Economic performance of fish farms: an analysis by the profit function of fish farmers in Republic of Benin

Bienvenu KAKPO[1], Ygué Patrice ADEGBOLA[2]

[1] International Center of Research and Training in Social Science, Abomey-Calavi, Benin

[2] National Agricultural Research Institute of Benin, Bénin

*Corresponding author
bienvenukakpo077@gmail.com

Received 29/12/2025
Accepted 19/02/2026

Abstract

This study investigates the economic performance of different types of fish farms in Benin, using the profit function approach to avoid the simultaneous equation bias associated with production functions. Data was collected from 649 fish farmers on input and output prices, production factors, and socio-economic characteristics. The Translog specification of the normalized profit function was estimated using Zellner's SURE method. The results suggest that the profit of fish farmers of different farm types is influenced by the price of the variable inputs they use. Fingerlings are the most limiting factor in fish production, given their indirect elasticity on production. The implications of the findings suggest that the profit of different types of fish farms can be improved by enhancing the ability of fish farmers to manage variable and fixed costs to maximise profits. Additionally, research should develop an innovative strategy to make fingerlings and feeds more available and accessible to fish farmers.

Keywords: Profit, fish farms, demand for inputs, elasticities

INTRODUCTION

The growth of a country's population is generally accompanied by an increase in demands for basic needs. This is the case of the unrestricted increase in the demand for foods rich in protein of animal origin. FAO (2020) recommends a fish intake of 20 kg per person per year for sub-Saharan African countries. This recommendation is based on the nutritional importance of fish as a source of animal protein, vitamins and minerals.

In Benin, fish and fish products provide about 50% of the total protein intake (JICA-MAEP, 2017). Therefore, the fisheries and aquaculture sub-sector plays a very important role in animal protein supply and in the economy.

In Benin, with a contribution of 3% to GDP, this subsector employs 15% of the total working population and 25% of the working population in the agricultural sector. It represents approximately 600 000 jobs and provides nearly 30% of the total amount of animal protein consumed (Fisheries Directorate, 2013). However, the trade balance in fishery products remains in deficit due to demand exceeding national production. Benin imports 2/3 of its fish needs. According to data from the Directorate of Agricultural Statistics (2021), the volume of imports amounted to 105 817 tons in 2021 against 106 187 tons in 2020. The increase in commercial fish production therefore becomes essential to guarantee of food security for populations and an improvement in the trade balance while maintaining employment in the fishing environment. The number of aquaculture farms has increased from 403 farms in 2004 to 1188 in 2010 (PROVAC, 2010). In 2017, there were an estimated 2018 active fish farmers (PROVAC-2, 2017). Fish farming has the potential to increase fish production and will therefore play an important role in fish production as natural fish stocks continue to decline (Diana, 2009). It is a sector with a great future and has considerable advantages linked to natural factors and the existence of markets for production of clarias and tilapia (Comhafat, 2014).

However, the development of fish farming remains constrained to a not very productive artisanal model. Similarly, the fish farming systems practiced are not sufficiently efficient on the biotechnical and economic levels to promote sustainable development. The economic performance of an enterprise is evaluated in relation to the short or long term achievement of economic objectives (Brealey *et al.*, 2007). It can be evaluated by the economic surplus or economic margin obtained by the difference between income and cost. For Debryune (2010), economic performance is based on the expression of the value added to sales, the rate of profitability which measures the ability to generate a sufficient result to remunerate the equity and the quantification of the net economic profitability. Therefore, the criteria for measuring farm performance must be clearly defined. Several studies have examined the use of net farm income (NFI) as a measure of performance (Haden et Johnson, 1989).

In Benin, data on the economics of aquaculture are scarce, yet these data are important for the choice of appropriate aquaculture production systems. Although a number of studies have been conducted on fish production systems, most of these studies have focused on technical efficiency with only a few addressing the critical issue of economic profitability (Imorou *et al.*, 2010; Elegbe *et al.*, 2015; Elegbe *et al.*, 2019).

A large number of studies have looked at the technical efficiency of aquaculture production systems (Irz and McKenzie, 2003; Chiang *et al.*, 2004; Dey *et al.*, 2005, Begum *et al.*, 2013; Mango *et al.*, 2015; Islam et Kusairi, 2016; Mavrommati *et al.*, 2022). Most of these studies have used the stochastic frontier production function. Also, the estimation of these functions is based on the implicit assumption that the production technology is common to all producers (Orea and Kumbhakar, 2004).

https://doi.org/10.5281/zenodo.18686260

Fish farms may use different technologies. If a global approach is used, it is unlikely that the estimated technology represents the true technology (Stevenson *et al.*, 2007); the estimate may be biased (Orea and Kumbhakar, 2004). Therefore, it is necessary to form homogeneous types of fish farms with similar circumstances for which we can make the same recommendations (Byerlee *et al.*, 1980). The analysis of the profit function by type of fish farm allows a comparative analysis of economic performance between the different types.

Adesina and Kouakou (2007) used the profit function method to test differences in technical efficiency between male and female farmers in Africa. Okoruwa *et al.* (2009) on the other hand, used the profit function method to analyze the differences in economic efficiency between small and large rice farms in central Nigeria. These authors carried out their study taking into account the gender of the farmers and the size of their farms. However, group analysis is the most typical method of comparative analysis methods (Meeusen et Van Den Broeck, 1977). It compares the performance of different groups of production units using statistical methods for differences between the groups.

Since there are large differences in income between farms, we hypothesize that it possible to identify the factors that allow some farms to make a different profit than their peers. By examining the factors that have a strong influence on the profit of fish farms, it is possible to improve their economic performance.

This study examines the determinants of profit at the level of the different types of fish farms in Benin. Indeed, a better understanding of the determinants of fish farmers' profit is important for several reasons. Farm managers should be able to use this knowledge to improve their profit. Extension workers and other companies that interact with fish farmers can use the results to help them improve the economic performance and long-term viability of their operations. Finally, fish management researchers and educators can improve their understanding of the determinants of farm profit and guide future research aimed at improving farm management.

CONTEXT OF AQUACULTURE IN BENIN

In Benin, fish farming has been introduced since the years 1958-1960. Attempts to revive intensive Tilapia farming in pens and ponds conducted from 1979 to 1987 by the Godomey Fish Farming Development Center failed (FAO, 2009). Due to a lack of technical expertise, these centers were abandoned very early and in 1968 proposals were made to relaunch the Savè center, improve the Zangnanado facilities and then create the Tanéka-koko center (Vincke and Phillippart, 1984). In Benin, the activity is essentially based on Tilapia from the Nile called *Oreochromis niloticus* and certain indigenous species, mainly catfish *Clarias gariepinus* (Directorate of fisheries; 2010). It was after, that the activity spread throughout the area of southern Benin with the implication of national and international institutions involved in the field. These institutions generally intervene through projects and programs. From 1978 to 2011, a total of 14 donor agencies have invested in the fisheries and aquaculture sub-sector. These agencies help the sector with credits, donations and loans. Currently, various structures are involved in fish farming, in particular NGOs and the Continental Aquaculture Extension Project (PROVAC).

In recent years, Benin has experienced strong population growth (3.5% between 2002 and 2013) resulting in increased food needs and strong pressure on natural resources, including fish stocks in Beninese fisheries (RGPH, 2013). Thus, the national demand for fishing products has continued to increase during the last five (05) years due to the constantly growing population while the supply is far from reaching half of the demand. The supply of fishery products has stagnated around 40 000 tons for several years. The population's needs for fishery products are currently estimated at more than 120 000 tons. In 2021, imports of fishery products are estimated at 105 817 tons (DSA/MAEP, 2023). According to the statistics of the Directorate of Agricultural Statistics in 2021, the products of artisanal marine fisheries increased from 34 443 tons in 2020 to 37 591 tons in 2021, those of inland fisheries from 44 726 tons to 36 631 tons and those of aquaculture from 3 030 tons to 2 649 tons during the same period.

The implementation of actions aimed at sustainable development of aquaculture involves profound changes both at the level of the production systems and the institutions concerned by this activity. However, these changes will be all the more «easy» if the actions they imply correspond to the behaviors and practices of the aquaculture producers. It is then a question of defining actions that are accepted by the greatest number of aquaculturists in a context of great diversity of production systems. This situation requires us to carry out a homogenization by constructing types or "ideo-types", that is to say sets of production systems which are similar or have certain characteristics in common. This is a typology and is a prerequisite: its purpose is to structure the knowledge of fish farming systems. The work of Adégbola *et al* (2022) identified four types of fish farming systems in Benin, namely extensive farms with low management capacity (type 1), farms specialized in improved extensive monoculture (type 2), polyculture farms with high management capacity (type 3) and semi-intensive polyculture farms (type 4).

MATERIAL AND METHODS

Study setting

Benin is a West African country with a total area of 114763 km^2 located between the equator and the Tropic of Cancer in the tropical zone. The country lies between 6°30" and 12°30" N and 1° and 30°40" E and is bordered to the south by the Gulf of Benin, to the east by the Federal Republic of Nigeria, to the west by the Togolese Republic, to the north by Burkina Faso and the Republic of Niger. Regarding the climate, from south to north, Benin can be divided into three sub-regions. The first region extends from the Gulf of Benin to the latitude of the commune of Savè. Average temperatures range between 26° C and

28° C. The region has two rainy seasons, from April to July and from September to November. Precipitation is bimodal and varies from 1100 mm to 1400 mm per year (BEIA, 2017). The second covers an area from latitude Savè to Bembèrèkè. The climate is humid tropical with average air temperatures of 30° C to 34° C. The rainy season extends from April to October with an average annual rainfall of 1100 mm. The third region extends from the latitude of Bembèrèkè to the Niger valley. Its climate is dry tropical and average maximum temperatures are >35° C. The region has a rainy season (May to October), which alternates with a dry season (November to early May). The area receives annual rainfall of 900 mm to 1100 mm.

Data

The data used in this paper are from a sample of 649 fish farms (Table 1) randomly selected from a list of fish farms compiled from a census funded in 2015 by the Projet d'Appui à la Diversification Agricole (PADA) (Kpenavoun *et al.*, 2015). The census had enumerated a total of 1166 fish farmers, including 80 groups or associations of fish farmers, distributed in the 12 departments of Benin. Data were collected from March 6 to April 22, 2015 using a structured questionnaire. The survey provided information on farmers' characteristics, including age, occupation, and education; farm characteristics, such as types of structure, farm area, quantities of fingerling, amount of labor, animal feed and fertilizer use, farming techniques and production; production costs; and income. These data were supplemented with mostly qualitative information in 2017. The fieldwork conducted in 2017 allowed for a better understanding of the process of setting up fish farms, a good description of the fish farming infrastructure, and an appreciation of the various supports received by fish farmers. To estimate the profit function, the price (FCFA/kg) of fingerlings, the price of fingerlings (FCFA/kg) and labor are included as variable factors of fish production. In addition, capital and area are included as fixed factors of production. The labor cost of Type 4 fish farmers is slightly higher than the labor cost of Type 1, 2 and 3 fish farmers. Type 3 fish farmers use the lowest cost labor. The observed difference in labor cost is significant. There is a significant difference between capital and area at the level of all types of fish farmers.

THEORETICAL FRAMEWORK

The theory of the farm profit function and the relationship between the profit function and the production function were developed by McFadden (1966). By definition, the profit function expresses the maximized profit for a farm in a competitive situation in terms of product prices, variable and fixed production factors. The profit function is non-negative, convex, increasing in production prices, decreasing in the prices of fixed factors. It is homogeneous of degree 1 in the prices of inputs and outputs. The assumptions used to formulate the profit function are:

- Farms maximize profit;
- Farms are influenced by market prices of fish and variable inputs; and
- The production function curve is concave with respect to variable inputs.

The derivative of the profit function with respect to a price of a factor of production can be used to determine the demand for that factor. Similarly, the production function can also be derived from the profit function.

The quest for economic performance is a crucial aspect in fish farms, as production objectives can vary from one farm to another and change over time for the same farm. To survive in a complex and multi-stakeholder influenced environment, a farm must perform well. Performance can be measured by economic profit maximization, profitability, etc. A farm that makes significant profits is considered to be efficient in the economic framework. In the production theory framework, profits are determined by the difference between the revenues obtained from sales and the costs associated with production. Fish farmers are assumed to act rationally and their profit function can be expressed as follows:

$$\pi = PY - wx \qquad (1)$$

Where π represents profit, *P* represents unit price of fish, *w* represents cost of variable factors. *Y* represents the quantity of fish produced, it is a function of the vectors *x* and z of variable and fixed factor quantities, respectively. The production function is given by the following equation:

$$Y = F(x; z) \qquad (2)$$

Table 1: Descriptive statistics of the variables included in the fish farming profit model

Characteristics	Overall (N=649)	Type I (N= 143)	Type II (N=123)	Type III (N=301)	Type IV (N=82)	Statistics
Cost of fingerlings (FCFA/ kg)	7 551	7 450	7 843	7 424	7 757	0.85 [1]
Cost of feed (FCFA/ kg)	170	141	164	147	314	1.04 [1]
Cost of labor (FCFA/ Man-day)	1276	1280	1293	1257	1311	1.15 [1] ***
Capital (FCFA)	188 317	84 701	155 983	114 318	689 143	1.58 [1] *
Area (m^2)	834	486	493	638	2671	1.38 [2] *
PDA4(%)	0.07	0.13	0.04	0.08	0.01	12.4 [2] *
PDA5(%)	0.16	0.27	0.02	0.19	0.04	40.4 [2] *
PDA6 (%)	0.10	0.03	0.26	0.06	0.09	47.1 [2] *
PDA7 (%)	0.63	0.51	0.61	0.63	0.84	23.7 [2] *

*[1] anova [2] = z-khi2 * significant at 10%, ** significant at 5%, *** significant at 1%.*

The profit function can be solved for the maximization situation.

$$max\ PY - wx, \quad s.c. Y(x;z) \leq 0 \quad (3)$$

The solution to this problem is a set of functions of input demand and fish production given by:

$$X = x(P, w, z)$$
$$Y = q(P, w, z) \quad (4\ and\ 5)$$

Substituting equations (4) and (5) into the general profit function (1) gives the following maximum profit level:

$$\pi = P'q(P, w, z) - w'x(P, w, z) \quad (6)$$

The production factor demand function and the supply function can be obtained by differentiating the profit function in (6) with respect to the unit price of each variable input *w* and that of fish P.

$$X_i^* = \frac{\partial \pi}{\partial w_i} = X^*(P, w, z)$$
$$Y^* = \frac{\partial \pi}{\partial P} = X^*(P, w, z) \quad (7\ and\ 8)$$

Model specification

The modified translog form was specified to estimate the parameters of the profit function in Eq. 6 and determine the price elasticities for each type of fish farm. The modified translog form is used because it is a flexible and self-dual functional form. A generalization of the normalized translog profit function for a single product is given by Diewert (1974) and Christensen *et al.* (1973) as follows:

$$\begin{aligned}\ln \pi^* = \alpha_0 &+ \sum_{i=1}^{n} \alpha_i lnP_i^* + \frac{1}{2}\sum_{i=1}^{n}\sum_{h=1}^{n} \gamma_{ih} lnP_i^* lnP_h^* \\ &+ \sum_{i=1}^{n}\sum_{k=1}^{m} \delta_{ik} lnP_i^* lnZ_k \\ &+ \sum_{k=1}^{m} \beta_k lnZ_k \\ &+ \frac{1}{2}\sum_{k=1}^{m}\sum_{j=1}^{m} \emptyset_{kj} lnZ_k lnZ_j \\ &+ \varepsilon_i \end{aligned} \quad (9)$$

With $\gamma_{ih}=\gamma_{hi}$, $\delta_{ik}= \delta_{ki}$ and $\emptyset_{ik}= \emptyset_{ki}$ for *j, i* and *k* and the function is homogeneous of degree one in the prices of all variable inputs and outputs. The definition of the variables and the notations used in the profit function are as follows: π* is the restricted profit (total revenue minus the total cost of variable inputs) normalized by P_q, Z_k, Z_k is the price of output, P_i* is the price of the variable input x_i, normalized by , is the k th fixed factors; *i* = h = 1,….n, *k* = *j* = 1,… *m*; *ln* is the natural logarithm; and α_0,α_i,γ_{ih},δ_{ik},β_k and, are the parameters to be estimated and is a random error.

The partial derivatives of the constrained profit function with respect to the logs of the input price give the share equations as follows:

$$S_i = \frac{P_i^* X_i}{\pi^*} = \frac{\partial ln\pi^*}{\partial lnP_i^*} = \alpha_i + \sum_{h=1}^{n} \gamma_{ih} lnP_h^* + \sum_{k=1}^{m} \delta_{ik} lnZ_k$$
$$S_q = \frac{P_q^* X_q}{\pi^*} = 1 + \frac{\partial ln\pi^*}{\partial lnP_q^*} = 1 - (\alpha_i + \sum_{h=1}^{n} \gamma_{ih} lnP_h^* + \sum_{k=1}^{m} \delta_{ik} lnZ_k \quad (10\ and\ 11)$$

Where S_i is the share of i[th] input and S_q is the share of production (*q*). S_q equals the ratio of the total value of output to the restricted profit. Since the shares of output and input come from a singular system of equations, their sum is equal to 1 and one of the share equations can be ignored. Normalized input prices and fixed factor quantities are considered as the exogenous variables under the price-taking behavior. Using lemme of Hotelling Lemma, the translog profit function can be used to obtain the following equations:

Derivative function of factor demand:

$$X_i = -\frac{\pi^*}{P_i}\left[\alpha_i + \sum_{h=1}^{n} \gamma_{ih} lnP_h^* + \sum_{k=1}^{m} \delta_{ik} lnZ_k\right] \quad (12)$$

Derivative function of fish supply:

$$X_q = \frac{\pi^*}{P_q}\left[1 - \left(\alpha_i + \sum_{h=1}^{n} \gamma_{ih} lnP_h^* + \sum_{k=1}^{m} \delta_{ik} lnZ_k\right)\right] \quad (13)$$

Using share equations and profit function estimates, the elasticity of output supply and input demand will be estimated simultaneously.

Production supply elasticities

We evaluate the elasticities of output supply with respect to output price, variable input price, and fixed input quantities at S_i given means and levels of exogenous variables. It can also be expressed as linear functions of restricted profit function parameters. The fish supply equation (*q*) can be written as follows using duality theory:

$$q = \pi + \sum_{i=1}^{n} P_i X_i \quad (14)$$

By inserting the equation (12) in the equation (14) we obtain:

$$q = \pi\left(1 - \sum_{i=1}^{n} \frac{\partial ln\pi}{\partial lnP_i}\right)$$
$$lnq = ln\,\pi + ln\left(1 - \sum_{i=1}^{n} \frac{\partial ln\pi}{\partial lnP_i}\right) \quad (15\ and\ 16)$$

The elasticity of production with respect to the price of *i*[th] variable input is given by the equation:

$$\epsilon_{qi} = -S_i - \sum_{h=1}^{n} \gamma_{hi} / \left(1 + \sum_{h=1}^{n} S_h^*\right) \quad (17)$$

Where *i*=*h*=1….*n* .

The price elasticity of production ϵ_{qq} and the elasticity of production ϵ_{qk} with respect to fixed inputs Z_k are calculated using the following equations:

$$\epsilon_{qq} = \sum_{i=1}^{n} S_i^* + \sum_{i=1}^{n}\sum_{h=1}^{n} \gamma_{ih} / \left(1 + \sum_{h=1}^{n} S_h^*\right) \quad (18\ and\ 19)$$
$$\epsilon_{qk} = \sum_{i=1}^{n} \delta_{ik} lnP_i + \beta_k - \sum_{i=1}^{n} \delta_{ik} / \left(1 + \sum_{h=1}^{n} S_h^*\right)$$

Estimation Model

A generalization of the normalized restricted translog profit function for a single output is given by Diewert (1974), Christensen *et al.* (1973).

- ***Overall model***

$$
\begin{aligned}
ln\pi^* = \alpha_0 &+ \sum_{i=1}^{n} \alpha_i lnP_i^* \\
&+ \frac{1}{2}\sum_{i=1}^{n}\sum_{h=1}^{n} \gamma_{ih}\, lnP_i^* lnP_h^* \\
&+ \sum_{i=1}^{n}\sum_{k=1}^{m} \delta_{ik} lnP_i^* lnZ_k + \sum_{k=1}^{m} \beta_k lnZ_k + \frac{1}{2}\sum_{k=1}^{m}\sum_{j=1}^{m} \varphi lnZ_k lnZ_j + \sum_{l=1}^{p} \phi_l D_l \\
&+ \sum_{o=1}^{s} \omega_o T_o + \phi_{41}R_1 + \phi_{43}R_2 + \phi_{71}R_3 + \phi_{72}R_4 \\
&+ \varepsilon
\end{aligned}
\tag{20}
$$

- ***Model for each of the fish farm types 1, 2, 3 and 4***

$$
\begin{aligned}
ln\pi^* = \alpha_0 &+ \sum_{i=1}^{n} \alpha_i lnP_i^* \\
&+ \frac{1}{2}\sum_{i=1}^{n}\sum_{h=1}^{n} \gamma_{ih}\, lnP_i^* lnP_h^* \\
&+ \sum_{i=1}^{n}\sum_{k=1}^{m} \delta_{ik} lnP_i^* lnZ_k + \sum_{k=1}^{m} \beta_k lnZ_k + \frac{1}{2}\sum_{k=1}^{m}\sum_{j=1}^{m} \varphi_{kj} lnZ_k lnZ_j \\
&+ \sum_{l=1}^{p} \phi_l D_l \\
&+ \varepsilon
\end{aligned}
\tag{21}
$$

Where π^* is the restricted profit from fish production: total revenue minus the total cost of fingerlings, labor and feed normalized by the price of fish; P_1^* is the fingerling price normalized by the unit fish price (FCFA/kg), $P_2^*$is the feed price normalized by the fish price (FCFA/kg), P_3^* is the labor cost normalized by the fish price (FCFA/kg). The fixed inputs included in the specification of the profit function are Z_1, the cost of capital (FCFA) and Z_2, the total area (Ha). Parameters D_1, D_2, D_3, and D_4 represent PDA 4, 5, 6 and 7, respectively.

α_0 = constant, R_1 = PDA4-TYPE1 interaction, R_2 = PDA4-TYPE3 interaction, R_3 = PDA7-TYPE1 interaction, R_4 = PDA7-TYPE2 interaction.

The partial derivatives of the normalized restricted translog profit function with respect to the log of the price of inputs are the negative share equations for fingerling and feed as follows:

$$
-X = \alpha_i + \sum_{h=i}^{n} \gamma_{ih} lnP_h^* + \sum_{k=1}^{m} \delta_{ik} lnZ_k + v, i = 1,2 \tag{22}
$$

Where Xi denotes the variable input quantities and v is the error term. For maximum efficiency, the system of input demand equations and the profit function are estimated simultaneously.

Under the profit maximization hypothesis, the parameters of equation (20) must satisfy the symmetry condition. This approach allows us to verify the profit maximization hypothesis.

An error term of the profit function and the share equations is likely to be correlated simultaneously due to the large number of common explanatory variables. Thus, ordinary least squares (OLS) is not applicable for estimating the equation in the system. The OLS method is also not attractive because we have to impose cross-equation restrictions. This problem can be overcome by using Zellner's estimation procedure for seemingly unrelated regression (SUR) (Sidhu *et al.*, 1981; Adésina *et al.*, 1997). Furthermore, the normalized profit function must satisfy the theoretical requirements of homogeneity, of symmetry of monotonicity and convexity. The constraint of homogeneity is guaranteed in the whole system of equations by the normalization by the market price of fish. The symmetry is imposed by restrictions for the equations of the normalized profit and variable factors demand functions (Rahman, 2005): $\gamma_{ih}=\gamma_{hi}$, $\delta_{ik}= \delta_{ki}$ and $Ø_{ik}=Ø_{ki}$.

Monotonicity and convexity

In this study, we checked monotonicity and convexity after estimation. The monotonicity of the translog form of the profit function means that the estimated supply share is positive and the input demand share is negative (Farooq *et al.*, 2001) as in the present case. Convexity is a necessary condition for duality and the necessary condition for convexity is that all eigenvalues of the Hessian matrix of normalized prices are semi-definite and positive. As Barrett (2002) points out, if the conditions for monotonicity and convexity are not satisfied, the second-order conditions for optimization and duality theory fail.

A first approach is simply to impose regularity conditions to obtain accurate parameter estimates in econometric models (Serletis and Feng, 2015). However, this does not always guarantee the best solution for a given problem and other methods may be needed to solve more complex problems. Indeed, Lau (1978) and Diewert and Wales (1987) argue that imposing convexity destroys the flexibility of the Translog function and reduces it to the Cobb-Douglas form.

A second approach consists in testing the conditions after estimation. In this case, if the convexity hypothesis of the function is not satisfied, Baum and Linz (2009) recommend the choice of another functional form to conform to economic theory. But some researchers believe that a low percentage of violation of the convexity conditions (at less than 5%) is acceptable and attribute this to the stochastic nature of the estimates. When the violation percentage is high, it is recommended to modify the model to obtain an acceptable violation percentage. For example, when estimating a Translog variable cost function of U.S. airports, Kutlu and McCarthy (2016) include an additional term to reduce the violation percentages for the monotonicity and concavity conditions. In the present study, we inserted the PDAs into the model to reduce the violation rate to less than 5%.

RESULTS AND DISCUSSION

Profit function and input demand

All four (04) models are globally significant at 5%, which means that, from a statistical point of view, the coefficients of the explanatory variables are not simultaneously zero.

The estimates of the parameters of the translog profit function for each type of fish farm are presented in Table 2. Of the 31 variables introduced into the global model, 13 are significant. Of the 24 variables entered into the Type 1, 2, 3 and 4 models, it was found that the Type 2 and Type 3 models had more significant variables (16 and 10) than the Type 1 (6 variables) and Type 4 (8 variables) models (Table 2). The signs of the regression coefficients are generally consistent with the a priori expectations with the exception of the sign of labor of the Type 2 model. The coefficients of the variable inputs: fingerlings, feed and labor are statistically significant and negative for the overall model. This implies that for all inputs in the overall model, the profit of the fish farmers is negatively correlated by fingerlings, feed and labor. This means that when the costs associated with these inputs increase, the profit of the fish farmers decreases.

For the type 1 model, the profit is negatively correlated by fingerling and feed. This implies that at the level of fish farmers with an extensive production system with low management capacity, an increase in the price of inputs, such as fingerlings and feed leads to a reduction in profit. In the Type 2 model, the profit of fish farmers is negatively correlated with the price of feed. An increase in the price of feed therefore leads to a decrease in profit for fish farmers with a specialized improved extensive production system. The price of feed and labor have a negative and significant effect on the profit of type 3 fish farmers. The coefficients of the fingerling variable input are statistically significant and negative for Types 3 and 4. The fish farmers of these two types are owners of diversified farms with a high management capacity on the

Table 2: Estimation result of the Profit Translog function and the share of fish farmers' factors

Profit Function Variables	**Para-meters**	**Zellner's Seemingly Unrelated Regression Estimation (SURE Method)**				
		Model: Overall	**Model: Type I**	**Model: Type II**	**Model: Type III**	**Model: Type IV**
Fingerling	*α1*	-0.73 (0.11)***	-0.68 (0.24)***	-0.02 (0.22)	-1.03 (0.22)***	-0.23 (0.07)***
Feed	*α2*	-0.28 (0.18)*	-0.54 (0.39)*	-1.47 (0.48)***	-0.33 (0.32)	-0.38 (0.25)*
Labor -_	*α3*	-0.14 (0.10)*	-0.14 (0.21)	0.38 (0.26)*	-0.24 (0.15)*	-0.05 (0.26)
Capital	*β1*	2.01 (0.22)***	2.23 (0.51)***	2.49 (0.57)***	2.37 (0.40)***	1.62 (0.31)***
Area	*β2*	1.14 (0.1)***	1.14 (0.21)***	0.61 (0.26)**	1.79 (0.54)***	1.96 (1.38)*
Squared fingerling	*γ11*	-0.02 (0.01)	0.02 (0.03)	-0.05 (0.02)*	0.002 (0.02)	-0.004 (0.005)
Fingerling -Feed	*γ12*	-0.01 (0.01)*	-0.03 (0.02)	-0.05 (0.01)***	-0.006 (0.02)	-0.004 (0.003)
Fingerling -Labor	*γ13*	0.02 (0.01)	-0.03 (0.03)	0.10 (0.03)***	0.004 (0.02)	0.008 (0.005)*
Squared Feed	*γ22*	0.02 (0.01)	0.003 (0.03)	0.10 (0.03)***	0.004 (0.02)	0.008 (0.005)
Feed-Labor	*γ23*	-0.002 (0.01)	0.02 (0.03)	-0.05 (0.02)*	0.002 (0.02)	-0.004 (0.005)*
Squared labor	*γ33*	-0.01 (0.01)	-0.03 (0.02)	-0.05 (0.01)***	-0.006 (0.02)	0.004 (0.003)
Squared Capital	*φ11*	0.03 (0.07)***	0.04 (0.01)***	0.01 (0.01)	0.03 (0.01)***	0.009 (0.01)
Capital-area	*φ12*	-0.01 (0.02)	-0.07 (0.05)	-0.17 (0.06)***	-0.01 (0.03)***	0.02 (0.06)
Squared area	*φ22*	-0.15 (0.03)***	-0.1 (0.07)	0.02 (0.08)	-0.23 (0.08)***	-0.30 (0.17)*
Fingerling-Capital	*δ11*	0.09 (0.02)***	0.02 (0.05)	0.07 (0.05)	0.17 (0.04)***	-0.01 (0.05)
Fingerling -area	*δ12*	-0.05 (0.04)	0.05 (0.09)	0.18 (0.09)**	-0.15 (0.07)**	0.03 (0.08)
Feed-Capital	*δ21*	-0.01 (0.09)	0.03 (0.02)	0.05 (0.03)*	0.007 (0.01)	0.02 (0.01)*
Feed -area	*δ22*	0.01 (0.02)	-0.03 (0.05)	0.05 (0.05)	-0.03 (0.04)	0.008 (0.03)
Labor-Capital	*δ31*	-0.29 (0.10)***	-0.15 (0.2)	-0.49 (0.29)*	-0.24 (0.15)*	-0.34 (0.24)
Labor-Area	*δ32*	0.11 (0.19)	-0.08 (0.36)	0.55 (0.55)	-0.2 (0.28)	0.20 (0.4)
PDA4	*ϕ1*	0.53 (0.44)	0.17 (0.37)	0.13 (0.53)	0.59 (0.47)	0.29 (0.53)
PDA5	*ϕ2*	-0.36 (0.26)	-0.45 (0.37)	-1.12 (0.61)*	0.11 (0.45)	-0.26 (0.35)
PDA6	*ϕ3*	-0.09 (0.27)	0.05 (0.54)	-0.22 (0.42)	0.33 (0.48)	-0.06 (0.22)
PDA7	*ϕ4*	-0.08 (0.27)	-0.59 (0.35)*	0.82 (0.40)*	0.29 (0.44)	
TYPE II	*ω1*	0.06 (0.23)				
TYPE III	*ω2*	-0.26 (0.16)*				
TYPE IV	*ω3*	0.10 (0.22)				
PDA4-TYPEI	*ϕ41*	-0.14 (0.46)				
PDA4-TYPEIII	*ϕ43*	-0.43 (0.44)				
PDA7-TYPEI	*ϕ71*	-0.52 (0.20)**				
PDA7-TYPEII	*ϕ72*	-0.64 (0.23)***				
Constant	*α0*	2.43 (0.51)***	3.49 (0.95)***	3.48 (1.04)***	0.38 (2.22)	-0.12 (5.95)
		F[25.6] =83.7***	F[18.1] =39.5***	F[18.1]=24.0***	F[18.3]=25.2***	F[18.8] =35.0*
Fingerling demand						
Fingerling	*α1¹*	-0.02 (0.01)	0.19 (0.07)*	-0.05 (0.02)*	0.002 (0.02)	-0.004 (0.005)
Feed	*α1²*	-0.01 (0.01)*	-0.08 (0.02)*	-0.05 (0.01)***	-0.006 (0.02)	-0.004 (0.003)
Labor -_	*α1³*	-0.02 (0.01)***	-0.03 (0.18)	0.01 (0.01)	0.02 (0.01)*	0.01 (0.002)***
Capital	*β1¹*	0.02 (0.01)	0.03 (0.01)	0.1 (0.03)***	0.004 (0.02)	0.008 (0.005)*
Area	*β1²*	0.03 (0.02)*	0.17 (0.02)*	-0.03 (0.03)	0.06 (0.04)*	-0.004 (0.008)*
Feed demand						
Fingerling	*α2¹*	-0.01 (0.01)*	-0.08 (0.02)*	-0.05 (0.01)***	-0.006 (0.02)	-0.004 (0.003)*
Feed	*α2²*	-0.02 (0.01)	-0.17 (0.05)*	0.14 (0.09)***	0.004 (0.02)	-0.008 (0.005)*
Labor -_	*α2³*	-0.05 (0.04)	0.04 (0.35)	0.04 (0.05)	-0.08 (0.09)	0.01 (0.009)
Capital	*β2¹*	-0.002 (0.01)**	-0.42 (0.02)***	-0.05 (0.02)*	0.04 (0.02)	-0.004 (0.005)
Area	*β2²*	0.02 (0.08)	0.19 (0.05)*	0.01 (0.11)	0.04 (0.16)	0.005 (0.03)**

** Significant at 10%, ** significant at 5%, *** significant at 1%. Values in parenthesis is the t-statistic (t-ratio)* one hand and semi-intensive production system on the other. This therefore implies that an increase in fingerling cost is likely to affect the economic performance of farms. As a result, revenue will fall and so will profits.

These results are consistent with the work of several authors in the aquaculture field. For example, a study by Oluwasola and Ige (2015) examined the factors affecting the profitability of aquaculture in Nigeria and found that feed and labor costs were the two most important factors affecting the profitability of fish farmers. Similarly, a study by Hyuha *et al.* (2011) on aquaculture in Central Uganda also found a negative correlation between feed costs and profitability of fish farmers.

Regarding fingerlings, a study by Khan *et al.* (2021) on aquaculture in Bangladesh showed that costs associated with fingerling acquisition can have a significant impact on the profitability of fish farmers. In conclusion, the results of this study are consistent with previous research in the field of aquaculture and show that costs associated with inputs such as fingerlings, feed and labor can have a significant impact on the profitability of fish farmers.

Capital and area have a positive and significant effect on all fish farmers. This can be taken as an indication that additional investments in fixed factors such as infrastructure, fish farming equipment and area can improve technical efficiency and fish yield. This finding is in line with the results of many previous studies, such as Takibur *et al.* (2020) who showed that fixed factors such as capital and area have a significant impact on the productivity and profitability of fish farming.

PDA5 has a negative and significant effect on Type 2 fish farmers. This implies that a move of Type 2 fish farmers to PDA5 results in a reduction in their profit. This could be due to the fact that the main market for these fish farmers is Nigeria while a move into PDA5 takes them away from their main market. Onoja *et al.* (2013) showed that distance from the market can negatively affect fish farmers' profits due to additional costs associated with transportation and logistics. On the other hand, Jayanthi *et al.* (2019) explored how regional differences can influence fish farming activities. They showed that regional policies such as land use policies can impact the location of fish farming activities and thus the profits of fish farmers. As a result, these studies suggest that the choice of location for a fish farming activity can have a significant impact on fish farmers profits.

The demand for fingerling in relation to feed cost is negative for all models. This means that when the cost of feed is high, the demand for fingerling is reduced. The demand for fingerling is much lower for Type 2 farmers. The demand for feed is negatively and significantly affected by the price of fingerling, the price of feed at the model level: Type 1 and Type 4. Fingerling price has a negative and significant effect on feed demand at the model level: overall and type 2. The cost of capital has a negative and significant effect on the demand of the overall model, type 1 and type 2.

These results are consistent with the findings of some previous studies on the effect of input costs on the demand for aquaculture products. For example, a study conducted by Oluwasola and Ige (2015) in Nigeria showed that increased production costs, including feed and labor costs, led to a decrease in demand for fingerlings. The high cost of farmed fish feed led to a reduction in demand for fingerlings and ultimately limited the growth of the fish farming industry in the region. The results of these studies support the observations on the negative effect of input costs on the demand for aquaculture products in the models presented.

Indirect elasticities of factors of production

To determine the effects of individual production factors on fish production, the elasticities of these production factors were estimated. Positive input coefficients can be interpreted as implying an increase in output as the intensity of the input used increases (Kurbis, 2000). The results of the indirect elasticities of production with respect to the variable factors at the level of the overall model and of the different types are presented in Table 3. All the elasticities have a probability of significance of 1%. Estimates show that the elasticity of fish production at the level of the global model is highest at the fingerling level (0.19), followed by feed (0.15), labor (0.01). A 10% increase in fingerling for production will increase fish production by 1.9%. Similarly, a 10% increase in feed and labor will lead to 1.5% and 0.1% of fish production respectively. At the level of the different types of farms, labor has the same elasticity. But at the Type 4 model level, a 10% increase in labor will lead to a 0.2% increase in production.

The increase in fingerlings for production is the highest effect at the Type 2 level. Indeed, a 10% increase in fingerlings on Type 4 farms will increase production by 6.1% whereas on the other types we have: 2.1% for type 1, 4.9% for type 2 and 1.4% for type 3. This elastic response suggests that technologies which improve these factors of production are likely to have significant positive effects son fish production.

Type 1 and type 2 have the lowest indirect feed elasticities 0.08 and 0.03. But at the level of type 3 and du type 4, a 10% increase in feed increases production by 1.3% and 1.1%. The highly inelastic feed and labor response may reflect the presence of other technological and infrastructural constraints that limit fish productivity. These results show that fingerling, feed and labor are the main production factors influencing fish production. Fingerling is the most sensitive production factor to fish production, followed by feed and labor. These results are in line with the findings of other authors who

Table 3: Indirect elasticities of fish farmers' production factors

Production factors	Type 1	Type 2	Type 3	Type 4	Overall
Fingerling	0.21	0.49	0.14	0.61	0.19
Feed	0.08	0.03	0.13	0.11	0.15
Labor	0.01	0.01	0.01	0.02	0.01

have examined the determinants of fish production. For example, Munguti *et al.* (2021) reported that the proper use of high-quality fingerlings and feed was critical to successful fish production.

CONCLUSION

The overall estimates suggest that variations in market prices of variable inputs and output significantly affect fish farmers' profits. Meanwhile, fish farmers maximize profits based on the prices of inputs (fingerling, feed and labor), the price of fish and fixed production factors (capital and area).

The study concluded that Type 3 fish farmers dominate fish production in Benin. The profit of fish farmers of the different farm types is influenced by the price of the variable inputs they use. However, the profit of fish farmers of types 1, 3 and 4 is more affected by the market price of fingerling, while the price of feed is the most important factor for the profit of type 2. Labor is the most important factor for the profit of type 3 fish farmers. We also found that the demand for fingerlings depends on several variables, such as the cost of feed, the price of fingerlings and the cost of capital. In addition, the results of this study show the importance of proper utilization of production factors for efficient and profitable fish production. It is therefore important for fish farmers to consider these factors to maximize their yield and profitability. Therefore, further research on the subject is recommended to better understand the determinants of fingerling and feed demand in this sector. The information provided by this study can be useful for policy makers and fish producers to guide policies and strategies for fish production development.

The profitability of the different types can be improved by strengthening the capacity of fish farmers to manage variable and fixed costs. While high costs of fingerling and feed can erode competitiveness and drive some farmers out of business, policies should be designed to allow farmers to have inputs readily available on the local market at low prices.

Finally, it would be wise to consider these factors when making decisions for the development of the fish farming sector. In addition, it would also be interesting to conduct further studies to assess the impacts of other factors on this evolving sector.

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