response of harvests to the scale of fishing inputs. The estimated returns to scale are 0.61 and 0.93 in the tilapia and Nile perch fisheries, respectively. This shows that harvests in both fisheries are subject to decreasing returns to scale. The plots of elasticities over the scale variables are presented in the appendix in tables A.5-A.10. The plots reveal that in the Nile perch fishery, when one person operates the boat the elasticity of catch is greater than one. It becomes unity when about two people are employed on the boat. Further, the marginal product of gill nets becomes zero at 110 nets in the tilapia fishery. The marginal product of labour becomes zero after two men in the tilapia fishery, and three men in the Nile perch fishery. In this cross-sectional analysis, decreasing returns to scale imply the productivity of inputs declines with larger fishing units.

Table 7: Estimated Catch Elasticities, and the Returns to Scale

Elasticites w. r. t	Tilapia Fishery	Nile perch Fishery
Age of the Boat	-0.1575	-0.0306
Number of Gill nets	0.0601	0.1062
Size of the crew	0.2546	0.5372
Years spent in fishing	0.0514	0.0710
Size of the boat	0.2969	0.2892
Returns to scale*	0.6116	0.9326

*Returns to scale are calculated as the sum of the elasticities with respect to the scale variables (the number of nets, size of crew and size of boat).

In agricultural production, particularly in the persepective of traditional agriculture, farms have been observed variably to operate with increasing, constant and decreasing returns to scale. The inverse relationship between farm size and productivity has been a common finding in studies that analyse input use across ranges of farm sizes [see e.g., Fafchamps, 1992]. Decreasing returns to scale in this respect have been supported by a number of arguments. These include imperfections in both output and factor markets [Bardan, 1973;], the institutional framework in family owned farms, economic dualism [Fafchamp, 1992], and more recently uncertainity in production, and output price volatility [Barrett, 1993]. Bardan (1973) notes that market imperfections may lead to

International Journal of Agriculture Innovations and Research
Volume 2, Issue 4, ISSN (Online) 2319-1473

large firms employing labour and other inputs well above what is motivated by their marginal products. Production uncertainties may induce farm managers to employ input levels higher than the optimal size.

In fisheries production, particularly in the case of the fisheries we are examining, where imperfections in both output and input market prevail [Ministry of Finance and Economic planning, 1987/88], where entry is open-access, and both price and harvest subject to uncertainity, decreasing returns to scale may be expected. One plausible argument that can be used to explain decreasing returns in both fisheries is that in open-acess fishing where fluctuations in catches are expected to be higher, larger fishing units, presumably with higher incomes, are less risk everse. The reduction in their risk averseness enables them to use more effort even where productivity is jeopardized. This is in line with the Arrow-Pratt decreasing absolute risk aversion that has been widely used in explaining behaviour under uncertainity. There are other arguments that can explain the above finding, for example some fishing units were observed to employ family members. If to a large extent smaller fishing units were under family management, and larger boats being manned by employed labour, imperfections in the labour market may be a result of decreasing returns in larger operations as has been observed in agriculture. But boat size on the other hand serves as a platform for fishing, spells out the loading capacity, and also determines the stability or safety movement across fishing grounds. Thus the choice of the size of the boat a fishing unit opts for may be influenced by factors other than what it expects to reap from fishing. The low values for the elasticities of variable inputs suggest that increases in physical fishing gears have indeed very a small positive impact on catch in Lake Victoria's Nile perch and tilapia fisheries.

VII. Summary and Implications

A restricted form of the Translog technology, in which there were no complementary terms, was found to be the appropriate functional form for both fisheries. The empirical results revealed strong similarities in both fisheries. The age of the boat, size of the boat, size of the crew were the main determinants of the amount caught during the sample period. The mode of propulsion was an important factor for the Nile perch fishery. Year spent in fishing was significant determinant of tilapia catch but not for Nile perch. The mode of sharing fish proceeds was a significant determinant of catch in both fisheries. Indicating that fishing units in which crewmembers received a fixed monthly wage were fore going a labour productivity-enhancing tool.

The elasticities of catch with respect to the scale variables were quite small, and fishing units in both fisheries were operating with decreasing returns to scale. Such a finding is in line with fisheries operating under open access, and where uncertainty pertaining to catches is an important variable in the fishing units' production decision making. This study clearly supports the policy of the Uganda Fisheries authorities to withdraw significant amounts of effort from the Lake Victoria fisheries.

Appendix

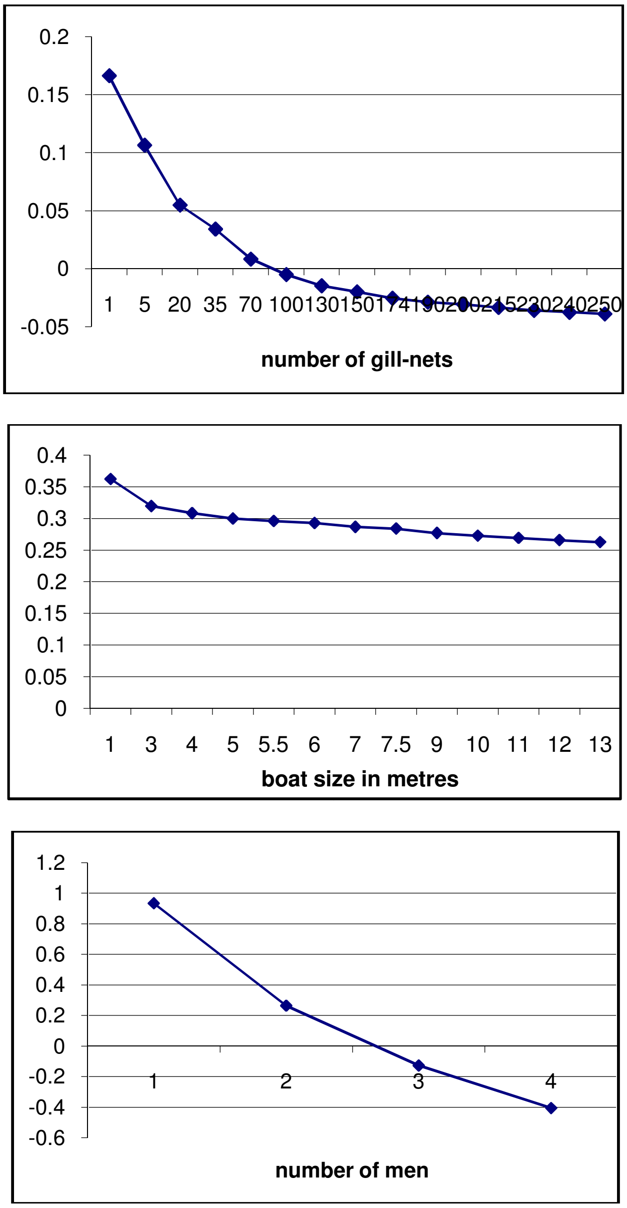
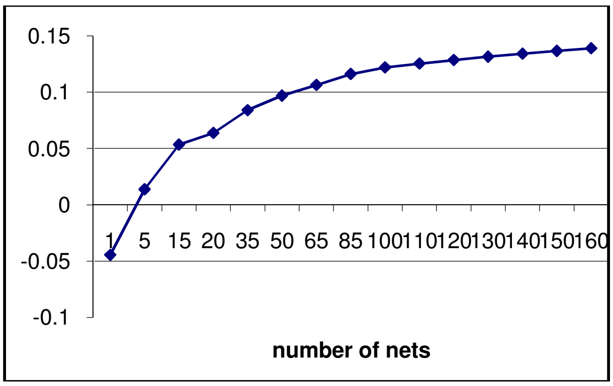
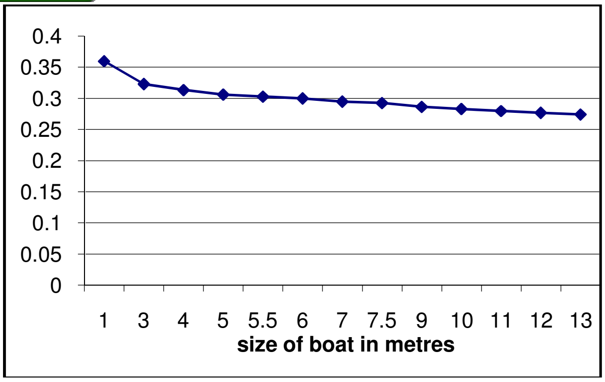


Fig.A.1. Variation of the Elasticity of Catch over Number of gill-nets, Boat size and size of Crew: Tilapia Fishery





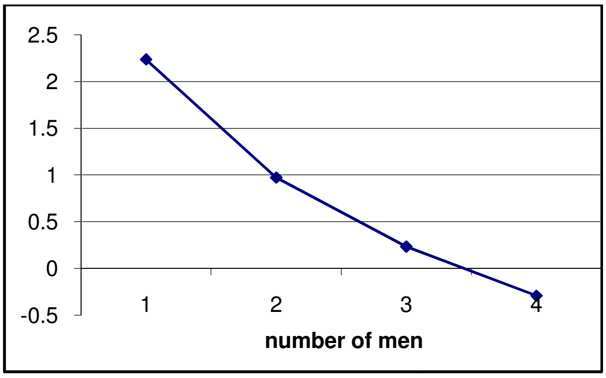


Fig.A.2. Variation of the Elasticity of Catch over Number of gill-nets, Boat size and size of Crew: Nile Perch Fishery

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[i] Ogutu-Ohwayo (FIRRI) quoted in *The New Vision*, of 24th May 2001, "fish species in Lake Victoria have declined by 30% due to over fishing and predation by other species like the Nile perch. ……, however, though the Nile perch has contributed to the endangering of other species, it is a big economic asset to the country".

[ii] In the "Fish and Crocodile law" amendment of 1992.

[iii] A test of the restrictions imposed on the Translog function is conducted by an F-test of the following form:

$$F = \frac{\frac{s_R^2 - s_u^2}{j}}{\frac{s_u^2}{N-K}} \sim F_{j,N-K}$$, where s_R^2 = the squared residuals from the restricted function, s_u^2 = the squared residuals from the un restricted Translog functions, j= the number of restricted parameters, N=number of observations, and K= number of estimated parameters in the Translog.

[iv] The names of all year operating beaches were written on pieces of papers, placed in a box, and then we selected one at a time randomly. The exercise was conducted separately for each district.

[v] Paddled boats dominated tilapia fishery, while in the Perch fishery many of the sampled boats are operated with engines.