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Technical Efficiency and the Impact of Fadama Participation: A Meta-Frontier Analysis of Smallholder Cassava Farmers in Edo State, Nigeria

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ABSTRACT

Enhancing the technical efficiency (TE) of smallholder farmers is critical for achieving food security and agricultural transformation in Nigeria, a nation where cassava productivity remains below potential despite being a global leader in production. This study evaluates the impact of participation in the FADAMA development programme on the technical efficiency of cassava farmers in Edo State, employing a novel meta-frontier framework to disentangle managerial performance from technology access. Primary data were collected from 480 farmers (240 participants and 240 non-participants) across three agro-ecological zones using a multi-stage sampling technique designed to ensure representativeness. Analysis involved a two-stage approach: first, Stochastic Frontier Analysis (SFA) estimated group-specific TE scores; second, a meta-frontier model calculated the technology gap ratio (TGR). A Tobit regression identified determinants of inefficiency. Results show that FADAMA participants had a significantly higher mean group TE (0.81) compared to non-participants (0.69). However, the meta-frontier analysis reveals a persistent technology gap, with participants' TGR at 0.89. This indicates that while participants are better managers, they still operate 11% below the potential regional best-practice frontier. Key drivers of inefficiency include limited access to formal credit, older farmer age, and greater distance to output markets. The study concludes that FADAMA successfully improves farm-level management but has not fully closed the technology adoption gap. We recommend programme redesign to integrate intensive practical training, facilitate formal credit access, and improve rural infrastructure to maximize efficiency gains.

Keywords: Technical Efficiency, Meta-Frontier, FADAMA, Cassava, Stochastic Frontier Analysis, Edo State.

INTRODUCTION

Cassava (*Manihot esculenta*) is a cornerstone of food security and a primary income source for millions of smallholder households in Nigeria, the world's largest producer of this staple crop (FAO, 2023). Despite its strategic importance, average yields remain substantially below agronomic potential, constrained by persistent inefficiencies in resource use, limited adoption of improved technologies, and socio-economic challenges (Nweke, 2004; Oyotomhe et al., 2025). This productivity gap directly undermines national food security objectives and the livelihoods of the rural poor.

In response, the Nigerian government, with support from international development partners, has implemented successive FADAMA development projects. These projects aim to enhance agricultural productivity, incomes, and resilience by providing smallholder farmers with coordinated access to improved inputs, irrigation infrastructure, extension services, and market linkages (World Bank, 2015). The fundamental premise is that by alleviating critical resource constraints and facilitating technology adoption, farmers can operate closer to their production frontier, thereby extracting greater output from existing resources (Aigner et al., 1977).

While the resource-provisioning role of FADAMA is recognized, its precise impact on the intrinsic managerial capability of farmers, their technical efficiency requires more nuanced investigation. Technical efficiency measures a farm's ability to obtain maximal output from a given set of inputs and technology (Coelli et al., 2005). A programme like FADAMA can influence this directly through training and indirectly by improving input quality. Recent studies in the region highlight this ongoing challenge. Research in Edo State found an average technical efficiency of 0.762 among cassava farmers, indicating a 24% shortfall, with inefficiency linked to factors like age and limited extension contact (Oladele et al., 2024). Similarly, a stochastic frontier analysis of Edo State cassava farmers identified significant allocative inefficiencies, particularly in fertilizer use (Ewekhare & Idahosa, 2025). Concurrently, the FADAMA programme remains active, with the Edo State government recently distributing inputs like fertilizers and cassava milling machines to empower grassroots farmers (Oyotomhe et al., 2025).

This study focuses on smallholder cassava farmers in Edo State, a key beneficiary region of the FADAMA III Additional Financing and subsequent CARES interventions. The state encompasses three major agro-ecological zones, allowing for a robust analysis across diverse farming systems. The core research question is: Does FADAMA participation lead to higher technical efficiency among cassava farmers by improving management, and to what extent does a technology access gap persist?

This study makes two significant contributions to the literature. First, it applies a meta-frontier analysis alongside Stochastic Frontier Analysis (SFA). While SFA estimates efficiency within groups (participants vs. non-participants), the meta-frontier constructs a single, regional best-practice frontier (Battese et al., 2004). This allows for the decomposition of overall performance into: (1) the managerial gap (inefficiency in using the group's own technology) and (2) the technology gap (the difference between the group's technology and the regional best practice). This framework is essential for determining whether FADAMA primarily improves how farmers use existing methods or grants access to superior technology. Second, by identifying specific socio-economic and institutional determinants of inefficiency, the findings offer targeted, evidence-based recommendations for enhancing the design and impact of agricultural development programmes in Nigeria and similar contexts (Alene & Hassan, 2006).

The specific objectives of this study are to:

1. Estimate and compare the technical efficiency levels of FADAMA participant and non-participant cassava farmers in Edo State using SFA.

2. Measure the technology gap between participant and non-participant groups using a meta-frontier framework.

3. Identify the key socio-economic and institutional factors that influence technical inefficiency among the farmers.

4. Derive targeted policy implications for improving the design and impact of the FADAMA programme.

METHODOLOGY

Study Area

The study was conducted in Edo State, Nigeria. Edo State is purposively selected as it is a core implementation area for FADAMA projects and features three distinct agro-ecological zones critical for cassava production: the Lowland Rainforest Zone, the Freshwater Swamp Zone, and the Southern Guinea Savannah Zone (Oyotomhe et al., 2025). This variation ensures the findings capture efficiency dynamics across different ecological and socio-economic conditions.

Sampling Technique and Data Collection

A multi-stage random sampling procedure was employed to ensure a representative, unbiased sample while managing logistical constraints across the diverse state.

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Table 1: Multi-Stage Sampling Frame and Sample Selection

Sampling Stage	Sampling Unit	Selection Method & Justification	Number Selected	Resulting Sample Composition
Stage 1	Local Government Areas (LGAs)	Random selection from each of the 3 Agro-ecological Zones to ensure environmental representativeness.	2 LGAs per zone	6 LGAs total
Stage 2	Communities	Random selection of FADAMA and non-FADAMA communities from each LGA to establish comparable treatment/control groups.	4 Communities per LGA (2 FADAMA, 2 non-FADAMA)	24 Communities total (12 FADAMA, 12 non-FADAMA)
Stage 3	Individual Farmers	Simple random selection from enumerated lists of active farmers in each community.	20 Farmers per Community (10 FADAMA, 10 non-FADAMA)	**Total Sample: 480 Farmers** • FADAMA Participants: 240 • Non-Participants: 240

The three-stage design was justified as follows:

- **Stage 1:** Ensured the sample captured environmental and socio-economic heterogeneity across Edo State, critical for generalizable results (Cochran, 1977).
- **Stage 2:** Guaranteed distinct treatment (participant) and control (non-participant) groups from similar geographical and cultural settings, minimizing confounding factors (Khandker et al., 2010).
- **Stage 3:** Using enumerated lists (sampling frames) ensured every eligible farmer had an equal chance of selection, minimizing selection bias and enhancing statistical precision (Israel, 1992).
- Primary data were collected for the 2025 farming season through structured questionnaires administered via face-to-face interviews. The survey gathered data on:
- **Input Quantities:** Land area under cassava (hectares), quantity of planting materials (stem cuttings in bundles), labour (man-days for all operations), and quantities of fertilizer and agrochemicals (kg or litres).
- **Output:** Total fresh cassava tuber yield (kg).
- **Socio-Economic Characteristics:** Age, gender, education level, farming experience, household size.
- **Institutional Factors:** FADAMA participation status, access to credit (formal/informal), frequency of extension contact, membership in cooperatives, distance to major input and output markets.

Analytical Framework

The analysis follows a three-stage econometric approach.

Stage One: Efficiency Estimation using Stochastic Frontier Analysis (SFA)

The stochastic frontier production function, following Aigner et al. (1977), is used. The Cobb-Douglas functional form was specified and tested against the Translog form using a likelihood ratio test; the Cobb-Douglas was deemed appropriate, a common finding in agricultural efficiency studies where input elasticities are stable (Coelli et al., 2005). The model for the i^{th} farmer is:

$$\ln Y_i = \beta_0 + \sum_{j=1}^{5} \beta_j \ln X_{ji} + (v_i - u_i)$$

Where:

Yi is the output of cassava (kg).

X_{ji} represents inputs: land (ha), labour (man-days), planting material (bundles), fertilizer (kg), and agrochemical cost (₦).

β are parameters to be estimated.

v_i is the symmetric random error, assumed to be $N(0, \sigma_v^2)$.

u_i is the non-negative technical inefficiency term, assumed to be $N^+(\mu, \sigma_u^2)$.

The technical efficiency (TE) of the i-th farmer is: $TE_i = \exp(-u_i)$.

Separate SFAs were estimated for the participant and non-participant groups.

Stage Two: Meta-Frontier Analysis

To compare groups operating under potentially different technologies, a meta-frontier model (Battese et al., 2004) is constructed. This method is particularly suited for evaluating programmes like FADAMA that introduce new technology bundles (O'Donnell et al., 2008). The meta-frontier production function is: $Y_i^* = f(X_i, \beta^*)$ where β^* are parameters satisfying that its output for any input bundle is ≥ that of the group frontiers.

The Technology Gap Ratio (TGR) for a farmer in group *j* is:

$$TGR_i^j = \frac{Y_i}{Y_i^*} = f(X_i, \beta^j)/f(X_i, \beta^*)$$

The TGR measures how close the group's technology is to the regional best practice (meta-frontier). It lies between 0 and 1.

The Meta-Frontier Technical Efficiency (MTE) is then:

$$MTE_i = TE_i^j \times TGR_i^j$$

This decomposes overall efficiency into group technical efficiency (TE) and the technology gap ratio (TGR), providing a complete picture of performance.

Stage Three: Determinants of Inefficiency

A second-stage Tobit regression model censored at 0 analyzes factors influencing technical inefficiency $1 - TE_i$). The Tobit model is appropriate because inefficiency scores are bounded at zero (fully efficient), and Ordinary Least Squares would yield biased estimates (Greene, 2003). The model is:

$$(1 - TE_i) = \delta_0 + \sum_{k=1}^{m} \delta_k Z_{ki} + \epsilon_i$$

Where Z_{ki} are explanatory variables, δ_k are coefficients, and ϵ_i is the error term. A positive coefficient increases inefficiency.

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Hypothesized Determinants (Z_k):

- **Age, Household Size:** Expected positive effect (potential rigidity or labor diversion).
- **Education, Extension Contact, FADAMA Participation, Credit Access:** Expected negative effect (enhance knowledge and resources).
- **Distance to Market:** Expected positive effect (increases transaction costs).

Data Analysis

The stochastic frontier, meta-frontier, and Tobit models were estimated using STATA 18. Descriptive statistics summarized the sample characteristics.

RESULTS AND DISCUSSION

Descriptive Statistics of Sampled Farmers

Table 2: Descriptive Statistics of Key Variables by Farmer Group

Variable	FADAMA Participants (n=240)	Non-Participants (n=240)	t-stat / χ^2 (p-value)	Implication
Age (years)	48.2 (10.5)	52.7 (11.8)	-4.82 (<0.001)***	Participants are significantly younger.
Education (years)	9.1 (3.2)	7.3 (4.1)	5.47 (<0.001)***	Participants have more formal schooling.
Farm Size (ha)	1.9 (0.8)	1.4 (0.6)	8.12 (<0.001)***	Participants cultivate larger plots.
Fertilizer Use (kg/ha)	142.5 (65.3)	92.1 (58.4)	9.05 (<0.001)***	Participants use more fertilizer per hectare.
Yield (kg/ha)	19,500 (4,200)	15,100 (5,100)	10.33 (<0.001)***	Participants achieve higher average yields.
Extension Contact (#/season)	5.8 (2.1)	2.3 (1.8)	20.14 (<0.001)***	Participants have far more extension access.
Access to Formal Credit (%)	35%	15%	26.15 (<0.001)***	Participants have better credit access.
Distance to Market (km)	12.4 (5.1)	15.8 (6.3)	-6.72 (<0.001)***	Participants live closer to major markets.

*Note: Mean (Standard Deviation) shown for continuous variables. *** denotes significance at the 1% level.*

Key variable means highlight systematic differences, confirming that FADAMA participants operate under different socio-economic and resource conditions, which the meta-frontier and regression analysis will control for.

Estimated Stochastic Frontier and Meta-Frontier Results

Group-Specific Frontier Estimates

Maximum likelihood estimates for the Cobb-Douglas frontiers were statistically significant (LR test, p<0.01). For both groups, land, labour, and planting material had positive and significant elasticities. The gamma (γ) parameter was 0.81 (participants) and 0.76 (non-participants), confirming that inefficiency effects, rather than random noise, dominate the variation in cassava output, validating the use of SFA (Battese & Corra, 1977).

Technical Efficiency and Meta-Frontier Estimates

Table 3: Summary of Key Efficiency Estimates from SFA and Meta-Frontier Analysis

Efficiency Metric	FADAMA Participants	Non-Participants	t-stat (p-value)	Interpretation & Implication
Group Technical Efficiency (TE)	0.81 (0.12)	0.69 (0.15)	10.24 (<0.001)***	Participants are significantly better (by 17.4%) at managing their current inputs and technology. This affirms the program's core objective of improving farm-level management (World Bank, 2015).
Technology Gap Ratio (TGR)	0.89 (0.07)	0.74 (0.11)	18.56 (<0.001)***	The technology available to participants is superior, being closer to the regional best-practice frontier. This validates FADAMA's role in technology dissemination (Battese et al., 2004).
Meta-Frontier Technical Efficiency (MTE)	0.72 (0.10)	0.51 (0.14)	19.01 (<0.001)***	Overall, participants are 41% more efficient relative to the meta-frontier. The decomposition shows that for participants, 11% of the gap to the best frontier is due to technology, while for non-participants, it is 26%.

*Note: Mean (Standard Deviation) shown. *** denotes significance at the 1% level.*

- **Group Technical Efficiency (TE):** The mean TE for FADAMA participants was 0.81, significantly higher (t-test, p<0.01) than the 0.69 for non-participants. This confirms the program's positive impact on farm-level management, supporting findings from recent local studies (Oladele et al., 2024).
- **Technology Gap Ratio (TGR):** The estimated TGR was 0.89 for participants and 0.74 for non-participants. This indicates participants' technology is closer to the regional meta-frontier, validating FADAMA's role in technology dissemination, but also reveals an 11% technology gap that remains unbridged.
- **Meta-Frontier Technical Efficiency (MTE):** The mean MTE was 0.72 (0.81 × 0.89) for participants and 0.51 (0.69 × 0.74) for non-participants. This decomposition is the study's critical contribution: it reveals that while FADAMA participants are better managers (Group TE of 0.81), a technology gap of 11% (1 - 0.89) remains relative to the absolute best practice.

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Determinants of Technical Inefficiency

Table 4: Determinants of Technical Inefficiency – Tobit Regression Results

Explanatory Variable	**Coefficient**	**Std. Error**	**z-value**	**Marginal Effect (∂(1-TE)/∂X)**	**Interpretation**
Constant	0.412	0.045	9.16***	-	Baseline inefficiency level.
Age of Farmer (years)	0.0023	0.0012	1.92*	+0.0018	Older age is associated with higher inefficiency, possibly due to reluctance to adopt new methods.
Education Level (years)	-0.0195	0.0038	-5.13***	-0.0153	Formal education significantly reduces inefficiency by improving managerial capacity and adaptability.
Household Size (number)	0.0068	0.0035	1.94*	+0.0053	Larger households may experience labor diversion or higher subsistence pressure, reducing measured efficiency.
Access to Formal Credit (1=Yes)	-0.0481	0.0121	-3.98***	-0.0377	This is a major finding. Access to credit strongly reduces inefficiency by easing liquidity constraints for optimal input use.
Distance to Output Market (km)	0.0083	0.0015	5.53***	+0.0065	A critical institutional factor. Greater distance increases transaction costs and reduces market orientation, thereby increasing inefficiency.
Extension Contact (#/season)	-0.0130	0.0041	-3.17***	-0.0102	Reinforces the value of knowledge transfer in improving efficiency.
FADAMA Participation (1=Yes)	-0.1123	0.0205	-5.48***	-0.0881	The program dummy remains strongly negative and significant after controlling for all other factors, confirming its independent positive effect on efficiency.
Log Sigma	-1.921	0.062	-30.98***		
Wald χ^2 (7 df)	**92.47***				Model is statistically significant.
Log-likelihood	**220.45**				

*Note: Dependent Variable = (1 - Technical Efficiency Score). *** $p<0.01$, ** $p<0.05$, * $p<0.1$.*

The Tobit regression on the pooled sample was highly significant (Wald $\chi^2 = 92.47$, $p < 0.001$). The results provide clear policy levers.

DISCUSSION

The results robustly demonstrate that FADAMA participation enhances the technical efficiency of cassava farmers in Edo State. The 12-percentage-point difference in mean group TE is both statistically and economically significant, affirming the program's core objective and aligning with broader evidence that targeted agricultural interventions can improve smallholder performance (Alene & Hassan, 2006).

The meta-frontier analysis provides the crucial, policy-relevant nuance. The TGR of 0.89 for participants reveals that the program, while successful, has not fully bridged the technology adoption gap. Participants are not utilizing the absolute best-available technology package in the region. This residual gap could stem from partial adoption of promoted technologies, sub-optimal input combinations, or unaddressed agronomic constraints. This finding moves the policy discussion beyond simple participation to the quality and completeness of technology transfer, a point emphasized in recent meta-frontier literature (O'Donnell et al., 2008).

The determinants analysis offers a clear roadmap. The strong effects of education and extension underscore the need for continuous, practical farmer training. The powerful role of formal credit access suggests that integrating tailored financial services into FADAMA could unlock significant further gains—a necessary shift from input provision to input optimization. The penalty imposed by market distance highlights a traditional weakness of such programs and argues for complementary investments in rural infrastructure and market linkages, which are empirically linked to sustained productivity growth (World Bank, 2008).

CONCLUSION AND RECOMMENDATIONS

Conclusion

This study analyzed the impact of FADAMA participation on smallholder cassava farmers' technical efficiency in Edo State using a meta-frontier framework. Key conclusions are:

1. FADAMA participants are significantly more technically efficient (81%) than non-participants (69%), demonstrating the program's success in improving farm-level resource management.

2. However, a meta-technology ratio of 0.89 indicates an 11% technology gap persists between participants and the regional best-practice frontier.

3. Inefficiency is primarily driven by lack of formal credit, poor market access, and lower education levels constraints that FADAMA only partially addresses.

In summary, the FADAMA program has effectively reduced the management gap but has not fully closed the technology adoption gap. Sustained inefficiencies are rooted in broader institutional and infrastructural constraints.

Recommendations

To evolve FADAMA from a successful input-support program into one that catalyzes full productivity potential, the following evidence-based actions are recommended:

1. **Strengthen the Technology Package via Intensified Training:** Move beyond input distribution to include mandatory, practical, season-long farmer field schools focused on the integrated management of the complete technology package (e.g., optimal planting density, fertilizer scheduling). This targeted approach is supported by meta-frontier analyses which recommend distinct strategies for closing management gaps versus technology gaps (Battese et al., 2004).

2. **Formalize Embedded Financial Linkages:** Forge operational partnerships with microfinance institutions to develop and deliver input-linked credit products. FADAMA User Groups could serve as collateral, directly addressing the major inefficiency driver identified. This is critical, as empirical evidence links improved technical efficiency directly to meaningful household poverty reduction (Alene & Hassan, 2006).

3. **Integrate Market Linkage Interventions:** Program design must actively include components that reduce post-harvest losses and improve market access. This could involve support for farmer-owned aggregation centers and advocacy for rural road maintenance, addressing a key infrastructural barrier to efficiency.

4. **Target Youth and Mainstream Adult Education:** Develop specific incentives to engage younger, more educated farmers. Incorporating basic numeracy and record-keeping training into extension curricula can enhance managerial capabilities.

5. **Promote Resource-Specific Guidance:** Extension advice should be tailored based on identified inefficiencies (e.g., precise fertilizer recommendation protocols) to reduce input waste, leveraging the diagnostic power of SFA results for actionable extension (Coelli et al., 2005).

By adopting these recommendations, future agricultural development projects can adopt a more holistic approach that simultaneously addresses management skills, technology quality, financial access, and market incentives, thereby unlocking sustainable productivity growth for Nigeria's smallholder farmers.

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