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Efficiency differentials and its determinants between broadcasting and transplanting system of rice production in South East Zone of Nigeria

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Abstract
The study investigated the efficiency disparities and their determinants between broadcasting and transplanting systems of rice production in Southeast Nigeria. Employing a multi-stage sampling technique, 384 respondents (192 broadcasters and 192 trans planters) were selected for the study. Data collection was conducted using a structured questionnaire, and the collected data were analyzed using descriptive statistics, stochastic frontier analysis, and inferential statistics, including the paired t-test. Specifically, the study aimed to estimate the input-output relationship of rice farmers concerning transplanting and broadcasting, as well as determine the technical, economic, and allocative efficiency of each system. The findings from the stochastic Cobb Douglas production function for farmers utilizing broadcasting technology revealed a mean TE value of 0.505. Similarly, the transplanting system exhibited a mean TE value of 0.651. The null hypothesis was rejected due to a substantial difference in means (7.26) ***. Consequently, the study recommends efforts to enhance technology adoption among farmers to increase output.

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1. Introduction

The cultivation of Asian rice (*Oryza sativa*) began in Nigeria around 1890, gradually overshadowing the indigenous red grain species, African rice (*Oryza glaberrima*), which previously constituted about 60% of rice production within the Niger Delta region. With origins traced back to Latin America, rice, a monocotyledon plant, boasts over 60 wild species. In tropical and subtropical regions, rice cultivation thrives due to its convenience and widespread preference as a staple food (Obianefo *et al*., 2022) [14]. This carbohydrate-rich crop serves as a vital source of dietary energy for Nigeria's populace, although it is relatively low in protein and micronutrients (Madugu *et al*., 2017) [8]. Nigeria stands as Africa's second-largest rice producer, trailing only behind Egypt (KPMG, 2019). The country cultivates both upland and lowland rice varieties, the latter often grown in irrigated areas such as fadama or through various irrigation methods like drip, sprinkler, or free-flow water systems.

Significant shifts in rice consumption patterns have occurred in Nigeria and neighboring regions in recent decades. Since 1973, regional demand has surged at an annual rate of 6%, primarily fueled by population growth and a shift away from traditional grains. Consumption of traditional cereals like sorghum and millet has declined by 12kg per capita, with their share of cereal consumption dropping from 61% in the early 1970s to 49% in the early 1990s. In contrast, rice's share of cereal consumption has risen from 15% to 26% over the same period (Olorunfemi & Victor as cited in Amos, 2018) [1]. Regional rice consumption growth remains robust, with the FAO projecting a 6.55% annual growth rate beyond 2020, indicating a potential 70% increase in rice consumption over the decade. Nigeria has experienced particularly rapid growth in rice demand since the mid-1970s, with per capita consumption increasing from a mere 3kg annually during the 1960s to 32 kg presently.

To meet rising demand, local rice production has surged, expanding by an average of 9.3% per annum, primarily attributed to a significant increase in rice cultivation area by 7.9% annually, albeit with a lesser contribution from yield increases at 1.4% per annum. Despite these efforts, production growth has not kept pace with consumption increases.

Hence, the elucidation highlights the significance of studying farm efficiency and production systems, particularly in developing agricultural economies like Nigeria, with a particular focus on the South East region, where resources are scarce, and opportunities for adopting better technologies are limited. Efficiency, as described by Nnamdi *et al*. (2016) and cited in Obianefo *et al*. (2020) [13], refers to the effective management of time, effort, or cost for a specific task or purpose, as well as the ability to generate maximum output from a given set of inputs (Ajayi *et al*., 2018) [2]. It is crucial to measure efficiency as it leads to significant resource savings, with implications for policy formulation and farm management (Amos, 2018) [2] delineate three facets of efficiency: technical efficiency, which assesses a firm's ability to produce maximum output from a given input; allocative efficiency, which evaluates a firm's capability to choose an optimal input mix based on their relative prices; and overall or economic efficiency, which encompasses both technical and allocative efficiencies.

Despite the vital role of rice production in the states and the nation as a whole, there is a dearth of comprehensive and up-to-date information on the level of resource use efficiency and production systems employed by farmers in the region. Existing studies have primarily focused on specific local governments or states and have mainly addressed aspects such as rice production and consumption, profitability analysis, determinants of rice output, and technical efficiency in rice production (Nwike *et al*., 2017; Obianefo *et al*., 2020) [13]. However, there has been a lack of in-depth investigation into the efficiency of farmers' production systems and the factors influencing their efficiency levels.

To bridge this gap, the study aims to assess the efficiency disparities and determinants between the broadcasting and transplanting systems of rice production in the South East region of Nigeria. Thus, the study seeks to specifically:

1. Estimate the input output relationship of rice farmers with respect to transplanting and broadcasting systems in the study area
2. Determine the technical, economic and allocative efficiency of each production system
3. Identify the determinants of technical, allocative and economic efficiencies of rice production

Null Hypothesis (HO)

H0$_1$: There is no significant difference in the technical efficiency of rice production under the broadcasting and transplanting systems.

H0$_2$: There is no significant difference in the allocative efficiency of rice production under the broadcasting and transplanting systems.

H0$_3$: There is no significant difference in the economic efficiency of rice production under the broadcasting and transplanting systems.

2. Materials and Methods

2.1 Study Area

The study area for this research is Southeast Nigeria, also referred to as the southeast geopolitical zone. Comprising five states – Abia, Anambra, Ebonyi, Enugu, and Imo – it is one of the six geopolitical zones in Nigeria. Southeast Nigeria has an estimated land area of 41,440 km2 and a population of 22,012,828 as of 2020, according to the National Population Commission (NPC). Geographically, the zone lies between longitude 6°35' and 8°27' East and latitudes 04°47' and 08°71' North of the Equator (Mba *et al*., 2021) [9]. It shares borders with Benue and Kogi States to the north, Rivers, Akwa Ibom, and Bayelsa States to the south, Delta and Edo States to the west, and Cross River State to the east. The southeastern region comprises two distinct ecological zones: the tropical rainforest in the south and the derived guinea savanna in the north. The mean annual temperature ranges from 21.6 °C to 32.4 °C, while the annual rainfall varies from 720 mm to 1440 mm in the rainforest region (NAERLS and FDAE, 2019).

The primary occupations of the people in the area include farming, trading, civil service, and teaching. Major crops cultivated by the inhabitants consist of yam, cassava, cocoyam, maize, vegetables, plantain, and rice. Livestock rearing includes chicken, sheep, goats, pigs, and a small population of Muturu cattle. Additionally, tree crops such as oil palm, citrus, mango, breadfruit, and coconut are commonly grown in homesteads and plantations. Southeast Nigeria ranks fourth among the six geopolitical zones in rice production, with an estimated output of 11.35 million tonnes cultivated on 968,000 hectares of land in 2019, yielding an average of 4.5 tonnes per hectare (NAERLS and FDAE, 2019).

2.2. Sampling Techniques

Given that the exact population of rice farmers in Southeast, Nigeria is unknown, an infinite sample size determination technique adapted from Obianefo *et al.* (2022) [14] was used to calculate the sample size for the study:

$$n = \frac{Z^2 * P(1-P)}{e^2}$$

Where:

n = sample size

Z = Z-score at 95% confidence interval

P = probability of success

1- P = failure

e = error term at 0.05 level of probability.

However, the sample is calculated as

$$n = \frac{1.96^2 * 0.50(1-0.50)}{0.05^2} = 384$$

The research also employed a multistage and random sampling technique in selection of the study representative.

At stage I, three States namely Ebonyi, Anambra, and Enugu were purposively selected from the five states in the zone, based on their intensity and long history of rice production.

Stage II was the random selection of two Local Government Areas (LGAs) from each of the three States to arrive at six (6) LGAs.

At stage III, two autonomous town communities were selected from each of the six selected LGAs bringing the total number of communities to twelve (12), from where four (4) villages were randomly selected from each community to make a total of forty-eight (48) villages.

The final stage (Stage IV) involves the random sampling of eight (8) rice farmers (4 broadcasters and 4 transplanters) from each village, resulting in a total of 384 respondents (192 broadcasters and 192 transplanters).

Data Analysis

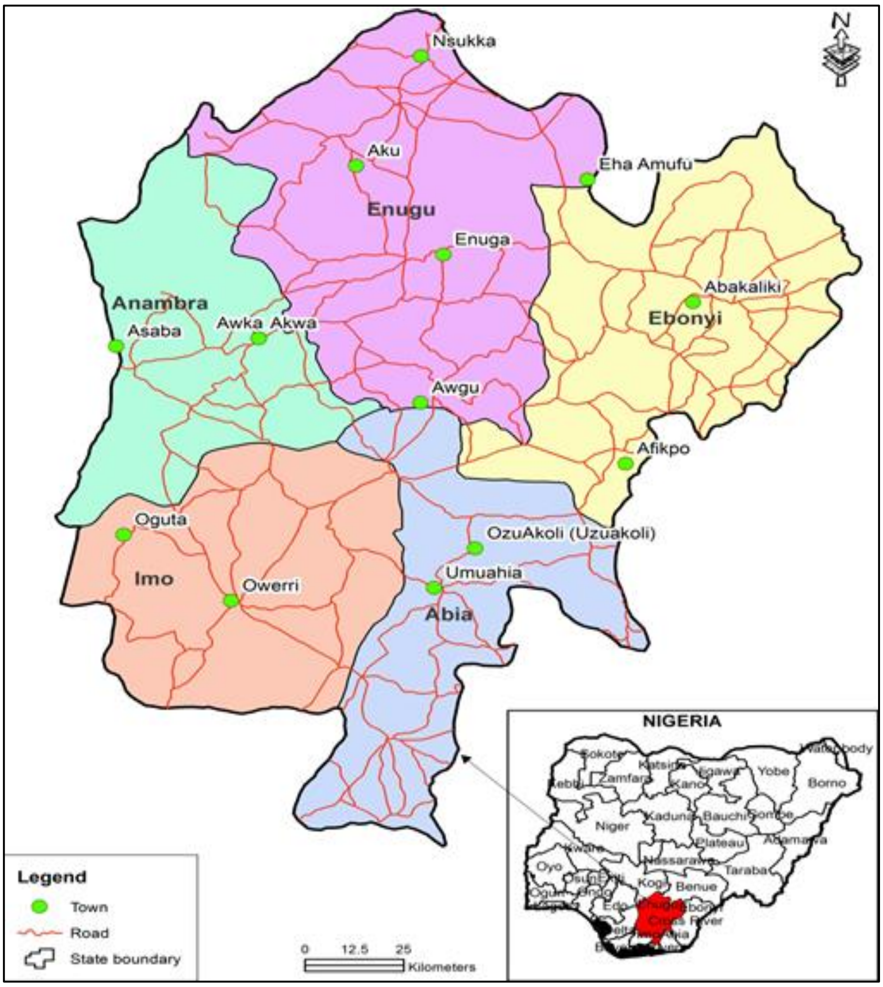
The study utilized a combination of analytical tools of Descriptive statistics, Stochastic frontier analysis, and inferential statistics of paired t-test or comparative mean test. Objective I (determine the rice farmers production function with respect to transplanting and broadcasting) was achieved using the Stochastic frontier model (SFA). Objective II (determine the technical, economic and allocative efficiency of each system) was achieved using one stage stochastic frontier model. The objective III (identify the determinants of technical, allocative and economic efficiency) was achieved using stochastic frontier model.

Hence, null hypotheses (HO) were tested using the paired sample t-test or comparative mean test.

Model specification

The descriptive statistics is mathematically stated as:

$\underline{X} = \sum fx/n$



Source: Merem *et al*. (2019)

Fig 1: Map of Nigeria showing Southeast region

Where $\underline{X}$=mean, x= variable outcome, n= sample size, and F=frequency

1) The cobb douglas function for objective 1 is implicitly stated as

$$LnYi = \sum BjLnXji + (vi-ui)$$

Where:

Ln = natural log

Yi = yield (kg), X_1=seed (bags), X_2=fertilizer (kg), X_3=Agro-chemical(lt), X_4= labour (mandays), X_5 =farm size(ha), X_6 = capital(N), Yi= random noise, (vi-ui)= inefficiency variables

2.) Technical, Economic and Allocative Efficiency and Determinants for objective 2 and 3were stated as TE is defined in terms of observed output (Yi) to expected output (Y*) as:

$$TEij = f(Xi; B)\,exp(Vi - Ui), = exp(-U)$$

$$F(Xi; B)\,exp(V)$$

$$TEij = Yi/Y^{x} = \frac{f(Xi; B)\,exp^{(Vi-Ui)}}{f(Xi; B)\,exp^{Vi}} = exp^{-u} \text{ or } e^{-u}$$

Economic efficiency is estimated from the stochastic cost function defined as:

$$Ci = f(Yi, Pic; a)\,expeic,\ i = 1, 2 \ldots\ldots\ldots\ldots n$$

Where: *Ci* is the normalized cost of the product, *Pic* is the vector of input prices, *Yi* is the ouput is the output, *a* is the vector of unknown parameters to be estimated, eic is the composite error term (*Vi+ Ui)*

$$EE = \frac{f(Pic, exp(Vi + Ui)}{f(Pic, <) \, exp \, Vi} = expUi$$

The Allocative Efficiency is the ratio of EE to TE

$$AE = \frac{EE}{TE} = \frac{\exp^{Ui}}{\exp^{-Ui}}$$

3 Results and Discussion

3.1 Production Function of Rice Farmers

The production function of rice farmers under broadcasting and transplanting system is presented in Tables 1 and 2, and is discussed thus:

Table 1: Final maximum likelihood estimates for broadcasting system

Parameter	Estimate	Std. Error	Z
(Intercept)	6.546	2.231	2.93
Landholding	0.256	0.014	17.75***
log Seed	-0.179	0.086	-2.09**
Agrochemical	0.001	0.003	0.44
log Fertilizer	0.168	0.076	2.21**
log Labour	-0.109	0.149	-0.74
log Depreciation	0.296	0.191	1.55
Sigma-squared	0.403	0.062	6.55***
Gamma	0.625	0.027	23.18***
log-likelihood value	-89.8302		
Obs.	192		

Source: Field Survey, 2023. Significant at 10% (*), 5% (**), and 1% (***)

The study findings indicate that rice farmers operating under the broadcasting system exhibit a stochastic production function, with a significant Sigma-square value of 0.403 at a 1% level of probability. According to Obianefo *et al.* (2022) [14], this parameter signifies the inefficiency term within the stochastic frontier model. A higher Sigma-square value denotes increased inefficiency in the production process, unexplained by the model's variables. In this context, 40.3% of inefficiency in rice production under broadcasting is attributed to external variations not captured by farmers' managerial abilities.

Similarly, the Gamma value is noteworthy, standing at 0.625 and also significant at a 1% level of probability. Obianefo *et al*. (2022) [14] highlight Gamma as a parameter associated with technical inefficiency effects in the stochastic frontier model. A higher Gamma value indicates lower technical inefficiency. Hence, the 0.625 value suggests that approximately 62.5% of observed output stems from technical efficiency, while the remaining 37.5% is due to inefficiency.

Furthermore, the constant term (6.546), significant at a 5% level of probability, represents the baseline level of rice production under the broadcasting system when all other independent variables are zero. This implies that if all other inputs remain constant, rice production under this technology would increase by 6.546 units.

Regarding specific coefficients, the positive and significant coefficient of landholding (0.256) at a 1% level of probability suggests that larger landholdings positively impact rice output under broadcasting technology, contributing an increase of 0.256 units in production per unit increase in landholding.

Conversely, the negative coefficient of the log of seed (-0.179), significant at a 5% level of probability, implies that as seed usage increases, rice production decreases. This negative coefficient indicates that excessive seed usage may not lead to higher yields, potentially due to diminishing returns or inefficient resource allocation. Broadcasting's competitive nature for nutrients and space likely influences rice production performance.

On the other hand, the positive and significant coefficient of the log of fertilizer (0.168), at a 5% level of probability, suggests that increased fertilizer usage is associated with higher rice production under broadcasting technology. This underscores the positive contribution of proper fertilizer application to output in this context.

In summary, the model suggests that landholding and the log of fertilizer usage positively contribute to rice production under the broadcasting system, while the log of seed usage has a negative impact.

Table 2: Final maximum likelihood estimates for transplanting technology

Parameter	Estimate	Std. Error	Z-value
(Intercept)	11.574	1.552	7.46
Landholding	0.283	0.023	12.30***
log Seed	-0.195	0.025	-7.80***
Agrochemical	-0.012	0.009	-1.33
log Fertilizer	0.130	0.065	2.00**
log Labour	0.045	0.018	2.50**
log Depreciation	-0.017	0.082	-0.21
Sigma-squared	0.199	0.030	6.70***
Gamma	0.965	0.026	37.12***
log-likelihood value	-182.08		
Obs.	192		

Source: Field Survey, 2023. Significant at 10% (*), 5% (**), and 1% (***)

Additionally, concerning transplanting technology, the Sigma-square value of 0.199 indicates a 19.9% level of unobserved heterogeneity or inefficiency within the production process. Correspondingly, the Gamma value of 0.965 suggests that approximately 96.5% of observed output stems from technical efficiency, while 3.5% is attributed to technical inefficiency. A high Gamma value denotes relatively low inefficiency. Moreover, the absolute value of the log-likelihood, standing at 182.08, underscores the model's goodness of fit. Higher log-likelihood values imply better model fit, often used by researchers to compare alternative models or specifications. The intercept value of 11.574 represents the baseline level of rice production when all other independent variables are zero. Essentially, it serves as a reference point for comparison, depicting the expected output in the absence of landholding, seed, agrochemicals, fertilizer, labor, or asset depreciation.

Analyzing specific coefficients, the positive and significant coefficient of Landholding (0.283) at a 1% level of probability suggests that increased landholding correlates with higher rice production, contributing an increase of 0.283 units per unit increase in landholding under transplanting technology. This implies that larger landholdings positively influence rice output, potentially enabling farmers to adopt advanced agricultural technologies and invest in modern machinery and equipment, thus enhancing efficiency and productivity. Conversely, the negative coefficient of the log of Seed (-0.195), significant at a 1% level of probability, indicates that increased seed usage leads to a decrease in rice production by 0.195 units. This suggests diminishing returns to seed input or suboptimal seed use, possibly due to over-seeding or inadequate attention to seed quality.

The positive and significant coefficient of the log of Fertilizer (0.130) at a 5% level of probability suggests that increased fertilizer usage is associated with higher rice production by 0.130 units under transplanting technology. Proper fertilizer application positively contributes to output, but attention to nutrient management and application practices is crucial to avoid environmental concerns and diminishing returns.

Similarly, the positive and significant coefficient of the log of Labor (0.045) at a 5% level of probability indicates that increased labor supply correlates with higher rice production by 0.045 units. This underscores the role of labor in rice cultivation, particularly during peak seasons, creating seasonal employment opportunities in rural areas where agriculture is a significant economic activity.

3.2. Technical Efficiency Level of Rice Production

The technical efficiency of rice production under the two systems in the study is presented in Table 3.

Table 3: Technical Efficiency Level of Rice Production

	Broadcasting		Transplanting	
Efficiency level	**Frequency**	**Percentage (%)**	**Frequency**	**Percentage (%)**
0 - 0.250	30	15.6	3	1.6
0.251 - 0.450	57	29.7	33	17.2
0.451 - 0.650	49	25.5	48	25
0.651 - 0.850	40	20.8	74	38.5
0.851 and above	16	8.3	34	17.7
Total	192	100	192	100
Minimum	0.034		0.209	
Maximum	0.915		0.932	
Mean	0.505		0.651	
Std. Dev.	0.232		0.185	

Source: Field Survey: 2023.. Significant at 10% (*), 5% (**), and 1% (***)

Broadcasting: The efficiency levels are classified into five categories: 0 - 0.250, 0.251 - 0.450, 0.451 - 0.650, 0.651 - 0.850, and 0.851 and above. A significant portion of observations falls within the middle-efficiency ranges (0.251 - 0.650), with 29.7% falling in the 0.251 - 0.450 range and 25.5% in the 0.451 - 0.650 range. Approximately 15.6% of observations are categorized as lower efficiency (0 - 0.250), while 20.8% fall into the higher efficiency range (0.651 - 0.850). Around 8.3% of observations exhibit an efficiency level of 0.851 and above. This distribution highlights variability in technical efficiency levels among rice producers, with significant representation across different efficiency ranges. The mean efficiency level, calculated at 0.505, suggests that, on average, rice production units in the sample operate at a moderate level of technical efficiency, falling in the middle of the efficiency spectrum. The range of efficiency levels spans from a minimum of 0.034 to a maximum of 0.915, indicating diversity in efficiency levels within the sampled units. The minimum value suggests some units operate at relatively low efficiency, while the maximum value indicates highly efficient units.

The standard deviation of 0.232 indicates the degree of dispersion or spread of efficiency levels within the dataset. A higher standard deviation signifies greater variability in the data. Overall, these findings offer insights into the current state of technical efficiency in rice production under broadcasting technology, providing valuable information for targeted interventions and enhancements in the agricultural sector.

Transplanting: Conversely, a small fraction of observations (1.6%) fall within the lowest efficiency range (0 - 0.250), while the majority are spread across higher efficiency ranges. Notably, the largest percentage of observations (38.5%) falls within the 0.651 - 0.850 efficiency range, indicating a significant number of units operating at relatively high-efficiency levels. This distribution suggests that a substantial proportion of rice production units utilizing transplanting technology operate at higher efficiency levels, with a peak concentration in the 0.651 - 0.850 range, signifying a clustering of units with relatively high technical efficiency.

The mean efficiency level, calculated at 0.651, indicates that, on average, rice production units in the sample operate at a relatively high level of technical efficiency. The range spanning from a minimum of 0.209 to a maximum of 0.932 demonstrates notable diversity in efficiency levels within the sampled units. While the minimum value suggests the presence of units with lower efficiency, the maximum value indicates highly efficient units. The standard deviation of 0.185 is moderately sized, indicating a moderate degree of dispersion or spread of efficiency levels around the mean.

However, the concentration of units in higher efficiency ranges suggests that, overall, the adoption of transplanting technology in rice production has been associated with relatively efficient practices. Despite this, farmers with efficiency levels below the mean may still benefit from interventions or improvements to enhance their production processes, although they represent a small proportion of the total.

3.3. Allocative Efficiency Level of Rice Production

The allocative efficiency of rice production under the two technologies in the study is presented in Table 4.

Broadcasting: Efficiency levels are categorized into five ranges: 0 - 0.250, 0.251 - 0.450, 0.451 - 0.650, 0.651 - 0.850, and 0.851 and above. A small fraction of observations (3.6%) fall within the lowest efficiency range (0 - 0.250), while the majority are distributed across higher efficiency ranges. The largest percentage of observations (36.5%) falls within the 0.651-0.850 efficiency range, indicating a significant number of units operating at relatively high allocative efficiency levels. This distribution indicates a substantial proportion of rice production units under broadcasting technology operate at higher allocative efficiency levels, with a peak concentration in the 0.651 - 0.850 range. The mean efficiency level of 0.653 suggests that, on average, rice production units in the sample operate at a relatively high level of allocative efficiency. The range from 0.003 to 0.999 shows broad diversity in allocative efficiency levels within the sampled units. While the minimum value indicates some units with very low allocative efficiency, the maximum value indicates highly efficient units in resource allocation. The moderate standard deviation of 0.196 indicates a moderate degree of dispersion or spread of allocative efficiency levels around the mean.

Table 4: Allocative Efficiency Level of Rice Production

	Broadcasting		Transplanting	
Efficiency level	**Frequency**	**Percentage (%)**	**Frequency**	**Percentage (%)**
0 - 0.250	7	3.6	0	0
0.251 - 0.450	22	11.5	0	0
0.451 - 0.650	61	31.8	0	0
0.651 - 0.850	70	36.5	52	27.1
0.851 and above	32.000	16.7	140	72.9
Total	192	100	192	100
Minimum	0.003		0.681	
Maximum	0.999		0.966	
Mean	0.653		0.871	
Std. Dev.	0.196		0.057	

Source: Field Survey, 2023.Significant at 10% (*), 5% (**), and 1% (***)

Farmers with efficiency levels below the mean may benefit from interventions or improvements in resource allocation to enhance their production processes, although they represent a small proportion of the total. Units with very high allocative efficiency levels can serve as benchmarks for best practices, and dissemination of these practices could potentially further improve overall allocative efficiency in the sector.

Transplanting: Interestingly, there are no observations in the lower efficiency ranges (0 - 0.650). All observations fall into higher efficiency ranges. The majority of observations (72.9%) fall within the highest efficiency range (0.851 and above), indicating a significant number of units operating at very high allocative efficiency levels.

This distribution suggests an unusual but positive pattern where all observations fall in higher allocative efficiency ranges, specifically 0.651 and above, indicating a concentration of units with very high allocative efficiency.

The mean efficiency level of 0.871 is exceptionally high, indicating that, on average, rice production units in the sample operate at a very high level of allocative efficiency. The relatively narrow range of allocative efficiency, ranging from 0.681 to 0.966, indicates consistently high allocative efficiency within the sampled units. The low standard deviation of 0.057 indicates a low degree of dispersion or spread of allocative efficiency levels around the mean.

The results suggest that farmers adopting transplanting technology are, on average, making effective decisions in allocating resources, crucial for optimizing production inputs and minimizing wastage. The absence of observations in lower efficiency ranges suggests common adoption of best practices or efficient resource allocation strategies among farmers using transplanting technology.

3.4. Economic efficiency level of rice production

The allocative efficiency of rice production under the two technologies in the study is presented in Table 5.

Table 5: Economic Efficiency Level of Rice Production

	Broadcasting		Transplanting	
Efficiency level	**Frequency**	**Percentage (%)**	**Frequency**	**Percentage (%)**
0 - 0.250	76.00	39.60	7	3.6
0.251 - 0.450	72.00	37.50	42	21.9
0.451 - 0.650	36.00	18.80	74	38.5
0.651 - 0.850	8.00	4.20	68	35.4
0.851 and above	0.00	0.00	1	0.5
Total	192.00	100.00	192	100
Minimum	0.00		0.183	
Maximum	0.80		0.866	
Mean	0.32		0.567	
Std. Dev.	0.177		0.166	

Source: Field Survey, 2023

Broadcasting: A majority of observations (77.1%) fall within the lower efficiency ranges (0 - 0.450), with the highest frequency in the 0 - 0.250 range (39.60%). This concentration indicates that a significant proportion of farmers utilizing broadcasting technology exhibit lower economic efficiency levels, with no observations in the highest efficiency range (0.851 and above). The mean efficiency level of 0.32 is relatively low, suggesting that, on average, rice production units in the sample operate at a suboptimal level of economic efficiency.

The range of minimum and maximum efficiency levels, spanning from 0.00 to 0.80, signifies wide variation in economic efficiency levels within the sampled units. The minimum value of 0.00 indicates some farmers are not realizing economic benefits from broadcasting technology. A moderate standard deviation of 0.177 suggests a degree of dispersion or spread of economic efficiency levels around the mean.

These results indicate that many farmers using broadcasting technology may not be maximizing their economic benefits from rice production, possibly due to inefficient resource allocation, suboptimal input usage, or other management issues. Farmers in lower efficiency ranges could benefit from interventions, training, or support programs aimed at improving economic efficiency by adopting better farming practices, optimizing input use, or addressing other contributing factors.

Transplanting: The distribution is relatively dispersed, with no observations in the lowest and highest efficiency ranges.

THE majority of observations (74%) fall within the 0.451 - 0.650 and 0.651 - 0.850 ranges. This distribution suggests varied efficiency levels among farmers using transplanting technology, with concentrations in the 0.451 - 0.650 and 0.651 - 0.850 ranges, indicating a substantial number of farmers operating at these levels of economic efficiency. The mean efficiency level of 0.567 is moderate, indicating that, on average, rice production units in the sample achieve a reasonable level of economic efficiency.

The range of minimum and maximum efficiency levels, ranging from 0.183 to 0.866, indicates considerable variation in economic efficiency levels within the sampled units. The moderate standard deviation of 0.166 suggests a degree of dispersion or spread of economic efficiency levels around the mean.

Overall, while farmers using transplanting technology achieve a moderate level of economic efficiency on average, there is still room for improvement, especially for those in lower efficiency ranges. Interventions, training, or support programs aimed at enhancing economic efficiency could benefit these farmers. Identifying and disseminating best practices among farmers in higher efficiency ranges could contribute to broader improvements in economic efficiency across rice production.

3.5. Determinants of technical efficiency of rice farmers

The determinants of the technical efficiency of rice farmers are presented in Table 4.10.

Table 6: Determinants of Technical Efficiency of Rice Farmers

	Determinant of TE using beta regression					
	Broadcasting			**Transplanting**		
Parameter	**Estimate**	**Std. Error**	**Z-value**	**Estimate**	**Std. Error**	**Z-value**
(Intercept)	0.87	0.357	2.44	0.428	0.349	1.23
Age	0.021	0.005	4.20***	-0.018	0.005	-3.60***
Marital status	-0.005	0.068	-0.07	0.204	0.078	2.62**
Farming experience	0.037	0.006	6.17***	0.04	0.009	4.44***
Level of education	-0.013	0.014	-0.93	0.066	0.013	5.08***
Household size	0.009	0.017	0.53	-0.007	0.022	-0.32
Cooperative membership	-0.088	0.137	-0.64	-0.08	0.13	-0.62
Extension contacts	-0.007	0.067	-0.10	0.006	0.033	0.18
Access to Credit	-0.127	0.141	-0.90	-0.095	0.127	-0.75

***Source*:** Field Survey: 2023. Significant at 10% (*), 5% (**), and 1% (***)

Under broadcasting technology, the study findings reveal the following: Age: The positive estimate of 0.021, with a Z-value of 4.20***, indicates that as farmers' age increases, technical efficiency tends to increase significantly. This implies that older farmers tend to exhibit higher technical efficiency. Farming Experience: With a positive estimate of 0.037 and a Z-value of 6.17***, farming experience significantly impacts technical efficiency positively. As farmers accumulate more experience, their technical efficiency tends to improve by 0.037 units. The positive effects of age and farming experience on technical efficiency underscore the importance of continuous learning and experience accumulation in enhancing efficiency in rice production.

For transplanting technology: Age: The negative estimate of -0.018, with a Z-value of -3.60***, suggests that as farmers' age increases, technical efficiency tends to decrease under transplanting technology. This indicates that older farmers may experience a decline in technical efficiency when adopting transplanting technology. Marital Status: The positive estimate of 0.204, with a Z-value of 2.62**, suggests that married farmers tend to have higher technical efficiency. Additionally, the positive estimate of 0.066, with a Z-value of 5.08***, indicates that higher levels of education are associated with higher technical efficiency. These relationships highlight the significance of family support and educational background in enhancing technical efficiency. Policies promoting education and family support could positively impact efficiency. Farming Experience: The positive estimate of 0.04, with a Z-value of 4.44***, indicates that farming experience positively influences technical efficiency under transplanting technology. As farmers gain more experience, their technical efficiency tends to improve significantly. Supporting programs that facilitate knowledge transfer and skill development could enhance technical efficiency by leveraging the positive relationship with farming experience.

3.6. Determinants of allocative efficiency of rice farmers

The determinants of the allocative efficiency of rice farmers are presented in Table 7.

Under broadcasting: Age: The positive estimate of 0.071, with a very high Z-value of 23.67***, suggests a strong positive relationship between age and allocative efficiency. As farmers' age increases, allocative efficiency tends to increase significantly by 0.071 units. Farming Experience: The positive estimate of 0.04, with a Z-value of 13.33***, indicates that farming experience significantly impacts allocative efficiency positively. As farmers gain more experience, their ability to allocate resources optimally improves significantly. The strong positive relationships between age, farming experience, and allocative efficiency underscore the importance of experience and maturity in making optimal resource allocation decisions. Policies encouraging mentorship programs or knowledge-sharing platforms among farmers could enhance allocative efficiency. Marital Status: The positive estimate of 0.097, with a Z-value of 2.37**, suggests that married farmers tend to have higher allocative efficiency, indicating a statistically significant relationship. The positive impact of marital status on allocative efficiency implies that family support and collaboration may enhance the decision-making process related to resource allocation.

Table 7: Determinants of Allocative Efficiency of Rice Farmers

	Determinant of AE using beta regression					
	Broadcasting			Transplanting		
Parameter	**Estimate**	**Std. Error**	**Z-value**	**Estimate**	**Std. Error**	**Z-value**
(Intercept)	1.84	0.213	8.64	-0.159	0.348	-0.46
Age	0.071	0.003	23.67***	0.007	0.005	1.40
Marital status	0.097	0.041	2.37**	-0.038	0.077	-0.49
Farming experience	0.040	0.003	13.33***	0.016	0.009	1.78*
Level of education	-0.003	0.008	-0.38	0.017	0.013	1.31
Household size	-0.025	0.01	-2.50**	-0.004	0.022	-0.18
Cooperative membership	0.066	0.083	0.80	0.911	0.13	7.01***
Extension contacts	0.048	0.041	1.17	0.132	0.033	4.00***
Access to Credit	-0.104	0.084	-1.24	-0.014	0.127	-0.11

***Source*:** Field Survey: 2023. Significant at 10% (*), 5% (**), and 1% (***)

Household Size: The negative estimate of -0.025, with a Z-value of -2.50**, indicates a statistically significant negative relationship between household size and allocative efficiency. Larger household sizes are associated with lower allocative efficiency, suggesting that larger households may face challenges in efficiently allocating resources. Targeted support programs or educational initiatives addressing these challenges could be beneficial.

For transplanting technology: Farming Experience: The positive estimate of 0.016, with a Z-value of 1.78*, suggests a positive relationship between farming experience and allocative efficiency, indicating statistical significance. The positive impact of farming experience on allocative efficiency highlights the importance of accumulated knowledge and skills in making optimal resource allocation decisions. Continuous training and knowledge-sharing programs can contribute to improved allocative efficiency.

Cooperative Membership: The remarkably high positive estimate of 0.911, with a Z-value of 7.01***, indicates a very strong and statistically significant positive impact of cooperative membership on allocative efficiency. This suggests that being a member of a cooperative is associated with significantly higher allocative efficiency.

Extension Contacts: The positive estimate of 0.132, with a Z-value of 4.00***, indicates a strong and statistically significant positive impact of extension contacts on allocative efficiency. The highly significant positive impacts of cooperative membership and extension contacts highlight the potential benefits of collaborative efforts and information-sharing platforms. Cooperative structures and extension services that facilitate knowledge exchange and collective decision-making can enhance allocative efficiency.

3.7. Determinants of economic efficiency of rice farmers

The determinants of the economic efficiency of rice farmers are presented in Table 8.

Table 8: Determinants of Economic Efficiency of Rice Farmers

	Determinant of EE using beta regression					
	Broadcasting			Transplanting		
Parameter	Estimate	Std. Error	Z-value	Estimate	Std. Error	Z-value
(Intercept)	0.467	0.305	1.53	-0.751	0.305	-2.46
Age	-0.001	0.004	-0.12	-0.002	0.004	-0.46
Marital status	0.006	0.059	0.09	-0.208	0.068	-3.07***
Farming experience	-0.004	0.005	-0.85	0.002	0.008	0.22
Level of education	-0.009	0.012	-0.77	0.026	0.011	2.34**
Household size	0.002	0.015	0.14	-0.001	0.019	-0.06
Cooperative membership	-0.031	0.118	-0.26	-0.025	0.114	-0.22
Extension contacts	-0.002	0.057	-0.03	0.009	0.029	0.31
Access to Credit	-0.159	0.121	-1.31	-0.134	0.111	-1.2

***Source*:** Field Survey, 2023. Significant at 10% (*), 5% (**), and 1% (***)

The study findings indicate that none of the variables under broadcasting technology showed significance at any level. However, under transplanting technology:

Marital Status: The negative estimate of -0.208, with a Z-value of -3.07***, signifies a significant negative impact of marital status on economic efficiency. Married farmers tend to exhibit lower economic efficiency under transplanting technology. This suggests that married farmers may encounter specific challenges or constraints that hinder their economic efficiency. Policymakers might consider targeted interventions or support programs to address these challenges faced by married farmers.

Level of Education: The positive estimate of 0.026, with a Z-value of 2.34**, indicates a significant positive impact of education on economic efficiency. Farmers with higher levels of education tend to achieve higher economic efficiency. This underscores the importance of investing in education within the agricultural sector. Policies promoting education and skills development among farmers could lead to improved economic efficiency.

3.8: Hypothesis one: there is no significant difference in the technical efficiency of rice farmers.

Table 9: Hypothesis one: there is no significant difference in the technical efficiency of rice farmers under broadcasting and transplanting system

t-Test: Paired Two Sample for Means	Broadcasting	Transplanting
Mean	0.505456718	0.651119301
Variance	0.054	0.034
Observations	192	192
Pearson Correlation	0.127	
Hypothesized Mean Difference	0	
Degree of freedom	191	
t Stat	-7.26***	
t Critical two-tail	1.97	

Source: Field Survey, 2023. Significant at 10% (*), 5% (**), and 1% (***)

The analysis indicates that, on average, farmers employing transplanting technology demonstrate higher technical efficiency compared to those utilizing broadcasting technology. Furthermore, the variance in technical efficiency is notably lower for transplanting technology (0.034) in contrast to broadcasting technology (0.054). A lower variance suggests reduced variability in technical efficiency scores among farmers adopting transplanting technology. The Pearson correlation coefficient of 0.127 indicates a very weak positive correlation between the technical efficiency scores of farmers utilizing broadcasting and transplanting technologies. Despite being positive, the correlation is relatively weak.

The highly significant t statistic of -7.26*** implies that the disparity in mean technical efficiency scores between transplanting and broadcasting technologies is statistically significant. The critical t value for a two-tailed test at a 5% significance level is 1.97. Given that the calculated t statistic (-7.26) significantly surpasses this critical value, it supports the rejection of the null hypothesis. These results strongly indicate a notable difference in technical efficiency between broadcasting and transplanting technologies. On average, farmers adopting transplanting technology demonstrate higher levels of technical efficiency compared to those utilizing broadcasting technology.

Table 10: Hypothesis two: there is no significant difference in the allocative efficiency of rice farmers under the broadcasting and transplanting systems

t-Test: Paired Two Sample for Means	Broadcasting	Transplanting
Mean	0.653	0.872
Variance	0.038	0.003
Observations	192	192
Pearson Correlation	-0.004	
Hypothesized Mean Difference	0	
Df	191	
t Stat	-14.84***	
t Critical two-tail	1.97	

Source: Field Survey, 2023. Significant at 10% (*), 5% (**), and 1% (***)

The analysis indicates that, on average, farmers employing transplanting technology demonstrate higher allocative efficiency compared to those utilizing broadcasting technology. Additionally, the variance in allocative efficiency is notably lower for transplanting technology (0.003) compared to broadcasting technology (0.038). Lower variance implies reduced variability in allocative efficiency scores among farmers adopting transplanting technology.

The Pearson correlation coefficient of -0.004 indicates a very weak negative correlation between the allocative efficiency scores of farmers utilizing broadcasting and transplanting technologies. Despite being negative, the correlation is extremely close to zero, suggesting a limited linear relationship.

The highly significant t statistic of -14.84*** implies that the disparity in mean allocative efficiency scores between transplanting and broadcasting technologies is statistically significant. The critical t value for a two-tailed test at a 5% significance level is 1.97. Given that the calculated t statistic (-14.84) significantly surpasses this critical value, it strongly supports the rejection of the null hypothesis.

These results strongly indicate a significant difference in allocative efficiency between broadcasting and transplanting technologies. On average, farmers adopting transplanting technology demonstrate higher levels of allocative efficiency compared to those utilizing broadcasting technology. Farmers and agricultural practitioners may consider these findings when selecting between broadcasting and transplanting technologies, with factors such as resource availability, market conditions, and production goals playing significant roles in the decision-making process.

Table 11: Hypothesis three: there is no significant difference in the economic efficiency of rice farmers

t-Test: Paired Two Sample for Means	Broadcasting	Transplanting
Mean	0.323	0.568
Variance	0.031	0.028
Observations	192	192
Pearson Correlation	0.111	
Hypothesized Mean Difference	0	
Degree of freedom	191	
t Stat	-14.80***	
t Critical two-tail	1.97	

Source: Field Survey, 2023. Significant at 10% (*), 5% (**), and 1% (***)

The analysis reveals that, on average, farmers utilizing transplanting technology demonstrate higher economic efficiency compared to those employing broadcasting technology. Furthermore, the variance in economic efficiency is slightly lower for transplanting technology (0.028) compared to broadcasting technology (0.031). This suggests relatively less variability in economic efficiency scores among farmers using transplanting technology.

The Pearson correlation coefficient of 0.111 indicates a very weak positive correlation between the economic efficiency scores of farmers utilizing broadcasting and transplanting technologies. However, the correlation is extremely close to zero, suggesting a limited linear relationship.

The highly significant t statistic of -14.80*** indicates that the difference in mean economic efficiency scores between transplanting and broadcasting technologies is statistically significant. The critical t value for a two-tailed test at a 5% significance level is 1.97. Given that the calculated t statistic (-14.80) significantly surpasses this critical value, it strongly supports the rejection of the null hypothesis.

Thus, the results strongly suggest a notable difference in economic efficiency between broadcasting and transplanting technologies. On average, farmers utilizing transplanting technology appear to be more economically efficient than those employing broadcasting technology.

4. Conclusions and Recommendations

The analysis of the stochastic Cobb-Douglas production function reveals that farmers operating under the transplanting system demonstrated higher levels of technical (65.1%), allocative (87.1%), and economic (56.7%) efficiency compared to farmers utilizing the broadcasting system. Specifically, farmers under the broadcasting system exhibited technical, allocative, and economic efficiencies of 50.5%, 65.3%, and 32.0%, respectively.

Recommendations: The government should play a crucial role in addressing various agricultural challenges by prioritizing the elimination of poor-quality seeds and providing farmers with improved varieties and essential farm inputs. Adequate funding mechanisms should also be established to support farmers financially, alongside ensuring the provision of quality extension services. These measures are essential for enhancing farmers' overall output and productivity.

Additionally, farmers should be encouraged to adopt modern and efficient farming practices, moving away from conventional methods such as broadcasting. Utilizing improved seeds and fertilizers can significantly enhance crop yields and quality. Access to credit facilities should also be facilitated to enable farmers to invest in necessary inputs and technologies for improved agricultural production.

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