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Research article

Determinants of Technical Efficiency in Nigerian Catfish Aquaculture: Stochastic Frontier Evidence and Policy Implications

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ABSTRACT

Aquaculture has become an essential sector in Nigeria's agriculture, significantly contributing to food security, rural employment, and economic diversification. Despite the sector's rapid growth, Nigeria's aquaculture industry operates below its potential, with technical efficiency levels far from optimal. This study assesses the determinants of technical efficiency among catfish farmers in Nigeria, using secondary data from a survey of 604 farmers. The result indicate that, despite significant growth in Nigeria's aquaculture sector, technical efficiency remains suboptimal, with farmers operating at about 67% of their potential output. Using a stochastic frontier production function, we identify key factors affecting productivity and efficiency, including fish stock, household size, culture type, management system, and membership in farmers' associations. The study highlights the need for targeted policies to enhance resource utilization, promote diversified farming practices, and support farmer associations to optimize technical efficiency in Nigeria's catfish farming sector. These findings have important implications for improving productivity and ensuring food security in the country.

Key words:
aquaculture, technical efficiency, catfish farming, stochastic frontier, Nigeria

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INTRODUCTION

Aquaculture has emerged as a vital component of Nigeria's agricultural sector, contributing significantly to food security, employment generation, and economic diversification (Adewumi and Olaleye, 2011; FAO, 2022). As the most populous country in Africa with over 200 million inhabitants and a projected population growth rate of 2.5% annually, Nigeria faces substantial challenges in meeting the protein requirements of its rapidly expanding population (World Bank, 2023). Fish accounts for approximately 40% of animal protein intake in the average Nigerian household, yet domestic production meets only about 30% of the national demand, resulting in significant annual expenditure on fish imports exceeding US$1.2 billion (Olaifa et al., 2022; CBN, 2022).

Aquaculture presents a promising avenue to address these nutritional needs while creating livelihood opportunities in both rural and peri-urban communities (Ogunmefun and Achike, 2017). The Nigerian aquaculture sector has expanded substantially over the past decade, with production increasing from 200,000 tonnes in 2010 to approximately 415,000 tonnes in 2022 (Odioko and Becer, 2022). This growth reflects increasing private sector investments, supportive government policies, and rising consumer demand for fish products (Ogunji and Wuertz, 2023).

Despite this progress, Nigeria's aquaculture sector operates significantly below its potential capacity. The country possesses abundant water resources, suitable climatic conditions, and a growing domestic market, yet productivity levels remain suboptimal compared to global benchmarks (Ogunji and Wuertz, 2023). Technical efficiency, which is

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defined as the ability to achieve maximum output from a given set of inputs (Adewale et al., 2025), variesconsiderably among Nigerian aquaculture farmers, with estimates suggesting average efficiency levels ranging from 45% to 68% across different production systems and geographical regions (Ogunmefun and Achike, 2018; Oluwatayo and Adedeji, 2019).

This efficiency gap represents a substantial opportunity for increasing domestic fish production without necessarily expanding the resource base. Understanding the determinants of technical efficiency is therefore essential for developing targeted interventions to enhance the performance and sustainability of the sector (Adewale et al., 2024). Previous studies have identified various factors affecting aquaculture productivity in developing countries, including farm characteristics, socioeconomic variables, institutional support mechanisms, and the adoption of new technologies (Okoror et al., 2017; Kumar et al., 2018). Farm-specific factors such as pond size, stocking density, feeding practices, and water quality management have been shown to significantly influence production outcomes (Le et al., 2022). Socioeconomic characteristics, including farmer age, education level, experience, and access to credit, frequently emerge as critical determinants of management efficiency (Emokaro and Ekunwe, 2009). Institutional factors such as extension services, membership in producer organizations, and market access further shape the efficiency of aquaculture operations (Akinwumi et al., 2017; Miljatović and Vukoje, 2024).

The Nigerian aquaculture landscape is characterized by considerable heterogeneity, with production systems ranging from traditional earthen ponds to semi-intensive concrete tanks and emerging recirculating aquaculture systems (RAS) (Dauda et al., 2019). This diversity, coupled with regional variations in agro-ecological conditions, input availability, and market structures, creates complex efficiency dynamics that warrant systematic investigation (Johnson, 2023). While catfish (*Clarias gariepinus*) dominates production volumes accounting for approximately 80% of total aquaculture output, tilapia and other species are gaining prominence, introducing additional variables into efficiency considerations (Oluleye et al., 2024). As global fisheries approach maximum sustainable yields and climate change creates new uncertainties for capture fisheries, optimizing aquaculture efficiency represents a critical pathway for meeting Nigeria's growing demand for animal protein while supporting broader socioeconomic development objectives (FAO, 2022).

Existing studies on technical efficiency in Nigerian aquaculture are often region-specific, limited to particular production systems, or based on small primary samples, which restricts their generalizability across the diverse Nigerian aquaculture landscape (Okoror et al., 2017; Ogunmefun and Achike, 2018; Baruwa and Omodara, 2019). Additionally, the rapidly evolving nature of the Nigerian aquaculture sector, characterized by changing production technologies, market dynamics, and policy environments, necessitates contemporary analysis to inform current decision-making (Ogunmefun and Achike, 2017). Recent developments, such as increased feed costs, climate variability, and pandemic-related disruptions, have introduced additional challenges to efficiency optimization that remain inadequately documented in the literature.

This paper aims to address these knowledge gaps by conducting a comprehensive assessment of the determinants of the technical efficiency among aquaculture farmers across major production zones in Nigeria. Specifically, the research seeks to estimate the current levels of technical efficiency of aquaculture farmers, identify key determinants of technical efficiency, including farm-specific, socioeconomic, institutional, and environmental factors, and develop policy recommendations to enhance technical efficiency in the Nigerian aquaculture sector. Using a large, nationally distributed secondary dataset of 604 catfish farmers, this study provides updated sector-wide estimates of technical efficiency and jointly examines farm-specific, socioeconomic, and institutional determinants of inefficiency. The study also demonstrates how rigorously curated secondary data can be used to generate actionable, nationally relevant insights by linking these empirical results to concrete policy recommendations, thereby offering a transferable framework for efficiency analysis in other data-constrained settings. Understanding and addressing the factors influencing technical efficiency in Nigerian aquaculture carries significant implications for national food security, rural livelihoods, import substitution, and sustainable resource management. The study findings inform policy formulations, extension strategies, investment decisions, and capacity development initiatives aimed at optimizing resource utilization and enhancing productivity in Nigerian aquaculture.

MATERIAL AND METHODS

Data source

This study utilizes secondary data obtained from the comprehensive aquaculture production survey conducted by Van Tran et al. (2020), covering eight major aquaculture-producing states across Nigeria. Employing a multi-stage purposive and random sampling strategy, the original survey sampled 648 aquaculture producers from geographic clusters (urban, peri-urban, rural aquaculture zones, as well as fish markets) within each state. For this analysis, only

the data from 604 catfish farmers were included, while respondents engaged in tilapia and other aquaculture production were excluded to ensure production system homogeneity.
The dataset captures detailed farm-level inputs (fish stock, feed quantity, labor/transport/other costs), output (catfish production value), and socio-institutional characteristics (household size, experience, culture type, management system, technical support, association membership, integrated farming). Data were cleaned to address missing values and outliers, while preserving analytical integrity. All analyses were conducted using Stata 14.

Data analysis
***Descriptive statistics*:** Descriptive statistics were used to summarize the socio-economic and institutional characteristics of the sampled farmers.
Stochastic frontier production function: We employed the stochastic frontier production function proposed by Aigner et al. (1977), as it allows simultaneous estimation of the production frontier and farm-specific technical inefficiency, which is central to our research objective. The stochastic frontier production function separates the observed output into two components: one reflecting the maximum possible output (the frontier), and the other capturing inefficiencies in production. Unlike deterministic frontier or DEA approaches, the stochastic frontier model explicitly separates random shocks (e.g., weather conditions, measurement error) from inefficiency through a two-part error term, assuming a symmetric normal noise component *Vi* and a one-sided inefficiency component *Ui* following a half-normal distribution. These assumptions are widely used in efficiency analysis of agricultural production systems and are appropriate for aquaculture, where unobserved environmental and market shocks are common (Munezero et al., 2023).
The model used is specified as follows. The stochastic frontier production function (SFPF) was linearized in the form:

$$InYi = \beta 0 + \beta 1InX1 + \beta 2InX2 + \beta 3InX3 + \beta 4InX4 + \beta 5InX5 + Vi - Ui \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:
LnYi is the output (catfish production) of the i^{th} farmer;
X1, X2, X3, X4, and *X5* are the explanatory variables (e.g., fish stock, feed, labor costs, etc.);
ϵi represents the error term, which is decomposed into two parts: a symmetric noise component (*Vi*) and a one-sided inefficiency component (U_i).

The inefficiency component (U_i) was modeled as a function of farmer-specific variables, including years of experience, household size, culture type, management system, access to technical support, membership in associations, and integrated fish farming practices. The inefficiency model is specified as follows:

$$Ui = \delta 0 + \delta 1D1 + \delta 2D2 + \delta 3D3 + \delta 4D4 + \delta 5D5 + \delta 6D6 + \delta 7D7 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where:
δ are parameters to be estimated;
Ui is the inefficiency model;
D1 – D7 (as defined in Table 1).

The parameters of the stochastic frontier production function and the inefficiency model were estimated using Maximum Likelihood Estimation (MLE). This method is commonly used to estimate frontier models due to its efficiency in estimating both the frontier and inefficiency components simultaneously. The likelihood function was constructed based on the assumptions of the half-normal distribution for the inefficiency term (*Ui*) and a normal distribution for the noise term (*Vi*). The efficiency scores for each farmer were calculated based on the estimated parameters of the frontier model. These scores represent the ratio of observed output to the maximum possible output, indicating how efficiently each farmer is utilizing their resources relative to the best practice in the sample.

Table 1. Variables used in the Stochastic Frontier Production Function model

Variables	Description	Expected sign
Y = Fish output	Value in Naira	
X1=Fish stock	Numbers	+/-
X2= Quantity of feed	In Kilograms	+
X3= Cost of transport	Amount in Naira	-

X4= Cost of labor	Amount in Naira	-
X5= Other costs	Amount in Naira	-
Inefficiency Model		
D1=Years of experience	Number in years	-
D2= Household size	Number	+/ -
D3= Culture type	(1=Monoculture; 0=others)	+/-
D4=Management system	1 = Intensive, 0 = others	-
D5 = Access to technical support	(1=Yes; 0=otherwise)	-
D6= Membership of association	1 = yes, 0 = no	-
D7= Integrated fish farming	1 = yes, 0 = no	+/-

RESULTS AND DISCUSSION

Socio-economic and institutional characteristics of fish farmers

Table 2 presents the socio-economic and institutional characteristics of the fish farmers surveyed in this study (N = 604). A significant proportion of the farmers (82.0%) reported having access to technical support. This finding is consistent with earlier studies suggesting that technical support plays a crucial role in enhancing farming practices, especially among smallholder farmers. According to Antwi-Agyei and Stringer (2021), extension services have been shown to improve farmers' productivity by providing them with the necessary information, which can potentially lead to increased efficiency in operations. A majority of the respondents (61.4%) were members of an association. Membership in associations can foster the exchange of knowledge, collaborative problem-solving, and access to resources such as credit and improved fish farming technologies. These results are in line with the work of Shiferaw et al. (2011), who noted that farmers in associations benefit from collective action, which enhances their technical efficiency and access to resources and information. Most farmers (94.7%) practiced monoculture fish farming. This preference for monoculture could be driven by its simplicity, lower initial costs, and focus on high-demand species. This finding aligns with previous studies by Oboh (2022), who reported that monoculture is the dominant practice in Nigerian fish farming, largely due to market demand and lower operational costs compared to polyculture.

The practice of integrated fish farming, where fish farming is combined with other forms of agriculture (such as crop farming or poultry), was reported by 81.6% of the respondents, suggesting a widespread interest in diversified farming practices. Integrated farming systems have been linked with improved resource use efficiency and sustainability. Farmers involved in integrated fish farming often enjoy better economic returns by utilizing farm waste for feed and providing natural fertilizers for crops. These results corroborate findings by Ezeaku et al. (2015), who emphasized the importance of integrated farming in improving the economic viability and sustainability of smallholder farming in Nigeria. The majority of the farmers (86.6%) employed intensive management systems. The dominance of intensive farming systems is indicative of the need for higher production rates to meet market demand. Intensive systems are commonly used in commercial catfish farming because of their potential for higher yields, although they also require more investment in infrastructure, management, and technical expertise. The findings are consistent with those of Dauda et al. (2017), who found that intensive fish farming is the most common management system for commercial catfish farming in Nigeria.

The mean years of experience for the respondents was 14 years, indicating a relatively experienced group of farmers. Experience is a key factor in determining the efficiency of agricultural practices, as experienced farmers tend to adopt better practices and manage risks more effectively. This finding is in line with Iliyasu and Mohamed (2016), who found that experienced fish farmers tend to achieve higher technical efficiency owing to their familiarity with best farming practices and resource management. The average household size was 4.4 members, suggesting that fish farming households are relatively moderate in size. Larger households may contribute more labor, particularly in extensive farming systems, while smaller households may rely on hired labor for intensive operations. This finding aligns with earlier studies, such as that of Bhandari and Bhandari (2022), which found that household size is often associated with labor availability and, consequently, the adoption of more labor-intensive farming systems.

Table 2. Socio-economic and institutional characteristics of fish farmers (N = 604)

Variables	**Freq (%)**
Access to technical support	
Yes	495 (82.0)
No	109 (18.0)
Membership of an association	
Yes	371 (61.4)

No	233 (38.6)
Culture type	
Monoculture	572 (94.7)
Polyculture	32 (5.3)
Integrated fish farming	
Yes	493 (81.6)
No	111 (18.4)
Management system	
Intensive	523 (86.6)
Semi intensive	79 (13.1)
Extensive	2 (0.3)
	Mean (S.D)
Years of experience	14 (5.80)
Household size	4.4 (2.63)

Source: Authors' analysis of data from Van Tran et al. (2020)

Determinants of the technical efficiency of catfish farmers in Nigeria

Table 3 presents the maximum likelihood estimates for the parameters of the stochastic frontier production function, which was used to analyze the factors influencing the technical efficiency of catfish farmers in Nigeria. Fish stock was found to be the only significant predictor of catfish production. Fish stock is highly significant (p-value = 0.000), suggesting that an increase in fish stock positively influences the production output of catfish farmers. The fact that fish stock was the only statistically significant production input indicates that, under the prevailing management practices, output is primarily driven by stocking decisions, while variation in feed, labor, transport, and other costs does not translate into measurable differences in productivity. This highlights both the central role of stocking density in catfish production and potential inefficiencies in how other inputs are used, pointing to scope for improving feed management and cost allocation so that these inputs more effectively contribute to output. This finding aligns with those of Shoko et al. (2016), who emphasize the importance of adequate stocking densities for improving catfish yields. Shi et al. (2026) also reported that stocking density significantly influences aquaculture productivity and performance.

The inefficiency model identified household size, culture type, management system, and membership in an association as significant determinants of technical inefficiency in catfish production. Household size statistically and significantly influences the technical inefficiency of fish farmers (p-value < 0.05), indicating that larger households are associated with higher inefficiency. The positive association between household size and technical inefficiency suggests that, in this context, larger households may intensify competing demands on farm resources and management time, leading to suboptimal allocation of labor and capital rather than efficiency gains. This finding underscores the need for interventions that help farmers in larger households adopt labor-saving technologies and improve farm–household coordination. Chen et al. (2021) highlight the role of household labor in enhancing farm productivity. According to Syliver et al. (2026), household size significantly influences small-scale aquaculture productivity and technical efficiency, primarily because it dictates the availability of internal family labor. The monoculture system statistically and significantly influenced the technical inefficiency of fish production ($p < 0.10$), indicating that fish farmers who practice monoculture (farming a single species) tend to have higher inefficiency compared to those who practice polyculture. This suggests that monoculture may lead to inefficiencies, possibly due to the increased vulnerability to disease outbreaks or resource depletion. This finding is supported by the study of Mehrim et al. (2018), who reported that polyculture was the most economically efficient approach in aquaculture production. Conversely, Mansour et al. (2021) argue that intensive monoculture achieves superior economic scale, commands higher market prices, and requires less complex operational oversight.

Management system (intensive production) is statistically significant ($p < 0.10$) and has a negative coefficient, indicating that farmers using intensive management systems are less technically inefficient than those using other management systems. Intensive systems might be more efficient in terms of production practices, but this depends on access to resources like technical knowledge and infrastructure. This finding is consistent with Anvec et al. (2010), who report the superiority of intensive farming systems in terms of technical efficiency in aquaculture production. However, Long (2024) reported that intensive systems introduce severe technical inefficiencies in aquaculture production regarding electricity and labor, where the extreme reliance on automated aeration and power creates immense production risks. Membership in a farmers' association is statistically significant ($p < 0.01$) with a negative coefficient, suggesting that fish farmers who are members of an association are more technically efficient. This could

be because associations provide farmers with access to shared resources, knowledge, and technical support, which can improve their efficiency. Encouraging membership in farmers' associations could be a strategy for reducing technical inefficiency in fish farming. This finding is consistent with those of Olagunju et al. (2021) and Hukom et al. (2022), who found that association membership improves technical efficiency by facilitating collaboration and the sharing of best practices.

The non-significant coefficients for feed quantity, labor costs, transport costs, and other costs suggest that, within the sample, variation in expenditure on these inputs does not translate into systematic differences in output. Economically, this may reflect limited variation in input use across farms, suboptimal or uniform feeding and labor practices that fail to enhance productivity, or measurement error in cost variables, all of which can weaken the observed input–output relationships. Similarly, the non-significance of years of experience, access to technical support, and integrated farming in the inefficiency model may indicate that these factors are either already widespread and thus offer little marginal advantage, or that their effects operate indirectly through other variables such as management system and association membership rather than directly influencing technical efficiency.

Table 3. Maximum likelihood estimates for the parameters of the stochastic frontier production function

Variables	**Coefficients**	**Std. Err.**	**P-value**
Constant	7.083	0.240	0.000
Fish stock	0.948 ***	0.022	0.000
Quantity of feed	-0.003	0.019	0.889
Cost of transport	0.007	0.009	0.442
Cost of labor	0.001	0.006	0.810
Other costs	0.001	0.004	0.919
Inefficiency Model			
Constant	-300.18	101.767	0.003
Years of experience	18.387	17.875	0.304
Household size	28.973 **	13.766	0.035
Culture type (1=Monoculture)	124.526 *	68.714	0.070
Management system (1=intensive)	-35.930 *	19.932	0.071
Access to technical support (1=Yes)	-2.039	17.980	0.910
Membership of an association (1 = Yes)	-55.126 ***	18.917	0.004
Integrated fish farming (1=Yes)	-28.768	21.410	0.179
Usigma constant	4.391	0.218	0.000
Vsigma constant	-2.023	0.082	0.000
Sigma-u	8.983	0.979	0.000
Sigma-v	0.364	0.015	0.000
Lambda	24.701	0.979	0.000
Wald chi^2 (7)	2441.37		
Prob > chi^2	0.000		
Log-likelihood	- 545.6180		

Source: Authors' analysis of data from Van Tran et al. (2020). ***, ** & * denotes p value at 1%, 5%, and 10%, respectively

The efficiency levels presented in Table 4 indicate the distribution of technical efficiency among catfish farmers in Nigeria. The largest proportion of farmers (47.35%) falls within the efficiency range of 0.71 to 0.80, suggesting that the majority of farmers exhibit moderate technical efficiency. This is followed by 32.45% of farmers whose efficiency levels fall within the range of 0.40 to 0.70, indicating a group of farmers with relatively lower efficiency but still above the threshold of inefficiency. A small but notable proportion of farmers (6.46%) exhibit very low efficiency, with scores of < 0.40, while only 1.99% of farmers achieved efficiency scores above 0.90, indicating near-optimal technical efficiency. The fact that a substantial proportion of farmers fall into the lower efficiency brackets (39 farmers with efficiency < 0.40 and 196 farmers with efficiency between 0.40 and 0.70) highlights that significant inefficiencies still exist in the sector.

The mean efficiency score of 0.67 suggests that, on average, Nigerian catfish farmers operate at a technical efficiency level of about 67% of the potential output they could achieve under the current production system. This indicates considerable room for improvement in technical efficiency with the estimated efficiency gap of 33%. Factors that may contribute to inefficiency include suboptimal use of resources (e.g., fish stock, feed, and labor), limited access to advanced technologies, or management practices that do not fully exploit available resources.

Similar studies by Okoror et al. (2017) and Ajiboye et al. (2020) reported mean technical efficiency in aquaculture production of 88% and 61%, respectively.

Table 4. Technical efficiency distribution of fish farmers

Efficiency Level	Freq	Percent
< 0.40	39	6.46
0.40 - 0.70	196	32.45
0.71 - 0.80	286	47.35
0.81 - 0.90	71	11.75
> 0.90	12	1.99
Minimum Efficiency	0.13	
Mean Efficiency	0.67	
Maximum Efficiency	0.94	

Source: Authors' analysis of data from Van Tran et al. (2020)

CONCLUSION

This study assessed the factors influencing the technical efficiency of catfish farmers in Nigeria using a stochastic frontier production function. The analysis revealed significant variation in the technical efficiency of fish farmers, with a mean efficiency score of 0.67, indicating that farmers, on average, operate at 67% of the potential output they could achieve under the current production system. The distribution of technical efficiency showed that the largest proportion of farmers (47.35%) had efficiency scores ranging from 0.71 to 0.80, while a substantial proportion exhibited lower levels of efficiency, with 6.46% of farmers falling below an efficiency level of 0.40. Key factors identified as influencing technical efficiency included household size, monoculture farming, intensive management systems, and membership in farming associations, highlighting their importance in improving the overall productivity of catfish farming in Nigeria. Overall, while Nigerian catfish farmers demonstrate a moderate level of efficiency, considerable scope remains to reduce inefficiencies and improve productivity. The findings highlight the need for targeted interventions aimed at improving resource utilization, promoting best practices, and addressing constraints such as inadequate infrastructure and access to technical knowledge.

Based on the findings of this study, the following recommendations are made to enhance the technical efficiency of catfish farmers in Nigeria:

i. Given that fish stock is the only production input with a highly significant positive effect on output, policies should prioritize extension, training, and advisory services on optimal stocking densities, fingerling quality, and stocking schedules, and facilitate access to reliable hatcheries.

ii. Because larger household size is associated with higher technical inefficiency, interventions should focus on labor management, record-keeping, and the adoption of labor-saving technologies, helping farmers allocate household and hired labor more effectively between farm and non-farm activities, rather than targeting financial support to large households per se.

iii. The positive and significant effect of monoculture on inefficiency suggests scope for promoting more efficient culture strategies, such as well-designed polyculture systems or species diversification, through training and demonstration trials where these are technically and economically feasible.

iv. Since intensive systems are associated with lower technical inefficiency, policies should focus on improving farmers' access to the knowledge, infrastructure, and finance required to implement and properly manage intensive systems, in contexts where these are economically and environmentally sustainable.

v. The finding that membership in farmers' associations significantly reduces inefficiency justifies policy efforts to support formation and strengthening of farmer groups, including capacity building, facilitation of collective input procurement and marketing, and integration of associations into extension and credit programs.

It is important to note that the secondary data used in this study are from a single survey and, therefore, may not fully capture changes in farm practices or environmental conditions that have occurred since the survey. Additionally, the reliance on self-reported data may introduce biases, as farmers may underreport or overreport certain factors, particularly those related to financial or management practices. Future studies could benefit from primary data collection to validate and expand upon the findings from this secondary dataset.

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Data availability statement: The data presented in this study are available upon request from the authors.

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