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How Climate Variability Influence Rain-Fed Rice Production Frontier: Northern Agro-Ecology of Uganda

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Abstract

This study examined the impact of climate variability on rain-fed rice production in the northern agro-ecological zone (NAEZ) of Uganda. We used stochastic frontier model to analyse a four year (2013-2016) farm-level data. The results of the maximum likelihood estimates revealed negative effects of mean rainfall and coefficient of variation in rainfall on rice output but coefficient of variations in mean temperature was positive. The production frontier exhibited increasing returns to scale technology, low level of efficiency was exhibited and inefficiencies were driven by location, age, plot size and number of crops. We therefore conclude that rice farmers are producing inefficiently and increased variability in climate has adverse effects on rice production frontier but inefficiencies are being propelled by farmers' characteristics. Based on the findings, we recommend promoting awareness about climate variability and potential response alternatives for rice production and further research into coping strategies being used by rice farmers.

Keywords: Production frontier, Rainfall, Rain-fed rice, Temperature
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1 INTRODUCTION

Rice is grown and consumed throughout the world as the major source of calories (FAO, 2017; GRiSP, 2013). In Uganda, rice is one of the main cereal crops that ranks 3rd after maize and sorghum. Together with other food crops, it contributes 12.1% to the gross domestic product (GDP) and there are 103,570 rice growing households (GoU, 2009; UBOS, 2010). Historically, rice production acreage in the country has grown rapidly by 59% since 1997 (at an annual rate of 5%) while output increased by 169% during the same period. As a result, the Government of Uganda considers rice as a strategic crop with remarkable potential to contribute to increasing food and nutrition security, incomes and livelihoods of the rural population (GoU, 2010). Consequently, the National Rice Development Strategies (NRDS) was put in place as a measure for rice promotion (GoU, 2009).

Rice is traditionally a wetland crop, requiring reliable amount of moisture and warmth during growth stages (GRiSP, 2013; IRRI, 2015). However, only 2% of the country's rice cultivated area is irrigated compare to 11% in Africa and 53% worldwide, a situation which makes rice cultivation vulnerable to climate variability. Currently, up to 53% of the cultivation is lowland rain-fed and 45% is upland rain-fed while NAEZ is entirely rain-fed currently (Akongo, Gombya-Ssembajjwe, Buyinza, & Namaalwa, 2018; Haneishi, 2014). Like other countries in Sub-Saharan Africa (SSA) Uganda relies heavily on rain-fed weather-sensitive agriculture and thus vulnerable to negative variations in climatic conditions (Caffrey et al., 2013; IPCC, 2012; Thornton, Ericksen, Herrero, & Challinor, 2014). Mubiru, Komutunga, Agona, Apok, & Ngara (2012) analyzed historical data on rainfall and temperatures and found high variability in rainfall across different parts of Uganda. The researchers informed that the growing seasons are being shortened by quantity and distribution of rainfall while increases in maximum temperature (5 to 8%) and minimum temperatures (1 to 4%) between 2006 and 2010 are causing warmer days and nights. Experts therefore believe that variability in temperature and rainfall will significantly alter the country's production conditions (Caffrey et al., 2013; Kaggwa, Hogan, & Hall, 2009; Kansiime, Wambugu, & Shisanya, 2013). For instance, earlier flowering and maturity of crops have been associated with higher temperatures with yields reducing by 90% for a night temperatures of 32ºC (GRiSP, 2013; Mubiru et al., 2012). Drought besides deficiency in nitrogen has also been highlighted as one of the major challenges facing rice production (NEWEST, 2012). Shakoor, Saboor, Baig, Afzal, & Rahman (2015) observed susceptibility of rice crop to rising maximum temperature and increased rainfall in Pakistan. In Nigeria, differential impact of rainfall and temperature on rice revenue between irrigated and rainfed systems and between months has been reported (Ajetomobi, Abiodun, & Hassan, 2011). Within east Africa, both intra-seasonal and inter-seasonal variability in temperature and rainfall have been shown to influence cereal yields, rice inclusive (Rowhani, Lobell, Linderman, & Ramankutty, 2011). In Uganda yields are remarkably low at 2.5t ha^{-1} compared to global average of 4.6t and potential average of 5 to 8t depending on variety and production system (GoU, 2009; Luzi-Kihupi, 2011; UBOS, 2010, 2017). Meanwhile average as low as 1.7 to 1.9t ha^{-1} is exhibited in northern region, the country's second largest and oldest rice producing area (Akongo et al., 2018). A situation partly attributed to poor climatic conditions, abiotic and biotic factors (GoU, 2009; Haneishi, 2014; UBOS, 2010). For instance, a decline in production from 132,000tons (2003) to 121,000 tons (2004), from 232,986 tons (2011) to 213,772 (2013), and from 238,000 tons (2015) to 215,000 tons (2016) and persistent decline in agricultural GDP were attributed to extreme climate (UBOS, 2005, 2015, 2016). Meanwhile Hyuha, Bashaasha, Nkonya, & Kraybill (2007) and Asiimwe (2009) in their study of efficiencies in rice production also revealed that rice farmers in different parts of the country are producing inefficiently. Barungi & Odokonyero (2016); Caffrey et al. (2013); Elepu & Dalipagic (2014) mentioned exposure of rice farmers to climate variability particularly in the NAEZ. Akongo et al. (2018) observed declines in rice yield and variability in rainfall and temperature by 35% and 3.9%, respectively between 2013 and 2016 in the NAEZ.

However, there is still limited empirical evidence linking climate variability to rice production in the country. As a result, interpreting low trends in yield and identifying potential policy responses has proved difficult due to unclear understanding of factors affecting its production (GoU, 2009). Firstly, biotic and abiotic factors have been reported as causes of low production (GoU, 2009; Kijima, 2012; Miyamoto et al., 2012; NEWEST, 2012; Odogola, 2006; UBOS, 2010). Secondly, rice production is dominated by rain-fed cultivation the fact that makes it highly sensitive to climate variability (Caffrey et al., 2013; Rowhani et al., 2011). The declines in yield are of particular concern given the well documented variability in rainfall and temperature in the country (Kansiime et al., 2013; Mubiru et al., 2012; Wasige, 2009). Given the background, this paper was motivated by the need to examine the relationship between climate variability and rain-fed rice production frontier. The specific objectives were three folds: first to determine influence of rainfall and temperature on the rice frontier, second to determine the level of inefficiencies in rice production, and third to assess influence of farmers' characteristics on inefficiency.

2 METHOD AND MATERIAL

2.1 Location, climate, vegetation and socio-economic characteristics: The study was conducted in NAEZ (Figure 2.1). It lies between Latitude 03°80' N and Longitude 33°00' E with elevations varying between 600 and 1,200 meters above sea level (GoU, 2012). Overall, the NAEZ covers an area of 42,021.2km^2, representing 18% of total land area of Uganda (UBOS, 2016). The zone was chosen because it is the second longest and major rice producing area accounting for 21% of national acreage after eastern region (UBOS, 2010). It's also more prone to climate variability compared to the rest of the country (Akongo et al., 2018; Caffrey et al., 2013; Wasige, 2009).

The NAEZ is categorized by tropical dry climate with bimodal rainfall patterns (GoU, 2012). It has long-term mean annual rainfall of 1434mm however; the mean varies from year to year and season to season. To the extreme north, slightly low rainfall of 1291mm is received. In terms of rainy days, the area receives slightly above 120 rainy days per year although this also varies (GWIEA, 2013; UBOS, 2016; UNMA, 2017).

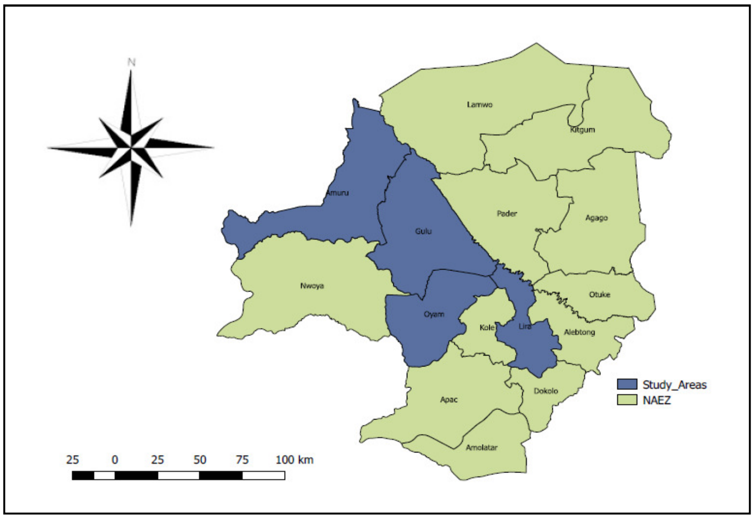

Figure 2.1: Northern agro-ecological zone

Mean temperature ranges from 17°C to 29.2°C however, the years 2012 to 2016 registered annual average exceeding minimum 19°C and maximum 30°C. To the extreme north of the zone extreme high temperatures of 18°C to 32°C is experienced (LDLG, 2011; UBOS, 2016; UNMA, 2017). The region is known to have relatively low rainfall and high temperatures relative to the rest of the country. Unclear trends have also been observed in the recent years: the lowest annual rainfall in ten years was received in 2011 (1197mm) while the highest amount was experienced during 2013 (1926mm). These trends clearly show some kind of variability in rainfall and temperature. The zone is characterised by sandy-clay to clay-loamy soils. The predominant vegetation is tropical vegetation and intermediate savannah grassland with scattered trees in the eastern districts, many of which are the valuable Shea trees. The cultivatable land constitute 24,610.8km^2 which is 58.6% of the total land (GoU, 2012; UBOS, 2016). The NAEZ is home to 3.6 million people of whom women constitute 51.5% (UBOS, 2016). Agriculture is the backbone of the economy and more than 81% of the population is engage in subsistence farming. Agricultural households totals to 533,321 while rice growing households are 230,279 (43.2%). Diversity of crops grown includes rice and other cereals, pulses, legumes, horticulture, roots and oil crops. Rice is rapidly becoming a major cash crop and the zone produced about 21% of the national production (UBOS, 2010).

2.2 Data: We adopted both descriptive and exploratory designs and the research approach was both qualitative and quantitative in nature. The study population consisted of rice farmers from rain-fed production systems.

Multiple-stage stratified sampling procedure was used to identify the farmers and the final sample of 240 rice growing farmers selected (CRS, 2012). Subsequently data was collected repeatedly from the same rice farmers for four production period using semi-structured questionnaire administered between 2014 and 2017 while rainfall and temperatures were obtained directly from the weather stations belonging to the Uganda national meteorology authority (UNMA). Since the study utilized data belonging to weather stations and not actual observation on-farm, each farm was assigned data for weather station within its proximity (Hughes, Lawson, Davidson, Jackson, & Sheng, 2011; Lazzaroni & Bedi, 2014). Subsequently, new rainfall and temperature data were reconstructed for each farm from the time rice was planted to harvest. This was intended to provide the nearest approximation of rainfall and temperature conditions since the different rice varieties have different growth duration and so require different amount of rainfall. The same approach was also used to reconstruct temperature (maximum and minimum). This was on presumption that both climate variables are critical during crop growth cycle (GRiSP, 2013; IRRI, 2015; Tsuboi, 2011).

2.3 Analysis: In this paper, we assumed that the observed output is often a result of a series of economic activities undertaken in the production process (transformation of inputs into outputs) such that the sub-elements must perform to their equilibrium in order to obtain optimal production. However, climate variability in terms of changing rainfall patterns and temperature conditions is a distortion that undermines the natural production system. Consequently, mismatch between the amount of rainfall and temperature conditions and timing of input application affects the production frontier. It is for this reason that certain farms may become inefficient / producing inside the production frontier (Hughes et al., 2011). Similarly, managerial behavior of the farmer as a result of his/her characteristics may directly influence production efficiency through their decisions. These relationships, therefore, contribute and sum up to production improvement or deterioration.

We therefore operationally define climate variability as changes (mean state) in intra-seasonal and inter-seasonal distribution of rainfall and temperatures during crop growth period (Climate literacy, 2009; IPCC, 2012). And we view production efficiency (technical efficiency) as the maximum possible output that can be produced with a given level of inputs and the best available production technology at a particular point in time. We therefore adopted stochastic frontier model to model this relationship (Ajetomobi et al., 2011; Belotti, Daidone, Ilardi, & Atella, 2012; Coelli, Rao, O'Donnell, & Battese, 2005; Hughes et al., 2011; Kumbhakar & Lovell, 2000). The model helps to predict and estimate efficiency and also account for statistical errors and inefficiencies. Give this definition, we specified the stochastic production frontier involving outputs and n-inputs and climate variables as follows:

$$y_{it} = f(x_{it}, z_{it}, \beta) + \varepsilon_{it} \tag{2a}$$

Where; y_{it} denote output of ith production unit, x_{it} is a vector of input, z_{it} is a vector of rainfall and temperature, β is the vector of technology parameters. The composed error term ε_{it} is the sum of a normally distributed disturbance (v_{it} and u_{it}), u_{it}, representing associated inefficiency (Coelli et al., 2005; Kumbhakar & Lovell, 2000). The farmers' major objective is to maximize production in equation 2a conditioned on critical inputs (x, z). However, the decision making unit may not be fully efficient due to slackness in production capabilities. As such, the farmers take climate (z) as given, and therefore adjust inputs (x) accordingly to maximize output. For instance, availability of moisture is of significance, particularly for rain-fed cultivation which is dependent on rainfall i.e. too much or too little rainfall may affect crop production (GRiSP, 2013; Lazzaroni & Bedi, 2014; IRRI, 2015). On the other hand, too low or extreme high temperature can impair plant growth. Therefore failure to include rainfall and temperature is likely to result in biased estimates of production frontiers and efficiency levels (Hughes et al., 2011). For example, farms that have experienced relatively low rainfall will be treated as being relatively inefficient. In addition, increases in both day time (maximum) and night time (minimum) temperature can exert negative effects on crop yield (Thornton et al., 2014). Furthermore, occurrence of drought across years and across many farms may result in incorrect estimate of technological progress. As a result, some studies have included climate variables in the production function (Ajetomobi et al., 2011; Haneishi et al., 2013; Rowhani et al., 2011; Shakoor et al., 2015). Haneishi et al. (2013) demonstrated an increase in rain-fed rice output as a result of an increase in annual rainfall. However, mixed or indecisive results have also been reported (Ajetomobi et al., 2011; Rowhani et al., 2011; Shakoor et al., 2015). Although some studies have also included irrigation as proxy for moisture availability (Hasnain, Hossain, & Islam, 2015; van Long & Yabe, 2012). Therefore, one way to account for variation in environmental conditions is to include rainfall and temperature as inputs alongside traditional market inputs, such as land, labour and capital. Other environmental variables relevant to rice production are soil type/quality which has been taken care-off within the production system (the lowland system is characterized by clay-loamy while upland is mainly sandy-clay). Therefore efficiency is measured as a ratio of actual output to potential output and thus from equation 2a, efficiency at each data point can be calculated as:

$$TE_{it} = \exp(-u_{it}) \tag{2b}$$

Slackness in production capability in (2a) is assumed to be restricted by managerial factors and so we adopted the model proposed by Battese & Coelli (1995) in which inefficiency effects are defined:

$$u_{it} = g_{it}\delta + w_{it} \tag{2c}$$

Where g_{it} is explanatory variable associated with inefficiency effects; δ is unknown parameters to be estimated; and w_{it} is unobservable random variables. A negative value suggests a positive effect and vice versa. Taking natural log of (2a), we specified Cobb-Douglas model (Battese & Coelli, 1995):

$$lny_{it} = \beta_0 + \sum \beta_i lnx_{it} + x_{1it} + x_{2it} + lnz_{rt} + lnz_{tt} + z_{rt} + z_{tt} + T_i + v_{it} - u_{it} \tag{2d}$$

Where; lny_{it} is the total output of rice in year t for the ith farmer, x_{it} are area planted, quantity of seeds, labour input and dummies for oxen and tractor service. z_{it} are mean rainfall, mean temperature and coefficient of variations in rainfall and temperature. T is time trend representing technological progress, ln are natural logs and β_s are unknown parameters. Coefficient of variation is computed according to (Curto & Pinto, 2009). We specified inefficiency effects model to identify its determinants (Battese & Coelli, 1995):

$$u_{it} = \delta_0 + \sum \delta_i g_{it} + v_{it} \tag{2e}$$

Where; g_{it} are location of the farm, production season, sex and age of the farmer, extension support, farm size, income and crop diversification and δ_s are unknown parameters to be estimated. We conducted likelihood ratio tests to identify appropriate distribution assumption (Ahmad & Bravo-Ureta, 1996), assumption of time invariant efficiency (Battese & Coelli, 1988) against time decay efficiency (Battese & Coelli, 1992). We also tested whether effects of climate variability on the frontier and effects of managerial factors on inefficiency are statistically different from zero. Variance inflation factors (VIF) was used to check for multicollinearity. We used critical values obtained from Johnson & Bhattacharyya, (2006). We adopted a one-step procedure as opposed to the two step procedure by introducing equation $(2e)$ into $(2d)$ (Belotti et al., 2012; Schmidt, 2011). And finally, we used the sfpanel option of the maximum likelihood estimation (MLE) procedure developed by Belotti *et al.* (2012) to fit the model in STATA 13.0 software. Prediction of technical efficiency was done via exp(-E(u|e)).

3 RESULT AND DISCUSSIONS

3.1 Descriptions of variables: The descriptive statistics for variables used in the SFM are presented (Table 3.1). Half of the sampled farmers were located in the lowland rainfed system while up to 84% cultivated rice in the first season. An average age of the farmer was 38 years suggesting relatively youthful population. About 44% of the farmers cultivated 0.4 hectares and below while an average annual income obtained from rice was Ugx 3.4 million and farmers grew approximately 4 crops. Ninety-three percent of the farmers were male heads and a total of 71% of the farmers had extension supports. Total output per plot was 1.07t, area cultivated was 0.63 hectares, and quantity of seed planted was 61 kilograms and total man-days of labour were 116 days. Up to 66 and 8% of the farmers respectively used oxen and tractor services. Rice plots received average of 588 mm of rainfall and mean temperature of 23.8ºC during growth period (planting to harvest). Coefficient of variation in rainfall and temperature were 34.9 and 3.9%, respectively.

Table 3.1: Descriptive statistics

Variable	Mean	Std. Dev.	Min	Max
System (1=lowland)	0.5	0.5	0	1
Season (1=first)	0.84	0.37	0	1
Sex (1=male)	0.93	0.25	0	1
Age	37.77	13.56	10	73
Extension (1=yes)	0.71	0.45	0	1
Crop diversification	3.65	2.18	1	15
Rice income (≥ 3.5million)	0.44	0.5	0	1
Farm size (≤ 0.4 hectare)	0.44	0.50	0	1
Output (t)	1.07	1.3	0.01	21
Area (Ha)	0.63	0.64	0.04	12
Seed (kg)	60.65	62.76	4	840
Labour (days)	115.6	105.66	2.5	905
Oxen services (1=yes)	0.66	0.47	0	1
Tractor services (1=yes)	0.08	0.27	0	1
Rainfall (mm)	588.16	211.67	261	1279
Mean temperature (ºC)	23.79	0.65	21.95	24.86
Coefficient of variations in rainfall (%)	34.89	18.49	3.41	78.43
Coefficient of variations in temperature (%)	3.9	1.87	0.35	8.96

3.2 Production frontier: The assumption of absence of inefficiency effects was rejected and the value of gamma showed that 96% of the total variations in the output were due to inefficiency. The model incorporating half-normally distributed one-sided error was rejected infavour of truncated normal distribution. The assumption of time-invariant efficiency was rejected as well. Lastly, assumption that climate variables does not influence production frontier and farmers' factors does not influence inefficiency, respectively were also strongly rejected. The rest of analysis proceeded with SFM of Cobb-Douglas truncated normal distribution and time decay specification.

The MLE for the production function showed positive relationship between output and general inputs as expected meanwhile the signs on the coefficients of climate variables were mixed (Table 3.2). Area cultivated had the highest response to output implying that a unit increase in area cultivated increases rice output substantially by 0.75t. The high elasticity of output from area implies that significant increase in output will be attained through area expansion. Asiimwe (2009) reported fairly similar range at 0.62. Output dependent on land is not limited to Uganda; Enwerem & Ohajianya (2013) also observed similar scenario among Nigerian rice farmers. A unit increase in seed planted resulted in an increase in output by 0.12t. This was attributed to the fact that upland farmers applied relatively lower seed-rate (92 kg ha^{-1}) than recommended average under broadcast method. The response from seed in this study is fairly higher than 0.01t for rainfed farmers elsewhere in the country (Asiimwe, 2009; Haneishi et al., 2013; Miyamoto et al., 2012). Positive response of output to seed (0.3t) has also been reported in West African region (Ajetomobi, 2009). Conversely, additional man-day increases rice output by 0.026t. Similarly, increased access to oxen and tractor services translates into an increase in output by 0.09 and 0.11t, respectively.

Coefficients of mean rainfall and coefficient of variation in rainfall were statistically significant but negative; the results imply that an increase in rainfall amount by 1mm during the growth period translates into a reduction in rice output by 0.8t. Likewise a 1% variation in mean rainfall brings about 0.1% reduction in output. Haneishi et al. (2013) reported contrary result where a 1mm increment in mean rainfall increased rice yield by 1.2kg under rain-fed cultivation in country. In Pakistan, Shakoor et al. (2015) confirmed increment in rice output from an increase in mean rainfall but he authors also revealed that simulations increase in rainfall and temperature will have negative effects on rice for 2030. The contrary result could be attributed to high rainfall variability experienced during the growth period between 36 and 1503mm as captured by coefficient of variation (at 35%). In addition, rainfall received during the growth period (588mm) was less than 2,500mm required in rice production (Bouman, 2009; IRRI, 2015). However, the results agrees with other studies in the country that rainfall extremity (erratic rains) affects rice crop (Barungi & Odokonyero, 2016; Odogola, 2006; UBOS, 2010). Elsewhere, (Ajetomobi et al., 2011) also observed mixed results where rice revenue reduced by 62911 and 52421 Naira ha^{-1}, respectively for a unit increase in January and annual rains but an improvement in revenue was observed for increases in April and July rains. Ali et al. (2017) revealed that rainfall could reduce rice yield by 1.3% in Pakistan. Likewise in Philippines prolonged excess rains during initial and critical growth period has been reported to abort crop or lead to yield reduction (Lansigan, de los Santos, & Coladilla, 2000).

Mean temperature did not have significant impact on output. In contrast, coefficient of variation was significant implying that a 1% variation in mean temperature brings about 0.05% increases in rice output. The positive impact was a result of low mean maximum (29.3ºC) which was able to neutralize negative impact of raising minimum temperature (19.1ºC). IRRI (2015) recommended below 10ºC (minimum) and 32ºC (maximum) for fruitful rice production. The positive effects of coefficient of variation also confirms (Shakoor et al., 2015) who reported a 7% increase in rice production brought about by variation in mean minimum temperature in Pakistan. However, contrary result was reported by other studies where temperature reduces rice output. Ajetomobi et al. (2011) observed a reduction in rice revenue among Nigerian rain-fed farmers by 11.7% as a result of a 2ºC increase in temperature. And a further reduction by 52.4% from a simultaneous increase in temperature (2°C) and decrease in rainfall (5%). Ali et al. (2017) observed reductions in rice yield by 3.92 and 0.70 due to rising maximum and minimum temperatures, respectively in Pakistan. However, Rowhani et al. (2011) observed mixed results in Tanzania where increasing temperature variability improves yields whereas, higher temperatures as well as relative increase by 2°C reduces rice yield.

Table 3.2: Production frontier model

				Number of observations=		960
Truncated-normal distribution				Number of observations=		960
Group variable: farmer				Number of groups=		240
Time variable: years				Observations per group=		4
				Prob > chi2=		0.000
Log likelihood =	-1057.7535			Wald chi^{2}(10)=		707.315
lnOutput	**Coef.**	**Std. Err.**	**z**	**P>|z|**	**95% CI**	
Frontier						
lnArea	0.7482	0.0245	30.5	0.000	0.7001	0.7963
lnSeed	0.1209	0.0235	5.14	0.000	0.0748	0.1670
lnLabour	0.0263	0.0108	2.44	0.015	0.0052	0.0475
Oxen	0.0864	0.0216	4.01	0.000	0.0442	0.1287
Tractor	0.1057	0.0329	3.21	0.001	0.0412	0.1702
Year	-0.0199	0.0098	-2.04	0.042	-0.0390	-0.0008
lnRainfall	-0.0761	0.0313	-2.43	0.015	-0.1374	-0.0148
lnTemperature	0.7070	0.7178	0.98	0.325	-0.6998	2.1138
Cvr	-0.0058	0.0010	-6.11	0.000	-0.0077	-0.0040
Cvt	0.0477	0.0087	5.51	0.000	0.0307	0.0647
_cons	-1.0359	2.3231	-0.45	0.656	-5.5891	3.5172
Sigma_u	1.0490	0.0275	38.16	0.000	0.9965	1.1043
Sigma_v	0.2163	0.0114	18.99	0.000	0.1951	0.2398
Gamma	0.9592					

P–values are significant at less than 0.05 (5%)

The coefficient on time trend was negative (-0.02) which suggests technological regress in rice production between 2013 and 2016 and as a result, the frontier is shifting downwards at annual rate of 2%. Moreover, technological regress observed in the study area was contrary to technological progress registered in Nigeria at 12% (Ajetomobi, 2009). The technological decline could be attributed to limited access and utilisation of productivity enhancing technologies such as fertilizer and improved rice varieties.

3.3 Estimates of efficiency and distribution of inefficiency gaps: Mean efficiency was 0.41 and it ranged between minimum 0.01 and 0.94 implying that inefficiency gaps were between 0.99 and 0.06. In addition, estimate of eta (η) using (G. Battese & Coelli, 1992) time varying decay models with truncated-normal distribution was negative indicting that efficiency declined at an annual rate of 18% over the period. Efficiency level observed in this study was below what has been reported among rice farmers in western region (0.61) and between 0.34 and 0.59 in northern region (Asiimwe, 2009; Hyuha et al., 2007), 0.92 in Ahero irrigation scheme in Kenya (Omondi & Shikuku, 2013) and 0.75 among Vietnam farmers (van Long & Yabe, 2012). Analyses of inefficiency level by rainfall amount showed that inefficiency narrowed to an average of 0.57 among farmers who received less rain (between 261 and 493mm) than those who received higher rainfall between 508 and 588mm (inefficiency gap increased to 0.63). Interestingly, higher rainfall above average (600mm and above) was associated with relatively lower inefficiency gap (0.61).

Table 3.3: Efficiency scores and its distribution by amount of rainfall

Group	Efficiency score	Inefficiency gap
Overall		
Mean	0.405	0.595
Min	0.006	0.994
Max	0.944	0.056
Distribution by rainfall amount		
261 - 493	0.435	0.566
508 - 588	0.377	0.623
603 - 1279	0.388	0.612

Observations: NAEZ = 960

3.4 Determinants of inefficiency: Rejection of the assumption of full efficiency led to investigation of the sources of inefficiency. Subsequently, farmers' characteristics were included in the model to explain inefficiency (Table 3.3). All the right hand variables were statistically significant thus justifying their relevance in explaining inefficiency. Note that the negative relationship depicts a reduction in inefficiency while positive implies an increment.

Location of the farm dummy was positive and significant implying that inefficiencies were higher among farmers located in the lowland by 47.2% than those located in the upland system. Our result does not support evidence provided by Haneishi et al. (2013) that lowland performs better than upland rainfed. Production season dummy was negative implying that inefficiency reduces in the first season by 33.2%. Sex of a farmer was negative indicating that inefficiency reduces among male farmers by 25.5%. We found this result consistent with other researchers who observed that women are not involved in economically viable production (Barungi & Odokonyero, 2016). According to the gender experts, women have limited access to production resources and services due to power relations in society (Okali, 2012). Meanwhile age of the farmers promote inefficiency in production and accordingly, inefficiency increases by 1% among older farmers. Positive influence of age on inefficiency could be due to inability of older farmers to effectively contribute labour for farm activities as well as inability to explore new technologies and innovation for rice production. Further diversification of crops promotes inefficiency by 1.9% above specialized farmers and therefore confirms priori assumption. It also agrees with Hyuha et al. (2007) where high profit efficiency was attained under crop specialization (59.4%) than under diversification (57.6%). Coefficient of farm size dummy was positive and significant suggesting that inefficiencies in small plots were higher than the large plots by 19.1%. This finding does not support earlier assumption that rice cultivation is intensive and therefore is a crop for smallholders. It is therefore departure from the evidence that yields are higher in small than large plots by 0.2t ha^{-1} (Haneishi et al., 2013). Elsewhere in Nigeria, higher efficiency of 59% was reported in small farms against 56% in large farms (Enwerem & Ohajianya, 2013). Whereas, a tremendous reduction in inefficiency by 158% we observed among farmers earning above 3.5million from rice points to the fact that higher income supports purchase of productivity enhancing inputs and also an incentive to farm profitably. Coefficient on extension was negative indicating that inefficiency reduces among farmers with knowledge in rice production by 12.1%. Knowledge is a platform for technology adoption and therefore consistent with (Hyuha et al., 2007) who observed reduction in inefficiency by 28% in northern Ugandan.

Table 3.4: Inefficiency effects model

lnOutput	Coef.	Std. Err.	z	P>|z|	95% CI	
Mu						
Location	0.4723	0.0711	6.64	0.000	0.3329	0.6118
Production season	-0.3325	0.0659	-5.05	0.000	-0.4616	-0.2035
Sex	-0.2552	0.1006	-2.54	0.011	-0.4524	-0.0580
Age	0.0057	0.0020	2.83	0.005	0.0018	0.0097
Extension	-0.1213	0.0541	-2.24	0.025	-0.2273	-0.0153
Rice income	-1.5759	0.0811	-19.43	0.000	-1.7349	-1.4170
Plot size	0.1908	0.0621	3.07	0.002	0.0691	0.3126
Number of crops	0.0193	0.0112	1.73	0.084	-0.0026	0.0411
_cons	1.3038	0.1304	10	0.000	1.0482	1.5594

P−values are significant at less than 0.05 (5%)

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions: Farmers are producing below expected level of output but variability in rainfall has adverse effects on the production frontier and inefficiency is being promoted by location, age, plot size and the number of crops grown.

4.2 Recommendations: Based on the key findings, we recommend the need to promote awareness about climate variability and potential response alternatives, enhance participatory and consultative approach that involves all stakeholders at all levels. There is need to explore coping strategies farmers are using to counter effects of climate variability in rice production.

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