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Original Article

Leveraging the Stochastic Frontier Model for Optimal Technical Efficiency in Tanzanian Maize and Paddy Crops Production

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Abstract - Food production has remained low, failing to meet household and national requirements, which points to technical inefficiency in production. Thus, the current study estimated the Technical Efficiency (TE) of maize and paddy production in the mainland of Tanzania. Specifically, the study analyzed the technical efficiency level and examined socio-demographic and institutional factors influencing the technical inefficiency. The targeted population consisted of 3352 households and a sample of 1699 heads of households studied from the National Panel Survey of 2014/15. The study applied the Stochastic Frontier Analysis to estimate the level of Technical Efficiency. The results indicate that, on average, the typical maize and paddy technical efficiency levels are 51.45% and 33.27%, respectively. This implies that there is a possibility that, on average, small-scale maize and paddy farmers could increase output by 48.55% and 66.73% without having to employ more inputs. The majority of maize farmers lie from 0.4 to 0.6, and for paddy lie from 0.2 to 0.4, which represent 63% and 48% respectively. Thus, maize farmers were more significantly efficient than paddy farmers. But also, the frontier model revealed that younger farmers are technically efficient compared to older farmers; educated maize farmers were more efficient than lowly educated; married farmers were more efficient than unmarried. Similarly, smallholder farmers with larger households were more efficient than those with smaller household sizes.

Keywords - Maize and Paddy Production, Technical Efficiency, Household Demand.

1. Introduction

In Tanzania, the agriculture sector has undergone regular change throughout technological innovations and adaptation (Food and Agriculture Organization [FAO], 2016). This adoption of agricultural innovations has changed the traditional farming practices among many smallholder farmers and brought about noteworthy success in food crop production (Dirk *et al*. 2015). The great achievements in agricultural improvement and food crop production play a part in poverty alleviation. For example, during the period of 2006 to 2012, the minimum resources needed for physical wellbeing (basic poverty) declined from 34.4% to 28.2% respectively (World Bank [WB], 2015). This constant turn down in poverty is strongly linked with improvement in agriculture due to the fact that agriculture employs about 65 percent of the country's population, mostly located in rural areas (Bank of Tanzania [BOT], 2018). Furthermore, agriculture during the period of 2015 to 2016 contributed about 29.0 percent to 29.1 percent in total Gross Domestic Product (GDP), respectively (BOT, 2017). Food crops such as paddy and maize play important roles in food insecurity, so as to meet the consumption needs of the household's members. Its cultivation is significant in meeting the food needs of the poor rural households, particularly in developing countries such as Tanzania. Household food security will be attained if there is availability of food at relatively low prices (Odebode and Ogunsusi, 2006).

The estimation of food efficiency in agricultural production plays a significant role in agricultural development and provides helpful information in the decision-making process for the wise usage of factors of production and policy formation related to improvement in the agriculture sector. Nevertheless, efficiency plays an important role in reducing food insecurity within the community (Dessale, 2019). Kalibwani (2018) put forward that knowing the level of technical efficiency has been important in advancement in agricultural production, which is associated with increasing the wealth of smallholder farmers and poverty alleviation. Moreover, Dhehibi *et al.* (2014) put forward that enhancement in the technical efficiency of food production is the first rational step towards significantly increasing crop production in the least developed countries. Thus, smallholders' attainment of knowledge on relative factors of production to output ratio is crucial to help farms to have a better chance of surviving and policy makers to draw up appropriate policy measures (Dhehibi *et al.* 2014).

Regardless of the importance of the technical efficiency of food crops associated with increasing productivity in sub-Saharan Africa (SSA). But low food production is still a challenge among smallholder farmers in developing nations (FAO, 2017). For instance, Tefaye and Beshir (2014) agreed that significantly introduced interventions purposively to increase the level of outputs have been prone to inefficiency. The presence of production inefficiency is due to insufficient utilization of available modern technology in food crop cultivation (Tefaye and Beshir 2014). FAO (2013) points out the challenges faced by sub-Saharan Africa, namely: low purchasing power of most small holder farmers, high cost of mechanization, insufficient agricultural credit, lack of well-trained machinery operators, importation of tools and machinery of poor quality (FAO, 2013).

In Tanzania, the Ministry of Agriculture, Livestock, and Fisheries presented the main challenges facing agriculture in production at its full potential. First is the low accessibility of factors of production such as land, labour, and capital (United Republic of Tanzania, 2015a). This is attributed to insufficient financing to acquire production inputs such as labour-saving technologies, improved quality seeds, fertilizers, chemicals, and pesticides. Secondly, there is over-dependence on rain-fed agriculture due to underdeveloped irrigation (URT, 2015a). Third is the deprived rural infrastructure, such as rural roads, railways, market linkage, inadequate communication facilities, well water supply, storage, processing facilities, and electrification, which are largely underdeveloped (URT, 2015a). The fourth challenge is the low quality of agricultural products, which is associated with low market prices. Another challenge is the too little involvement of the private sector in agri-business due to inherent risks associated with agriculture. A last-mentioned challenge is associated with environmental degradation and diseases (URT, 2015a).

Paddy plays a significant role in China's agricultural production sector for the stability of food security for the majority of the community. During 2018, the leading nation in paddy production was China with an approximation of 1484490MT, followed by India with 116000MT. In East African countries, Tanzania is the leading producer of paddy with 2,046 MT, followed by Uganda and Kenya with 179MT and 79MT, respectively (FAOSTAT, 2019). In Pakistan, paddy is the first and remarkable cash and food crops that contribute to elevating the nation's gross domestic product (GDP), which contributes more than 2 million tons to food supplies and is a significant basis for employment opportunity creation to improve the livelihood of rural area communities. Its significance in the national economy and share of rice in agriculture are approximately 3.1 percent and 0.7 percent in GDP (Government of Pakistan, 2014).

Maize is the most important source of energy for approximately 962 million individuals throughout Sub-Saharan Africa and is consequently significant in increasing food security. Maize dominates the cereal industry for almost 40 percent of total cereal demanded, followed by rice, which accounts for 27% (FAO, 2015). The greater production of maize in Africa is contributed to by the expansion of the area of land, coupled with support programs that increase the convenience of modern inputs to boost small-scale farmers in cultivation/production. The first five largest maize producers in Africa continent are Nigeria, Tanzania, Madagascar, Guinea, and Mali, which all contribute nearly 65 percent of the development in cultivation. Despite remarkable expansion in production, demand continues to rise in cereal imports and is expected to exceed 49 Mt by 2025. For example, there are more than 20 percent of wheat and rice imports in Sudan and Nigeria (OECD / FAO, 2016). Moreover, within these products, all nations in the region stay in deficit, and net exports increase throughout the region over the next century, with few exceptions for rice. The Sub-Saharan Africa (SSA) region has an excess of grain, while the excess is expected to decline by 2025, the trade balance remains positive for both maize and other coarse grains (OECD / FAO, 2016). Traditional excess producers like South Africa, Zambia, and Ethiopia continue to export the biggest share, while Kenya and Zimbabwe remain the biggest shortage economies (OECD / FAO, 2016).

In Tanzania, maize and paddy are significant food crops, which approximately 5,356,000 tons and 2,194 750 tons respectively were cultivated during 2012/2013, which contribute hugely to the Tanzanian community in food security and livelihood, mostly in rural areas. From the production of both maize and paddy seasons of 2005/06 up to 2012/13, the production increased and started to decrease from 2015 to 2017 (See figure 1). In general, the trend for paddy production (tons) has normally greater than before, from 1,238,560 tons in 2005/06 to 2,194,750 tons in 2012/13 agriculture year (see figure 1) (FAOSTAT, 2018). The presence of a little fluctuation with years is due to changes in climate conditions, such as rainfall intensity, where rice-growing areas depend on the rainy season (FAOSTAT, 2018). Regionally, Morogoro has the highest paddy cultivation yield in Tanzania, followed by Mbeya, Tabora, and lastly the Njombe region. Moreover, Kusini Pemba was foremost in the Zanzibar cultivated area, followed by Kaskazini Pemba, while Mjini Magharibi had the lowest area cultivated. The total harvested land with paddy in Tanzania was approximately 991,909 ha, of which 97.8 percent was harvested in the Mainland and 2.2 percent in Zanzibar (URT, 2018).

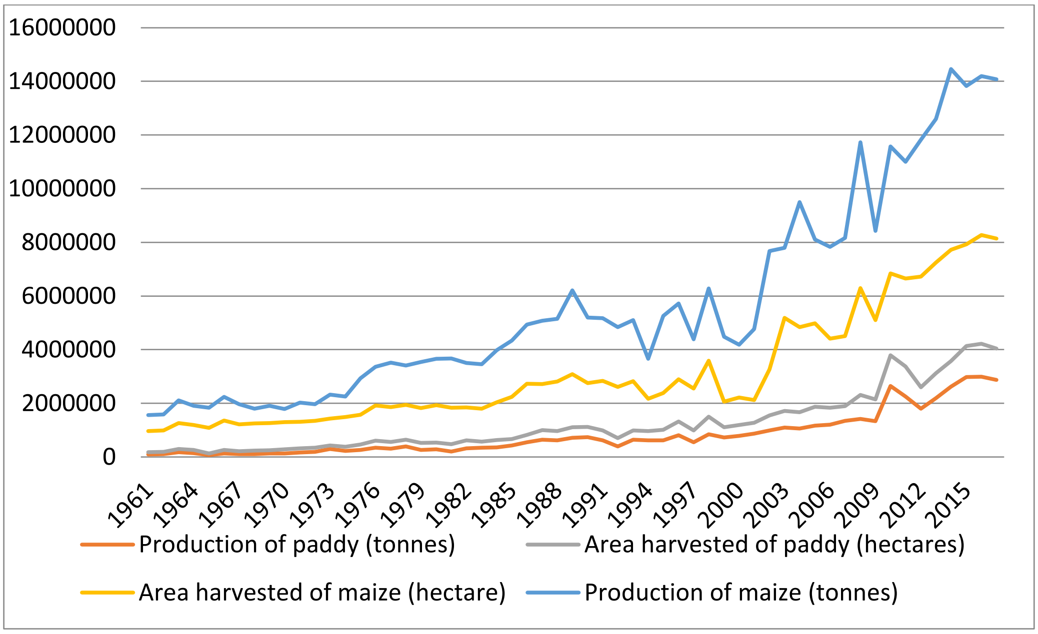

Fig 1. Production of Paddy and Maize in Tanzania (1961-2017)

Source: FAOSTAT (2022)

In Tanzania, maize is the main basket, but the participants in crop cultivation are still mainly small-scale and medium farmers using a traditional technique in cultivation and characterized by a small amount of output. About 5,766,984 tons were produced in Tanzania, where 99.9 percent were produced in the Tanzania Mainland and 0.1 percent was produced in Zanzibar. In Tanzania mainland, Mbeya represents the uppermost maize producer, followed by Tanga, Tabora, and Morogoro, while Dar es Salaam reported the lowest maize producer (URT, 2018). Figure 1.2 indicates that high production of maize in Tanzania occurred during 2008 and 2014, accounting for 5440710 tonnes and 6737197 tonnes respectively, and production fell down to 5939737 in 2017 (FAOSTAT, 2018).

In Tanzania, the policies of maize and paddy in the agriculture sub-sector formulated in different periods of time have primary objectives to increase production to ensure households' self-reliance and food security (URT, 2016). In Tanzania, there are various strategies/polices for enhancing the development of the agriculture sector, for instance, the National Development Vision, which highlights that by 2025, Tanzania's economy will have been transformed from a low production agricultural economy to a semi-industrialized one (Boulay, Morrissey, and Leyaro, 2014; URT, 2016). Secondly, Kilimo Kwanza was developed due to the global food price crisis during 2008/2009 and gave rise to renewed attention in the agriculture sector. The success of Kilimo Kwanza is a result of active involvement of the private sector, and nearly all plans were intended to improve technology adoption (e.g., improved seeds, mechanization, and fertilizer), expansion in market linkage, and encouragement in export (URT, 2016).

Moreover, from the most recent decade, a number of polices/strategies have been created to support agriculture in a more efficient way. For example, the Agricultural Sector Development Strategy (ASDS) was adopted in 2001, and gave rise to the Cooperative Development Policy (CDP) of 2002 and the Agricultural Sector Development Program (ASDP) of 2005 (Boulay, Morrissey, and Leyaro, 2014). In addition, the strategy and the ASDP are embedded in the National Strategy for Growth and Reduction of Poverty (NSGRP), which is a medium-term plan to realize Vision 2025. Kilimo Kwanza, developed in 2009, provides additional inputs for the implementation of ASDP and other programs favorable for the agricultural sector (Boulay, Morrissey, and Leyaro, 2014). These policies were created purposefully to advance accessibility and efficiency of production input; increase access to credit; advance the availability of extension services, and increase investment in rural areas, especially for irrigation and transport. Finally, the Rice Council of Tanzania (RCT) was formulated during 2015, which assists in the best engaging, supportive, coordinating, and well-prearranged trading system for rice stakeholders to improve performance, sustainability, and profitability (RCT, 2022).

Despite these agricultural strategies and policies being formulated, which are associated with short and medium-term development in agriculture, the technical efficiency has been insufficient due to an inability to match food demand among the communities. Nevertheless, advancement in agriculture remains an important policy objective in least developed countries, where agricultural productivity is still low (FAO, 2016) as a result of inefficiency of cultivation. For instance, critical food shortages were reported in some areas in the regions of Lindi, Mtwara, Singida, Dodoma, Simiyu, Mara, Shinyanga, and Arusha (BOT, 2017). During the year ending June 2016, the National Food Reserve Agency (NFRA) distributed 313,612.4 tonnes of food as follows: 32, 965.8 tonnes as subsidized food through Prime Ministers' Office to vulnerable people; 4,263.4 tonnes to prisons department; 23,999.8 tonnes to World Food Program (WFP); and 252,368 tonnes to millers/traders to increase supply and stabilize prices in the market. Table 1 presents the food production in 2021/2022 and the requirement in 2021/2022 (BOT, 2020). Thus, substantial effort must be devoted to the estimation of productive efficiency, which has been the subject of a myriad of theoretical and empirical studies for several decades since Farrell's (1957) seminal work.

Table 1: Food Production in 2016/17 and Requirement in 2020/2021

Zone	Production	Requirement	Surplus/Deficit	Self-sufficient ratio
Centre	2,174,737	1,944,045	230,692	111.9
Dar es Salaam	57,630	1,297,114	-1,239,484	4.4
Eastern	2,308,697	1,567,598	741,099	147.3
Lake	4,872,266	4,038,881	833,385	120.6
Northern	2,100,054	1,965,865	134,189	106.8
Southern	4,015,436	2,132,620	1,882,816	188.3
Total	**15,528,820**	**12,946,123**	**2,282,697**	**119.9**

Source: BOT, 2020

Different authors have been put forward concerning the technical efficiency of maize and paddy food crops production. Most of the conducted studies point out that coefficients of variables such as organic fertilizer, chemical fertilizer, labours, and machinery usage are positive and significant factors for increasing paddy efficiency level by 80.42 per cent in the Indian environment (Rajendran *et al*., 2018). In China, the average technical efficiency of indica-type rice is 0.90, which is higher than the 0.88 technical efficiency of japonica rice (Luan, 2007). In Western African countries such as Nigeria, the average efficiency score of swamp rice and upland rice is 56 percent and 91 percent, respectively (Bamiro and Janet, 2013). Gunda (2013) points out that the efficiency level of smallholder maize farmers in Zimbabwe lies on average at 77 %, and in Kenya, it lies on average at 53% (Kwena, 2016). 67% was maize technical efficiency observed in Ghana (Bempomaa & Cquah, 2014), and finally, Musaba and Bwacha (2014) report in Zambia, the level of technical efficiency ranged between 52.2% and 93.2% with a mean of 79.6%. On the other hand, different authors put forward different factors associated with inefficiency of maize and paddy production, such as education, membership to a self-help group, loan accessibility age, sex of smallholders, family size, fertilizer usage and farming experience, access to credit, and extension visit (Msuya and Ashimogo, 2007; Rahman *et al*., 2012; Zhuo *et al*., 2013; Mkanthama *et al.*, 2017; Kidane *et al*., 2015; Achandi, 2018). Thus, a current study adds a more comprehensive approach by using household data for the entire country to estimate the technical efficiency of food crop production in Tanzania mainland, which is different from other studies, which are mostly based on primary data for a specific geographical area within a particular country.

1.1. Objective of the study

To assess the technical efficiency of maize and paddy production among smallholder farmers in Tanzania mainland, and to identify socio-demographic factors that influence technical efficiency.

2. Study Methodology

2.1. Study Area

The study was conducted in Tanzania mainland using secondary data from the national panel survey wave 4. The study focused on measuring the technical efficiency of maize and paddy production among smallholder farmers in regions of Tanzania mainland of Tanzania that cultivate these crops extensively. The study only measured technical efficiency and did not consider economic or allocative efficiency. The study involved only the head of household cultivating maize and paddy producers in the mainland.

2.2. Sampling Design

The sample design for the study was a stratified two-stage design. The design consisted of 51 design strata (identified in the data as 'strataid') corresponding to a rural/urban designation for each of the 26 regions in the mainland. However, Dar es Salaam, being a pure urban area, constituted only one stratum. The allocation across the design strata was informed by the last round of the National Panel Survey (NPS) and aimed to balance multiple survey objectives and maximize precision given survey parameters. The intended sample design consisted of a new selection of 3,360 households corresponding to 420 Enumeration Areas (EAs) from the latest Population and Housing Census (PHC) in 2022. This new cohort in NPS 2021/2022 will be maintained and tracked in all future rounds between national censuses.

2.3. Data Source

This research adopted the secondary data obtained from the National Panel Survey Data 2021/2022 of Tanzania, which was generated by the National Bureau of Statistics (NBS). These data are used for academic purposes only to assess the technical efficiency of maize and paddy production among smallholder farmers in Tanzania mainland, and to identify socio-demographic factors that influence technical efficiency.

2.4. Targeted Population

The targeted population consisted of 3352 households and a sample of 1699 heads of households studied from the National Panel Survey of 2014/15, as clearly shown in Table 2. The study applied the Stochastic Frontier Analysis to estimate the level of TE.

Table 2: Number of Clusters and Households in Samples of NPS 2021/2022 by Area

Location	Cluster	Number of households
Tanzania	419	3,352
Tanzania mainland	359	2,872
Dar es Salaam	69	552
Other urban mainland	68	544
Rural	222	1,776
Tanzania-Zanzibar	60	480

Source: NBS (2022)

2.5. Ethical Consideration

After obtaining clearance and approval, the research was conducted following ethical guidelines, utilizing 2014-2015 National Panel Survey data from the National Bureau of Statistics. Confidentiality and the welfare of information were ensured, and plagiarism was checked before submission; no household member identification was published.

2.6. Variables and Measurement

The variables used in the current study are divided into two parts (i.e., dependent and independent variables). The dependent variables are maize and paddy output, measured in kilograms (kg). Furthermore, independent variables employed were divided into those incorporated in the efficiency model, which measure the efficiency score, and those incorporated in the inefficiency model. The variables included to measure efficiency score are farm size, labour, fertilizer, seed, and mechanization cost; sometimes they are named as factors of production used in the Cobb-Douglas production function, which are all continuous. Moreover, the variable included in inefficiency was divided into three groups as study-specific objectives, namely demographics and economic factors.

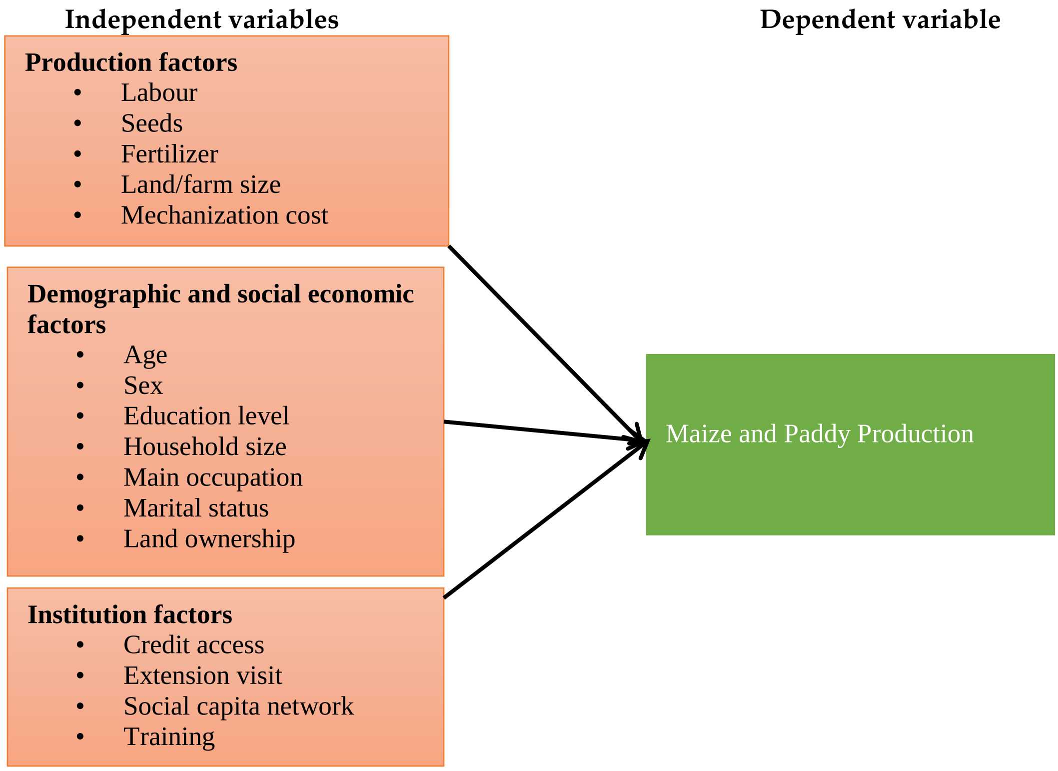

Fig. 2 A Conceptual Framework

Source: Author Construction (2023)

3. Analysis Methods

3.1. Econometric Model

First, the stochastic frontier function (parametric) is one among of the two most significant methods for estimating efficiency level. The ith company's technical efficiency is estimated by the proportion of the measured yield to the highest possible yield as indicated in equations 1-3 as follows,

$$TE = \frac{Y_i}{Y_i^*} \quad (1)$$

$$TE = \frac{\exp(X_i B)\exp(V-U)}{\exp(X_i B)\exp(\mathrm{V})} \quad (2)$$

$$TE = \exp(-U) \quad (3)$$

Secondly, the non-parametric approach has the capacity to accommodate various outputs and inputs in the assessment of technical efficiency. Nevertheless, the potential effect of random shocks, such as measurement mistakes and other noise in the information, is not taken into account (Coelli, 1996). The stochastic frontier, on the other hand, does not support various inputs and outputs. It is also more likely to be affected by problems of misrepresentation. Additionally, it incorporates stochastic elements into a model; however, it has improved its applicability in the assessment of agricultural production's technical efficiency.

3.2. Stochastic Frontier Production

A number of earlier studies specified a Cobb-Douglas production function to represent the frontier function; however, the Cobb-Douglas imposes a severe restriction on the farm's technology by restricting the production elasticities to be constant (Wilson *et al*., 1998). This study employed the flexible trans-log model to specify the stochastic border cultivation/production feature. The model shall be defined as follows;

$lnY_i = \beta_0 + \sum_{k=1}^{n} \beta_k \, lnx_{ki} + \frac{1}{2}\sum_{k=1}^{n}\sum_{j=1}^{n} \beta_{kj} \, lnx_{ki} lnx_{ji} + \varepsilon_i$ …………………………………..…………..... (4)

But we know
$\varepsilon_i = v_i - u_i$
Where ij represents the j[th] observation of the i[th] farm
Y_i Refers to the total value of rice and maize output
β_0 and β_k are parameters to be estimated
x_{ki} and x_{ji} are explanatory variables
On the other hand, the inefficiency model is estimated from the equation (5) specified below;
$u_i = \alpha_0 + \sum_{m=1}^{n} \alpha_m \, z_i$ …………………………………………………………………….……….…….. (5)

The variables z_i represent the inefficiency variables such as demographic features of the head of household, area of land cultivated, agricultural extension visit, and availability of financial assistance. Equation (6) below shows a combined estimation of a stochastic frontier function (Green, 2002).

The explicit Cobb-Douglas stochastic frontier is specified below:
$lnY_i = ln\beta_0 + \sum_{i=1}^{12} \beta_i lnX_i + V_i - U_i$ ……………………………………………..…………….……… (6)

V_i assumed to be independently and identically distributed random errors, fall under normal $N(0, \sigma_v^2)$ distribution and the U_i are non-negative one-sided random variables, known as technical inefficiency effects, which are associated with the small-scale farmers. It is assumed that the inefficiency effects are independently distributed with a half-normal distribution.$(U \, |N(0, \sigma_u^2)|)$. The equation of technical inefficiency influences the stochastic frontier of equation (12), which is defined by
$U_i = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_4 X_4 + \cdots \ldots \ldots .. + \alpha_5 X_{16} + W_i$…………………………….……….... (7)

Whereby,
Dependent variables
Y_1 Production output of paddy
Y_2 Production output of maize

Variable in the production equation
X_1 Farm size (hectare)
X_2 Labour (man-days)
X_3 Quantity of Seed used (kg)
X_4 Quantity of fertilizer used (kg)
X_5 Mechanization cost

Variables in the inefficiency equation
X_6 Sex
X_7 Age
X_8 Marital status
X_9 Household size
X_{10} Education level
X_{11} Occupation
X_{12} Social capital network
X_{13} Land ownership
X_{14} Training
X_{15} Extension visit
X_{16} Access to credit

W_i are unobservable random variables, which are assumed to be independently distributed with a positive half-normal distribution and α_i *and* β_i coefficients are unknown parameters to be estimated, together with the variance parameters, which are expressed in terms of
$\sigma^2 = \sigma_v^2 + \sigma_u^2$……………………………………………………………………………………….……. (8)
$\gamma = \frac{\sigma_v^2}{\sigma_u^2}$ ……………………………………………………………………..…………………... (9)

Where γ the parameters range from 0 to 1, the parameters of the stochastic frontier function model are estimated by the method of maximum likelihood. The model for the inefficiency effects can only be estimated when the inefficiency effects are stochastic and have a particular distributional specification.

Hence, there is interest in testing the null hypothesis that the inefficiency effects are not present, $H_0: \gamma = \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 0$.

This null hypothesis was evaluated using the test and t-test of the generalized probability-ratio. The generalized probability-ratio test is a one-sided test, as the negative values cannot be taken byγ. Under both the null and alternative hypotheses, the generalized probability ratio test needs model assessment. The model is equal to the traditional average answer function U_i under the null hypothesis $H_0: \gamma = 0$

This research is based on several hypotheses. Maybe the most evident is due to the data's very nature. The information is evaluated on the biggest field and the lowest field in which rice and maize were planted by a family during the primary rainy season harvest in 2014/2015. The second hypothesis is that production has the same function as production. In addition, the research assumes that the specification of the stochastic frontier model includes all the productivity inputs and socioeconomic features.

Lastly, the premise that the compound error term ($e_i = u + v$) is symmetrically distributed separately as $N(0, \sigma^2 v)$ random variables independent of u. Furthermore, it is presumed that u is a non-negative half-normal truncated distribution, $N(0, \sigma^2 v)$. The output of rice and maize weighing less than one bag was regarded as an outlier and was therefore excluded from the research.

In this study to examine the technical efficiency of food crop cultivation, a production economic theory was employed, and this production association can be articulated in more than a few forms, namely: Leontief (fixed coefficients), linear functional, Cobb-Douglas (Double log), Constant Elasticity of Substitution (CES), and Variable Elasticity of Substitution (VES) production functions. The Leontief function assumes zero elasticity of substitution between factors of production, the linear function assumes factors to be perfect substitutes, and the Cobb-Douglas function has a unitary elasticity of factors' substitution. The functions of CES and VES do not assume any specific value for substitution elasticity, but as their names imply, the former takes this elasticity as a constant while the latter allows it to vary. Thus, the elasticity of factor replacement determines the shape of the manufacturing function. Factor substitution elasticity is a measure of the simplicity with which it is possible to substitute one factor for another. Production variables are replacements in practice, but this connection is far from ideal.

4. Results and Discussion

4.1. Estimation of the level of technical efficiency

In Table 3, the technical scores for maize and paddy cultivation are presented, revealing that, on average, households surveyed achieved technical efficiency levels of 51.45% for maize and 33.27% for paddy. A comparison of technical scores indicates that maize smallholders exhibited higher technical efficiency than paddy smallholders. The distribution in Figures 3 and 4.1 further illustrates this difference, with a majority of maize small-scale farmers falling within the 0.4 to 0.6 technical score range (more than 63%), while most individual paddy farmers scored between 0.2 and 0.4 (comprising 48%). These findings suggest a significant discrepancy in technical efficiency between individual maize and paddy small-scale farmers.

Table 3: Technical efficiency level

Efficiency	Mean	Std.dev	Min	Max
Maize	0.5144579	0.1312569	0.2830404	0.999318
Paddy	0.3326627	0.249375	0.0536744	0.999994

Source: Author's computation based on NPS data (2020/2021)

4.2. Determinants of Technical Efficiency of Maize and Paddy Production

The results in Table 4, education exhibited a significantly negative influence on inefficiency in small-scale maize farmers, indicating that educated farmers were more efficient. However, for paddy, education had a positive but insignificant influence on efficiency, with a more substantial impact on technical inefficiency in paddy compared to maize. Extension visits positively affected technical efficiency in maize but had no influence on paddy. The age of farmers had a significant positive impact on inefficiency in paddy production, suggesting that older farmers were less efficient. Marital status showed a negative and significant impact on paddy inefficiency, implying married farmers were more efficient. Household size had a positive and significant effect on inefficiency in both crops, indicating that larger households were less efficient. Belonging to a social capital network reduced inefficiency in maize but had no effect on paddy. Paddy as the main occupation and training attendance had negative and significant impacts on inefficiency in their respective crops, suggesting that specialization and training improve efficiency. Overall, the standardized coefficient for paddy was higher in several cases, emphasizing the importance of factors in paddy cultivation compared to maize.

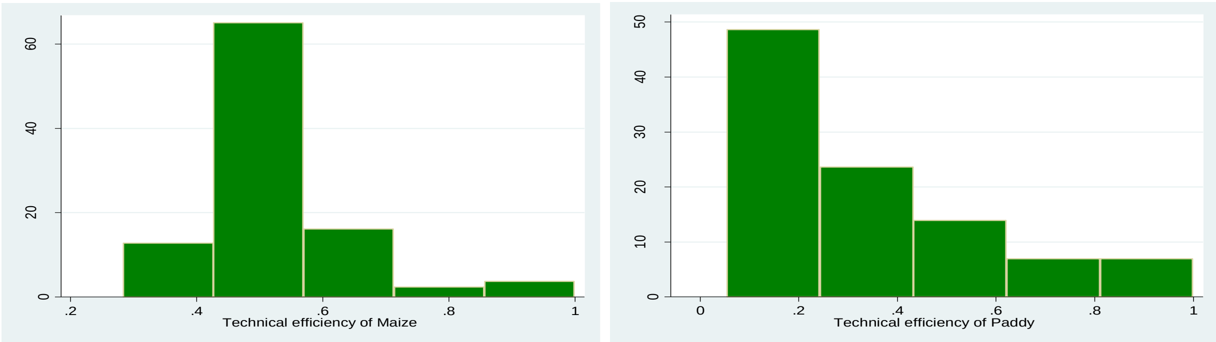

Fig. 3 Graph of the technical efficiency of Maize and Paddy

Table 4: Parameter Estimates of the Stochastic Frontier Model

	Stochastic frontier for maize				Stochastic frontier for paddy			
Frontier	**Coef.**	**Standardized Coef.**	**z**	**P>|z|**	**Coef.**	**Standardized Coef.**	**Z**	**P>|z|**
ln_labour_Hrs	0.034761	0.012845	0.31	0.760	-0.286063	0.110936	-1.70	0.089
ln_seedqnty	0.203718	0.202387	3.60	0.000	0.1495592	0.155614	5.92	0.000
ln_farmsize	0.482837	0.417095	7.02	0.000	0.6773742	0.612836	6.79	0.000
Ln_fertilizer	0.077383	0.023799	0.60	0.546	0.4276017	0.137733	2.01	0.044
Ln_mech_cost	-0.03106	-0.03049	-0.75	0.452	0.2670171	0.274481	2.98	0.003
_cons	6.561695		9.54	0.000	4.353439		3.55	0.000
Technical inefficiency								
Sex	-0.051238	-0.012773	-0.41	0.679	0.267017	0.108300	1.18	0.239
Marital status	0.005757	0.010908	0.21	0.832	0.149559	-0.20932	-2.15	0.032
Age	0.061613	0.017741	0.43	0.669	0.615849	0.185996	2.23	0.026
Education	-0.054482	-0.075965	-1.76	0.078	0.090621	0.130824	1.48	0.140
Occupation	-0.000259	-0.000085	-0.02	0.984	-0.08483	-0.29428	-2.91	0.004
Ln_Hsize	0.086393	0.047455	1.13	0.258	0.387148	0.575287	2.47	0.013
Social capital network	-0.350536	-0.09885	-1.91	0.057	0.001699	0.000005	0.00	0.997
Land ownership	-0.002162	-0.00046	-0.11	0.911	-0.014749	-0.03354	-0.33	0.743
Extension visit	0.322976	0.092059	2.33	0.020	0.1054485	0.031479	0.32	0.751
Training	0.963574	0.143651	2.57	0.010	1.452322	0.226900	1.87	0.062
Credit	0.045570	0.016271	0.37	0.712	0.211228	0.078990	-0.95	0.344
_cons	-1.35866		-1.62	0.104	-4.007366		-1.86	0.064
Usigma _cons	-8.56284		-.43	0.671	.7963757		-3.73	0.000
Vsigma _cons	-.447581		-5.44	0.000	-32.01302		-0.04	0.968
sigma_u	.013823		0.10	0.921	-.6715359		9.37	0.000
sigma_v	.7994825		24.31	0.000	$1.12 * 10^4$		0.00	0.998

Lambda (λ)	.0172899		0.12	0.905	6006310		$8.40 * 10^7$	0.000
Gamma ($\boldsymbol{\gamma}$) $\boldsymbol{\gamma} = (\frac{\boldsymbol{\lambda}^2}{1+\boldsymbol{\lambda}^2})$	0.029				0.9998			

Author's computation based on NPS data (2020/21)

4.3. Discussion for Technical Efficiency

In Tanzania, small-scale maize and paddy farmers have technical efficiency levels of 51.45% and 33.27% respectively. This indicates potential for output increase by 48.55% and 66.73% without additional resources. Maize farmers are more efficient than paddy farmers. The efficiency level is low compared to other countries. Variations exist due to different productivity inputs across Tanzania. There's substantial room for improvement in technical efficiencies. Increasing adoption and wise usage of production inputs could result in more. Mathijs and Vranken (2020) emphasize that a firm's inability to achieve optimal production efficiency can be attributed to insufficient adoption of improved technology and a lack of resources to create synergies or reach the technological frontier. In cases where production processes exhibit increasing returns to size and lack adequate funds for acquiring resources, inefficiency may result. Mwatete *et al.* (2015) demonstrated that the System Rice Intensification (SRI) technique outperformed conventional practices in rice production, suggesting higher efficiency with SRI. The lower technical efficiency (TE) score for paddy compared to maize can be attributed to paddy's greater capital and labour intensity. Paddy cultivation involves imported inputs and high mechanization costs, making it less accessible to small-scale farmers with limited resources. Additionally, paddy's reliance on rainfall and the need for significant capital investment may hinder small farmers, contributing to lower technical efficiency compared to maize (Pierre, 2000), than proportionate output increase, as these farmers achieved increasing returns to scale.

Analyzing the agricultural production performance of maize and paddy reveals variations in technical efficiency. On average, maize demonstrates higher technical efficiency than paddy, indicating differences in the adoption of production inputs such as improved seeds, fertilizer, and mechanization. Both crops exhibit low efficiency levels, attributed to prevalent traditional and subsistence farming practices in rural areas. Education's impact on efficiency is limited, as formal education often lacks practical relevance to farming, pushing individuals towards off-farm employment. These findings align with Edith's (2013) study on Ghana's irrigated rice farms, emphasizing the role of exogenous factors in technical efficiency. Input factors like fertilizer and mechanization positively affect rice production, while labour has a negative impact. Bempomaa and Acquah (2014) also support the idea of varying efficiency levels in maize farming, with a mean technical efficiency of 67%. This suggests that maize farmers could potentially increase output by 33% without additional resources, highlighting the influence of farm size, labour, and fertilizer on production efficiency.

The findings on paddy's technical efficiency (TE) in this study are inconsistent with Hua *et al.* (2016), who reported a general mean effectiveness of 78.4% in Cambodian rice production, indicating room for improvement in technical effectiveness. Hua *et al.* (2016) attributed variations in TE scores to differing levels of capital expenditure in agricultural machinery, rice harvested area, and fertilizer application across regions. In contrast, Kallika *et al.* (2010) found TE scores ranging from 49.69% to 97.17% in their study on Thai rice farmers, differing from the current study on paddy TE in Tanzania mainland. Possible explanations include geographical differences, with Thailand being a larger rice producer than Tanzania. Additionally, Musaba and Bwacha (2014) conducted a consistent study on maize production in Tanzania mainland, revealing a mean technical score ranging from 52.2% to 93.2%, suggesting a potential 20.4% increase in maize production through more efficient technology usage.

The research findings on the average technical efficiency score of maize align with similar studies by Nyariki *et al.* (2015) in Kenya and Kidane *et al.* (2015) in Tanzania, indicating the influence of factors such as fertilizer use, seeds, and fragmentation index on technical efficiency. For paddy cultivation, the study supports the Cobb-Douglas production theory, with statistically significant factors including mechanization cost, quantity of seed, farm size, quantity of fertilizer, and labor. The results highlight the importance of mechanization in paddy yield realization, with increased mechanization cost positively impacting output. However, an excess of labor per hectare may be currently employed, leading to decreased paddy yield. Additionally, a unit percent increase in fertilizer usage positively affects paddy yield, although the relationship is not strong. The study's findings are consistent with Ahmadu and Alufohai's (2012) research on the technical efficiency of irrigated rice farmers in Niger state, emphasizing the positive impact of seed usage on yield.

4.4. Discussion for Determinants That Influence Technical Inefficiency

The analysis indicates a negative relationship between education and inefficiency between maize and paddy production, revealing that educated small-scale maize farmers are more efficient, aligning with findings in studies by Afrin *et al.* (2017) in Bangladesh, Zhao and Barry (2014) in China, Donkoh *et al.* (2013) in Ghana, Khai and Yabe (2011) in Vietnam, and Bäckman *et al.* (2011) in north-western Bangladesh. Education's influence on agricultural production is attributed to skill-building, including literacy for following instructions and numeracy for calculating the correct dosage of inputs. Extension visits positively impact efficiency in maize production, consistent with results reported by Gebrehiwot (2017) in Ethiopia, Kallika *et al.* (2010) in Thailand, Edith (2013) in Ghana, and Yannick *et al.* (2018) in Cameroon. These studies suggest the need for widespread agricultural extension services in rural areas to share knowledge and promote good agricultural practices. However, the findings on extension services differ from studies by Afrin *et al*. (2017) in Bangladesh, Zhao and Barry (2014) in China, and Bäckman *et al*. (2011), indicating a potential geographical influence on the relationship between extension visits and inefficiency.

By providing information, extension services help smallholder farmers reduce their transaction costs in accordance with the institutional theory (Bhardan, 1989). To reduce risk, agriculture extension officers provide vital advice on seed, fertilizer, and crop selection. Older farmers are less efficient than younger ones when it comes to technical inefficiency in paddy production. This lends credence to the theory that older small-scale farmers are less productive than younger ones, maybe as a result of lower energy or aversion to new technology. While Zhuo *et al*. (2013), Ahmadu and Alufohai (2012), and Musaba and Bwacha (2014) concur that older farmers are typically less efficient than younger ones, citing factors like resistance to new practices, Villano and Fleming (2006) found that elderly farmers can improve technical efficiency with experience.

The technical inefficiency in paddy output is negatively impacted by marital status, suggesting that married farmers are more productive and efficient. This is in line with Ngeywo and Shitandi's (2015) emphasis on treating singles in farming equally. Ohen and Umar (2018) point out that married farmers' combined family effort results in higher agricultural output.

Technical inefficiency and household size have a positive correlation, suggesting that larger households are associated with lower productivity and efficiency. This result is consistent with Zhao and Barry's (2014) theory that households are more motivated to work harder when their dependency ratio is larger. Kidane and Ngeh (2015), on the other hand, contend that larger households provide more labour for farming, contrary to the findings of Ogada *et al*. (2014), who reported poorer efficiency in homes employing hired labour.

Technical inefficiency is negatively impacted by social capital networks, suggesting that membership in these networks improves paddy production efficiency. These networks influence the purchase of inputs like seeds and fertilizer by facilitating the exchange of knowledge on best farming techniques. This is consistent with Chirwa's (2013) findings, which emphasize how cooperative networks lessen inefficiency and the external effects of social capital networks on non-members.

According to Musaba and Bwacha (2014), cooperative social capital networks lessen technological inefficiency. This investigation confirms their findings. Social capital networks help farmers in Zambia obtain Farm Input Support Program (FISP)-subsidized inputs. Social capital networks, which emphasize how information transmission lowers transaction costs, risk, and uncertainty, are also consistent with institutional theory. According to Coase (2000), small-scale farmers can increase production efficiency by having timely knowledge of input prices, which is made possible via social capital networks that provide access to fair markets.

Mainly, farmers whose primary occupation is paddy farming show a significant negative association at the 1% level with the stated hypothesis. This implies that those relying on paddy farming as their main source of income exhibit a decrease in technical inefficiency or an increase in efficiency compared to those with alternative livelihoods. Farmers focusing on paddy farming, alongside non-farm income, tend to invest more resources, both material and managerial, resulting in higher efficiency. This aligns with Bempomaa and Acquaah's (2014) argument that off-farm activities can reduce technical efficiency in paddy production. Contrary to the positive connections found by Kibirige *et al*. (2014) and Dlamini *et al*. (2012), the negative relationship here suggests that engaging in non-farming activities may compromise farmers' attention and commitment to crop cultivation, leading to reduced efficiency.

Positive and statistically significant training impact at 10% and 5% for paddy and maize aligns with the research hypothesis. Small-scale farmers attending training exhibit increased inefficiency, lowering technical efficiency and productivity compared to those without training. Training enhances the decision-making capacity of household heads, particularly in good cultivation practices. Household heads with agricultural training are more efficient than those without. Results support Kuwornu *et al*. (2013) and Tefaye and Beshir (2014), indicating a positive and significant influence of training on technical efficiency. Strengthening farmer training is crucial for practical field application, contrasting with Al-hassan (2012), who showed a negative and insignificant relationship between training and technical inefficiency. Farmers applying knowledge from training on cultivation practices can reduce inefficiency.

5. Conclusion and Recommendation

5.1. Conclusion

This study highlights the relatively low technical efficiency among small-scale maize and paddy farmers in Tanzania, with average scores of 51.45% and 33.27% respectively. The findings reveal that substantial output gains of up to 48.55% for maize and 66.73% for paddy can be achieved through better utilization of existing resources. Maize farmers outperform paddy farmers, partly due to the lower capital and labour requirements in maize cultivation. The low efficiency levels, compared to other countries, reflect constraints in technology adoption, access to quality inputs, and systemic reliance on traditional farming practices. Factors such as fertilizer use, mechanization, and farm size significantly influence productivity, while excess labour and capital intensity in paddy production contribute to inefficiencies.

Moreover, the analysis of inefficiency determinants underscores the critical role of education, extension services, training, social capital, and farmer demographics. Educated and trained farmers, especially those with access to extension support and social networks, tend to be more efficient. Conversely, larger household sizes and engagement in off-farm activities can negatively affect farm performance. The results emphasize the need for policy interventions that promote practical farmer training, enhance access to productive inputs, strengthen cooperative networks, and improve targeted extension services. Addressing these inefficiency drivers will be vital in unlocking the productivity potential of Tanzania’s smallholder farming sector.

5.2. Recommendations

a) The study suggests that small farmers should use improved seeds, fertilizers, and contemporary machinery to increase rice and maize production efficiency in Tanzanian farming.
b) There is the need for NGOs and the Ministry of Agriculture work together to ensure the availability and affordability of these inputs. Thus, government and non-governmental organizations (NGOs) should improve and supply extension services to farmers on time, inspiring field staff to provide good instruction on methods such as timely planting and weed management, adequate fertilizer application, and insect control, thereby enhancing overall farm efficiency.
c) The authorities, like the government at local government levels, should encourage maize and paddy farmers in Tanzania to develop or join farmer-led organizations such as Mtandao wa Vikundi vya Wakulima Tanzania (MVIWATA) in order to improve production information dissemination and input procurement.
d) Stakeholders, non-governmental organizations, and the Ministry of Agriculture should promote and strengthen these associations in order to increase farmer output. Additionally, raising small-scale farmers' education levels through adult literacy programs is advocated to improve resource use efficiency and income. Then, attending training sessions on maize and paddy production activities is encouraged in order to boost farmer efficiency by keeping them up to date on new technology and best practices. Farmers must attend seminars on a regular basis to stay current on advances in farm mechanization, crop selection, soil and water management, post-harvest processing, farm planning, budgeting, organic fertilizer use, and value-added activities, and the impact of climate change.

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