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CLIMATE VARIABILITY, INPUT SUBSTITUTION, AND TECHNOLOGICAL GAPS OF MAIZE FARMS IN GHANA

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Abstract

In most developing countries climate variability affect food crop production due to its impact on input substitution and technological differentials. This study hypothesized that climate variability affect input substitutability and technological differential of maize farms across agro-ecological zones in Ghana. A metafrontier production function model for farms in different agro-ecological zones having different technologies were analyzed. Using cross-sectional data from 622 farmers across the three major agro-ecological zones, we found that all maize farms across the agro ecological zones are less efficient. However, farms in the forest zone have higher efficiency scores than farms within coastal and savannah zones. Farms in the coastal and savannah zones are closer to their potential output defined by the metafrontier function than farms within the forest zone. The stochastic frontiers for all farms within coastal and savannah zones are tangent to the stochastic metafrontier. Farms within coastal and savannah zones use more advanced technology than farms within the forest zone as indicated by the intercept term in the production function. Policy makers should ensure that climatic conditions prevailing in the different agro ecological zones across the country are taken into consideration while formulating agricultural policy. Since climate variability may have either positive or negative effects on these policies as well as farm technologies used.

Keywords: Climate Variability; Maize Production; Metafrontier; Technological Gap Ratios; input substitution

INTRODUCTION

In most developing countries, the agricultural sector provides the foremost source of revenue and employment to most of the populace and contributes considerably to national Gross Domestic Product (GDP) (Commission for Africa 2005). While agricultural productivity growth remains a necessary condition for food security in Africa, there is evidence that it is directly impacted by climate variability. According to the Intergovernmental Panel on Climate Change (IPCC, 2012), for countries in Sub-Saharan Africa (SSA), agricultural productivity growth are likely to be severely affected by climate change and climate variability. This stems from the fact that variations in climatic variables like temperature and rainfall cause variation in the soil moisture, fertility and the entire ecosystem, which affect sustainability of food crop production.

Besides drought and flood, the two climate variables that are noted to directly determine agricultural productivity or yield are temperature and precipitation. Precipitation determines the availability of freshwater and the level of soil moisture, which are critical inputs for crop growth. Based on an econometric analysis, Reilly et al. (2003) found that higher precipitation leads to a reduction in yield variability. Thus, higher precipitation will reduce the yield gap between rainfed and irrigated agriculture, and may also negatively impact yield if extreme precipitation causes flooding (Falloon and Betts, 2009). Temperature and soil moisture determine the length of growing season and control the crop's development and water requirements (IPCC, 2007). The extent to which climate variables affect yields depends on the farmer's ability to adapt or mitigate the potential impacts. This may require local learning and modifying general scientific principles and technologies to fit specific contexts. Thus, given the constraints imposed by climate variability, agricultural productivity undoubtedly depends on efficient and effective utilization of the factors inputs such as surface and underground water, seeds, fertilizer and labour to ensure optimum use of farm resources in sustainable manner. Since low rainfall, for example, implies limited water use in rainfed agriculture and hence low productivity, the ability to engage in farm practices such as input substitution to compensate for low precipitation is essential.

Although extensive literature exists in developing countries on the climate change impact on the delivery and effectiveness of irrigation systems and how temperature and precipitation variability affect food crop production and variations in the growing seasons of the farmers (Kundzewicz et al., 2007; Lane and Jarvis, 2007; Lobell and Burke, 2008), we are unaware of any research focusing on the extent to which farmers adapt to climate variability by engaging in inputs substitutions, coping mechanisms and climate adaptation strategies. Specific issues of concern are the extent to which climate variability determines technological gaps and technical efficiency of farms, as well as identifying factors responsible for variations in such gaps and efficiency, and adaptation strategies put in place by the farmers to ensure high productivity of food crop and sustainability of the environment. This study intends to fill this gap in the literature using data from Ghana. The scope of this paper includes analysis of the factors that affect the productivity of farmers in a changing farming environment; explore the climate variability and farm inputs substitution in different agro-ecological zones; determine the technological gap ratios of food crop farmers in different agro- ecological zones using the matafrontier production function analysis and the factors that influence farmers' choices of adaptation strategies. The evaluation of climate change impacts on agricultural production, food supply and agriculture-based livelihoods must take into account the characteristics of the agro-ecosystem where particular climate-induced changes in biochemical processes are occurring, in order to determine the extent to which such changes will be positive, negative or neutral in their effects.

This paper provides an empirical analysis of climate variability on maize production across the three major agro ecological zones in Ghana, namely the coastal, forest and savannah zones. It's believed that variations in climatic conditions such temperature and rainfall affect the production of these food crops across the zones. An increase in climate variability may result from human energy use but its impact is manifested through changes in agro ecological conditions and climatic factors, particularly rainfall and temperature. Rainfall and atmospheric temperature are the most important weather variables affected by climate change, play a crucial role in food crop production in Ghana. Across the zones, smallholder farmers already face numerous risks to agricultural production. Climate change is expected to disproportionately affect smallholder farmers and make their livelihoods even more precarious; however, there is limited information on how the climate variations affect their overall level of efficiency and also the technologies these farmers used. The main thrust of this paper is to looks at the effect of climate variability on input substitution and technological gaps of maize farms. It was expected that differences in the climatic conditions would affect the efficiency levels, input substitution and the technologies used by these smallholder farmers across the zones

THE METAFRONTIER MODEL

The purpose of this study is to show how metafrontiers and group frontiers can be estimated using stochastic frontier analysis (SFA) techniques for the climatic zones. Battese and Rao (2002) present SFA approach to the estimation of metafrontiers that is implicitly underpinned by two different data-generating mechanisms, one that explains deviations between observed outputs and (fixed) group frontiers, and another that explains deviations between observed outputs and the metafrontier. The problem with this approach is that points on the estimated metafrontier may lie below points on the estimated group frontiers. Battese, Rao and O'Donnell

(2004) solve the problem by specifying a single data-generating process that explains deviations between observed outputs and group frontiers, and by defining the metafrontier to be a function that envelops the deterministic components of the group frontiers. They decompose differences in performance into technical efficiency and technology gap effects.

Following Coelli et al (2005), stochastic frontier analysis involves parameterising the frontier and estimating it using econometric techniques. A stochastic frontier model for farm groups in each climatic zone is given by

$$y_{ik} = (x_{1ik}, x_{2ik}, ...x_{nik}; \beta)e^{V_{ik} - U_{ik}} \qquad [1]$$

Where x_{nik} is the n-th input quantity of the i-th farm in the k - climatic zone; β is a conformable parameter vector associated with the *k*-climatic zone; V_{ik} represent statistical noise and are assumed to be independently and identically distributed as $N(0, \sigma^2)$ -random variables; and the U_{ik} represent inefficiency and are defined by the truncation (at zero) of $N(\mu_{ik}, \sigma^2)$-distributions, where the $\mu_{ik}s$ are defined by some appropriate inefficiency model (Battese and Coelli, 1995). If the exponent of the frontier production function is linear in the parameter vector, β, then the model can be written as:

$$y_{ik} = (x_{1ik}, x_{2ik}, ...x_{nik}; \beta)e^{V_{ik} - U_{ik}} \equiv e^{x'_{ik}\beta + V_{ik} - U_{ik}} \qquad [2]$$

where x_{ik} is now a vector of inputs for the *i*-th farm in the *k-th* climatic zone. Data on the inputs and outputs of farms in the *k*-th climatic zone can be used to obtain either least squares or maximum-likelihood (ML) estimates of the unknown parameters of this frontier.

Following estimation, the technical efficiency of the *i*-th farm in the *k*-th climatic zone with respect to the zone frontier can be obtained using the result:

$$TE_{ik} = \frac{y_{ik}}{e^{x'\beta + V_{ik}}} = e^{-U_{ik}} \qquad [3]$$

A deterministic metafrontier production function is given by

$$y^*_{ik} = (x_{1ik}, x_{2ik}, ...x_{nik}; \beta^*)e^{V_{ik} - U_{ik}} \equiv e^{x'_{ik}\beta} \qquad [4]$$

where y^*_{ik} is the metafrontier output and β is a vector of metafrontier parameters satisfying the constraints

$$x'_{ik}\beta^{*} \geq x'_{ik}\beta \qquad [5]$$

for all climatic zones

The important features of the model given by equations (2) to (5) are noteworthy. The constraints given by (5) imply that the metafrontier function cannot fall below any of the group frontiers, and their stochastic metafrontier can be conveniently estimated using the inputs and outputs of all farms in all climatic zones, and the estimated metafrontier will envelop the estimated group frontiers. An estimated metafrontier function that envelops the estimated zone frontiers can be obtained by solving the optimization problem:

$$\min_{\beta} \quad \sum_{i=1}^{N}\sum_{k}^{K}\left[\ln f(x_{1ik}, x_{2ik}, x_{3ik}, ...x_{Nik}; \beta) - \ln f(x_{1ik}, x_{2ik}, x_{3ik}, ...x_{Nik}; \hat{\beta})\right]$$

$$s.t \quad \ln f(x_{1ik}, x_{2ik}, x_{3ik}, ...x_{Nik}; b) \ {}^{3} \ \ln f(x_{1ik}, x_{2ik}, x_{3ik}, ...x_{Nik}; \hat{b}) \qquad [6]$$

For all i and k, where β is the estimated coefficient vector associated with the zone stochastic frontier. Since these estimated coefficient vectors are fixed for the above problem, an equivalent form of the LP defined by equation (7) is

$$\min_{\beta} \quad \sum_{i=1}^{N}\sum_{k}^{K}\ln f(x_{1ik}, x_{2ik}, x_{3ik}, ...x_{Nik}; \beta$$

$$s.t \quad \ln f(x_{1ik}, x_{2ik}, x_{3ik}, ...x_{Nik}; \beta) \geq \ln f(x_{1ik}, x_{2ik}, x_{3ik}, ...x_{Nik}; \hat{\beta}) \qquad [7]$$

Additionally, if the function $f(.)$ is log-linear in the parameters, then the LP problem becomes:

$$\min_{\beta} \quad \overline{x}'\beta$$

$$s.t \quad x'_{ik}\,\beta \geq x'_{ik}\,\hat{\beta} \qquad \text{For all } i \text{ and } k \qquad [8]$$

Where $\overline{x}$ is the arithmetic average of the x_{ik}-vectors over all farms in all climatic zones. Battese, Rao and O'Donnell (2004) explained this optimization problem and a similar problem involving minimization of a sum of squared deviations. Standard errors for the estimators for the metafrontier parameters can be obtained using simulation or bootstrapping methods. After solving for equation (8), estimates of metatechnology ratios and technical efficiencies with respect to the metafrontier can be obtained using the following decomposition of equation (9):

$$y_{ik} = e^{-U_{ik}} \times \frac{e^{x'_{ik}\hat{\beta}}}{e^{x'_{ik}\beta}} \times e^{x'_{ik}\beta + V_{ik}} \qquad [9]$$

The first term on the right-hand side is the technical efficiency of the *i*-th farm in the k-th climatic zone with respect to the all zones frontier, defined by equation (10). The second term on the right-hand side is the meta-technology ratio for the *i*-th farm in the *k*-th climatic zone:

$$MTR_{ik} = \frac{e^{x'_{ik}\hat{\beta}}}{e^{x'_{ik}\beta}} \qquad [10]$$

Estimating the meta-technology ratio is simply a matter of substituting estimates of β and $\hat{\beta}$ into equation (11). The constraints in the LP problem defined by equation (7) guarantee that meta-technology ratios estimated in this manner will lie in the unit interval. Finally, equations (3), (9) and (10) together imply that the technical efficiency of the *i*-th farm in the *k*-th climatic zone with respect to the metafrontier is given by;

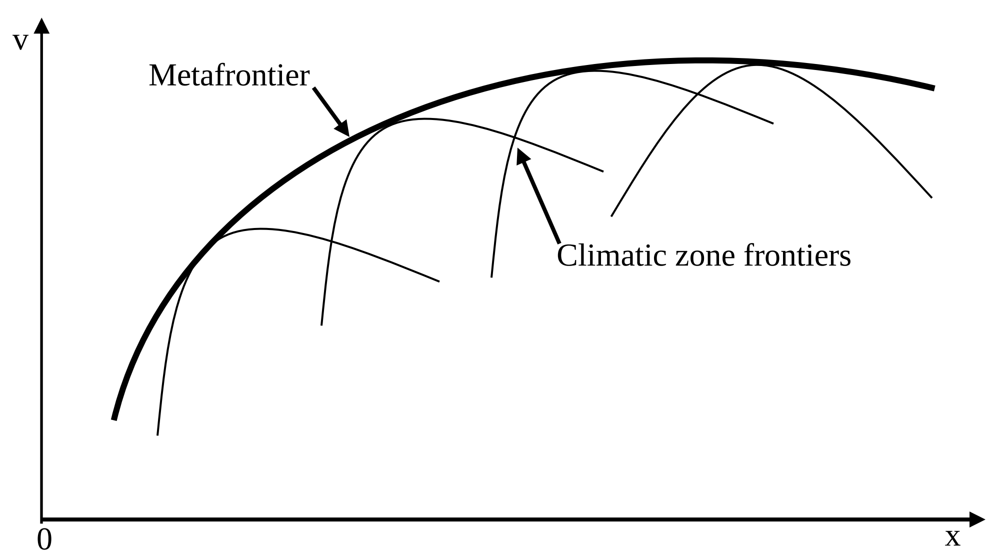
$$TE_{ik} = \frac{y_{ik}}{e^{x'_{ik}\beta + V_{ik}}} \qquad [11]$$

Thus, technical efficiency relative to the metafrontier is defined in an analogous way to equation (3) – it is the ratio of the observed output relative to the frontier output, adjusted for the corresponding random error. In practice, it is convenient to predict technical efficiency with respect to the metafrontier using the decomposition;

$$T\hat{E}_{ik} = TE_{ik} \times M\hat{T}R_{ik} \qquad [12]$$

Where $T\hat{E}_{ik}$ and $M\hat{T}R_{ik}$ implies that the technical efficiency relative to the metafrontier function is the product of the technical efficiency relative to the stochastic frontier for the group involved and the meta-technology ratio (MTR). The exceeding theoretical elucidation can diagrammatically be presented as

Figure 1: Illustration of Metafrontier and Climatic zone Frontiers



EMPIRICAL MODEL SPECIFICATION

Following Battese et al (2004), the stochastic frontier production function model for all farms in different climatic zones is presented in this section. The transcendental logarithm will be adopted because it has been assumed to specify the production technology of the farmers. We specified a transcendental logarithm stochastic frontier production function for the farms in different climatic zones as:

$$y_{ik} = \varpi + \delta_{1i} Z_{ik} + \delta_{2i} l_{ik} + \delta_{3i} l_{ik}^{\ 2} + \delta_{4i} Z_{ik}^{\ 2} + \delta_{5i} l_{ik} Z_{ik} + V_{ik} - U_{ik} \qquad [13]$$

Where y_{ik} is a vector of the valued of production for farms in different climatic zone; Z_i denotes a vector of physical capital use in the production of food crop, l_i is a vector of labour which consist of permanent and casual farm labourers employed by the farmers, i is a farm specific index; V_i is a vector of two-sided error term assumed to be identically and independently distributed; U_i is a vector of non-negative technical inefficiency component of the error term; ϖ and δ are vector of parameters to be estimated. All the variables are in natural logarithms.

Construction of the Metafrontier

This section is about obtaining the vector of estimate of the metafromtier parameters (i.e. δ^*). This is done in such a way that the estimated function best envelops the deterministic components of the estimated stochastic frontiers for the different groups. Battese et al (2004) proposed two methods to identify the best envelope: the minimum sum of absolute deviation and the minimum sum of squares of deviation. Minimum sum of absolute deviations in the construction of the metafrontier was employed. The use of this method involves solving the following linear programming (LP) problem of the form:

Minimize $$L^* \equiv \bar{X}_i \delta^* \qquad [14]$$

Subject to $$X_i \delta^* \geq X_i \hat{\delta}_{(k)} \qquad [15]$$

Where $\bar{X}$ is the row vector of means of the elements of the X_i vector for all observations in the data set and δ_{iks} are the estimated coefficients of the group stochastic frontiers and δ^* are parameters of the metafrontier function.

Technology Gap Ratio (TGR) and Technical Efficiency Ratio (TER)

The technical efficiency from the stochastic frontier for each ecological zone is estimated as

$$TE_{ik} = y_i \Big/ e^{\varpi_i + \beta_{1i} Z_{ik} + \beta_{2i} l_{ik} + \beta_{3i} l^2{}_{ik} + \beta_{4i} Z^2{}_{ik} + \beta_{5k} l_{ik} Z_{ik} + V_{ik}} = e^{-U_{ik}} \qquad [16]$$

The metatechnological ratio is also estimated as:

$$MTR_i = \frac{e^{\delta_{1i} Z_{ik} + \delta_{2i} l_{ik} + \delta_{3i} l^2{}_{ik} + \delta_{4i} Z^2{}_{ik} + \delta_{5i} l_{ik} Z_{ik}}}{e^{\delta^*{}_{1i} Z_{ik} + \delta^*{}_{2i} l_{ik} + \delta^*{}_{3i} l^2{}_{ik} + \delta^*{}_{4i} Z^2{}_{ik} + \delta^*{}_{5i} l_{ik} Z_{ik}}} \qquad [17]$$

The technical efficiency relative to the metafrontier is estimated as:

$$TE^*{}_i = \frac{y_i}{e^{\varpi_i + \delta^*{}_{1i} k_{ik} + \delta^*{}_{2i} l_{ik} + \delta^*{}_{3i} l^2{}_{ik} + \delta^*{}_{4i} k^2{}_{ik} + \delta^*{}_{5i} l_{ik} k_{ik}}} \qquad [18]$$

Thus the technical efficiency is defined as:

$$TE_i^* = TE_{ik} \times MTR_{ik} \qquad [19]$$

Determinants of Technical Efficiency

The appropriate Least Square estimation procedure was adopted in determining factors influencing the plot level technical efficiency scores. Thus, the equations specifying the determinants of technical efficiency is,

$$TE_i^* = \gamma + \theta z_i + \varepsilon_i \qquad [20]$$

Where γ is the intercept, z_i is the firm characteristics, ε_i is the disturbance term in the model.

Data Sources

Primary data was used for this study. Data was obtained from the three main agro-ecological zones, namely the forest, coastal and savannah zones using multi-stage sampling techniques. The food production potentials of these agro ecological zones have been recognized for years. The interview schedule covered an area cultivated, types of inputs used, maize production, input costs and output price of maize. The farmer's perception about the variability of temperature and rainfall was also sought. The simple random technique through the use of lottery approach was used the select farmers across the agro ecological zone. In all a total of 622 farmers were identified and interviewed from all the three agro ecological zones.

EMPIRICAL RESULTS AND DISCUSSION

Table 1 shows the definition and summary statistics of the variables used in the maize production function. These were the value of maize produced in each agro ecological zone; the labour employed measured in man-day; the amount of fertilizer usage of maize farmers measured in Ghana cedis and the material cost incurred which include pesticides, seeds rental equipment measured in Ghana cedis. The classification of the agro ecological zones in Ghana is based on the climatic conditions, which influences the agricultural activities throughout the country. Maize is one of the important cereals, and is produced across the three major agro ecological zones. Maize is Ghana's number one staple crop and there is a growing domestic demand. Between 2010 and 2015, maize demand is projected to grow at a compound annual growth of 2.6 %. However, the country is not self-sufficient in this most important staple crop, partly because maize production is in the hands of smallholder farmers who produce at the subsistence level. The country has experienced average shortfalls in domestic maize supplies of 12% in recent years (MiDA, 2012). Therefore, there is an interest in increasing production of this key staple food to meet the country's growing demand for maize and to improve food security.

Table 1: Definition and Summary statistics of the Variables used in Maize Production across the agro ecological zones

Variables	**Definition**	**Mean**	**Std dev**
Value of Maize	Value maize output measure in Ghana cedis (GHs)	474.2	337.6
Labour	Family and hired labour used measure in man-days	5.1	2.0
Fertilizer	Value of fertilizer used measured in Ghana cedis	50.2	29.9
Material cost	Value other material inputs these include seed, hand tools, pesticides, rental equipment used measured in Ghana cedis (GHs)	58.4	27.1
Coastal Zone			
Value of Maize	206 Value maize output measure in Ghana cedis (GHs)	426.7	309.7
Labour	Family and hired labour used measure in man-days	5.3	1.9
Fertilizer	Value of fertilizer used measured in Ghana cedis	47.8	32.0
Material cost	Value other material inputs these include seed, hand tools, pesticides, rental equipment used measured in Ghana cedis (GHs)	59.6	36.7

Forest Zone			*Table 1…..*
Value of Maize	Value maize output measure in Ghana cedis (GHs)	449.4	338.5
Labour	Family and hired labour used measure in man-days	5.2	2.6
Fertilizer	Value of fertilizer used measured in Ghana cedis	49.8	29.4
Material cost	Value other material inputs these include seed, hand tools, pesticides, rental equipment used measured in Ghana cedis (GHs)	55.1	22.2
Savannah Zone			
Value of Maize	Value maize output measure in Ghana cedis (GHs)	548.7	353.1
Labour	Family and hired labour used measure in man-days	4.9	1.4
Fertilizer	Value of fertilizer used measured in Ghana cedis	53.1	27.9
Material cost	Value other material inputs these include seed, hand tools, pesticides, rental equipment used measured in Ghana cedis (GHs)	60.7	17.2

The Table 1 indicate some differences in the means and standard deviations of maize farmers across the three-agro ecological zones with regard to value of maize produced, labour, fertilizer usage and other material production costs which include seeds, hand tools, pesticides and rental equipment. The standard deviations for all the variables (value of maize, labour, fertilizer and material cost) were smaller than their means indicating there were no wide variations around the mean of the variables. The mean value for maize production was higher for farmers in the savannah agro ecological zone than those in the other zones, with the maximum output occurring in savannah and coastal zones. The mean labour usage, which was measured in man-days, was lowest in the savannah zone. On the other hand, the farmers in the savannah zone on the average used more fertilizer than their counterparts in the forest and the coastal agro ecological zones. The material cost incurred in maize production was higher in savannah and coastal zones than the forest zone.

Estimation of Stochastic Frontier across the Ecological Zones

Given the importance of maize in Ghana's economy, the estimation of efficiency of smallholder farmers will facilitate answering questions on what factors that are holding them back from increasing their productivity. An understanding of the relationships between efficiency, policy indicators and farm-specific practices would provide policy makers with information to design programmes contributing to increasing maize production potential among smallholder farmers, who produce the bulk of the country's food. This study attempts to estimate the stochastic frontier production function for maize farmers across the three agro ecological zones and also for each zone and to determine their efficiency levels across and within the zones.

Table 2: Stochastic frontier estimates for maize production across the agro ecological zones.
Dependent variable: value of maize output per hectare

Ecological Zones **Variables**	**All** **Cobb**	**Coastal** **Translog**	**Forest** **Translog**	**Savannah** **Translog**
Constant	3.077*** (19.84)	2.829*** (12.67)	5.005*** (9.18)	3.366*** (6.44)
In labour	0.120* (1.78)	0.0489 (0.36)	1.876*** (4.46)	1.019* (2.29)
In fertilizer	0.793*** (15.47)	0.705*** (8.71)	-0.967* (-2.11)	0.850*** (7.59)
In material	0.0170 (0.33)	0.156* (1.95)	0.200*** (0.946)	-0.0446 (-0.22)
In labour^2		0.500** (2.59)	0.418*** (3.52)	
In material^2			-0.000138 (-0.79)	0.991** (3.28)
In fertilizer^2			0.369*** (3.70)	
In lab x lnFert			-0.806*** (-4.25)	-0.340* (-2.00)
InsigV-squared ($\sigma v2$)	-1.932*** (-10.85)	-2.061*** (-7.60)	-2.343*** (-6.82)	-2.614*** (-5.37)
lnsigU-squared ($\sigma u2$)	-0.719*** (-4.05)	-0.729*** (-2.88)	-0.773** (-2.93)	-0.297 (-1.32)
Sigma-squared (σ^2)	0.632	0.609	0.558	0.910
Gamma ((γ)	0.770	0.790	0.829	0.910
Lambda (λ)	1.834 (0.0901)	1.946 (0.127)	2.193 (0.135)	3.185 (0.153)
Wald(χ^2)	389.38***	159.41***	145.46***	106.76***
Likelihood ratio test H_o: σ_u=0 $\chi^2(1)$	16.25***	8.06***	8.62***	6.67***
Log likelihood	-496.544	-165.812	-147.613	-154.703
N	592	206	202	184
BIC	(1031.389) – (368.9184 +348.3077 +351.1264) = (-36.9635)			

t statistics in parentheses * *p < 0.1,* ** *p < 0.05,* *** *p < 0.01*

The results in table 2 indicate the maximum likelihood estimates (MLE) of the stochastic frontier for maize farmers in the study area. As indicated in the table, the estimated variance ratios sigma-square (0.632) for all the farmers across the agro ecological zone was statistically significant and different from zero at □ = 0.000 indicating goodness of fit and correctness of the specified distribution assumption of the composite error terms. The estimated values of the gamma (γ) were significant at 1% for all the farmers. The coefficients for gamma at 0.77, 0.79 and 0.83 for all maize farmers, and those in coastal and forest zones respectively implies that 77% 79% 83% and 91% of the variability in maize output for smallholder farmers respectively was due to technical inefficiencies. Put differently, the presence of technical inefficiency among subsistence maize farmers explains 77% of the variation in the output level of maize cultivated across the agro ecological zones, 79% in the coastal zone, 83% in the forest zone and 91% in the savannah zone. The presence of one-sided error components in the specified model is thus confirmed implying that the ordinary least square estimation would be an inadequate representation of the data. The generalized likelihood ratios $\chi^{2\prime}s$ are highly significant. This implies the presence of one-sided error components. The results of the diagnostic analysis therefore confirm the relevance of the stochastic parametric production function and maximum likelihood estimation.

The labour variable refers to the family and hired labour provided for farming operations. Across the zones, labour appeared to be one of the most important production resources with an elasticity of 0.120 positive and significant at 5%. For farmers in the forest zone elasticity of 1.876 was positive and significant at 1%. In the savannah zone elasticity of 1.019 was positive and significant at 1%. Even though labour was not a significant influence on maize output in the coastal zone its elasticity was 0.0489 and positive. The relative large coefficients for labour in the agro ecological zones are an indication that cultivation of maize is labour intensive particularly during weeding and planting. The product of labour (squaring labour) also increased maize output for farmers in the coastal and forest agro zones. This variable had elasticity of 0.500 and 0.418 with 5% and 1% significant levels respectively. This is also a clear indication that an increase in labour both family and hired would increase smallholder maize farmer's production across the ecological zones. Fertilizer variable with an elasticity of 0.793 was positive and significant at 1% for maize farmers across the zones. Within the coastal and savannah zones elasticity was 0.705 and 0.850 respectively and positive at the 1% level of significance. The fertilizer usage in the forest zone had elasticity of 0.967 and was negative and significant at 10%, which suggests that an initial stage of fertilizer usage in the forest zone had negative impact on maize production. However, squaring the fertilizer usage increased the output of maize in the forest zone. The interactive term between the labour and fertilizer was negative for both forest and savannah zones, at significance levels of 1% and 10% respectively. These results suggest that because of the moderate cost of fertilizer as indicated by the value of its elasticity, farmers were able to obtain more fertilizer to apply to their crop, which invariably resulted in increased maize production. On the other hand, care should also be taken to not apply too much fertilizer since that can lead to reduction in the maize output in some areas. This accentuates the need for relevant agencies to make conscious efforts to avail local farmers with fertilizer at affordable prices for meaningful production.

Material cost includes seeds, pesticides and rental of equipment used for weeding and planting. This variable was positive and had elasticity of 0.156 for the coastal zone and 0.200 for the forest zone, at significance levels of 10% and 1% respectively. These results support the need to encourage proper storage and preservation of seeds, availability of pesticides and easy accessibility of farm equipment for use by local farmers. These would not only ensure timely availability of planting materials to farmers but would reduce additional costs, which would otherwise have been incurred. The maize production frontier is expected to vary, depending on the degree of yield-enhancing interventions implemented by smallholder farmers. An understanding of the differences in specific production frontiers in different production systems should provide better assessments of yield performance across different locations and also enable policy makers to develop location-specific technologies as well as disseminate appropriate technologies to farmers in different climatic zones. A precise analysis of productive efficiencies, technology gaps and technical change among these zones may contribute to a more accurate targeting and effective design of the government’s maize program.

Table 3: Summary statistics of the technical efficiency scores of maize production across the agro ecological zones

Variable	Observation	Mean	Std. Dev.	Min	Max
Zone	592	0.620	0.160	0.154	0.910
Coastal Zone	206	0.628	0.170	0.125	0.898
Forest Zone	202	0.637	0.189	0.105	0.925
Savannah	184	0.524	0.200	0.077	0.931

Table 3 presents summary statistics of the technical efficiency scores of maize production across the agro ecological zones using a stochastic frontier production function. An important feature of the stochastic production frontier is its ability to estimate individual, farm-specific technical efficiencies. Table 4 shows farm-specific resource use efficiency indices. The efficiency indices for maize farms across the agro ecological zones show considerable variation while the technical efficiencies of all the sampled maize farms are less than one. This implies that no farm reached the frontier of production and therefore had the potential to increase efficiency.. Comparatively, farms in the forest zone were on the average more efficient ranging between 0.105 to0.925, followed by coastal zone with efficiencies ranging between 0.125 to

0.898. Savannah maize farming had the lowest mean average of 0.524 but was highest in terms of maximum efficiency levels. The mean efficiencies of both forest and coastal zones were higher than the mean of the pooled data. Hence, there is some scope for increasing farm output. The observed distribution suggests that little marketable product is wasted due to inefficient use of resource inputs. However, none of the maize farmers reached the frontier of production, being confronted with multifaceted production challenges ranging from technical constraints through socio-economic factors to environmental factors. This further confirms the small-scale nature of production; resources are mostly allocated to various uses on the basis of their marginal shadow prices, thereby preventing farmers from reaching the efficiency frontier.

Table 4: Maize inputs substitution across and within the agro ecological zones across the zones

			Cross input elasticities	
Inputs		Labour	Fertilizer	Material
	Labour	0.120*	2.312***	8.537***
		(1.78)	(2.30)	(2.37)
	Fertilizer	0.793***		0.504***
		15.47		(13.25)
	Material	0.017		
		(0.33)		
Coastal Zone				
		Labour	Fertilizer	Material
	Labour	0.148	1.517	1.846
		(1.16)	(0.13)	(0.13)
	Fertilizer	0.704***		0.497***
		(8.63)		(13.12)
	Material	0.131*		
		(1.65)		
Forest Zone				
		Labour	Fertilizer	Material
	Labour	0.132	3.034	5.895
		(1.40)	(0.03)	(0.03)
	Fertilizer	0.719***		0.499***
		(8.36)		(13.17)
	Material	-0.067		
		(-0.84)		
Savannah Zone				
		Labour	Fertilizer	Material
	Labour	0.182	4.178	6.089
		(1.28)	(0.04)	(0.03)
	Fertilizer	0.849***		0.517***
		(7.03)		(13.48)
	Material	-0.056		
		(-0.49)		

t statistics in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4 presents the summary result of the input elasticities and cross elasticities of maize inputs across the three major agro ecological zones in Ghana. The impetus here was to ascertain whether the variations in the climatic indicators like temperature and rainfall, would have influence on the usage of farm inputs across the zones. The results from cross elasticities, shows strong evidence of complementarities among maize inputs rather than input substitution. We also found a strong indication of significant relationship between labour and fertilizer, labour and material, fertilizer and material across the zones. The positive sign shows complementarities between the maize inputs across the zones. The cross-input elasticities mean that a 10% rise in the cost of labour would lead to an increase in demand fertilizer by 23% across the zones, by 15% within the coastal zone, by 30% within the forest zone and by 42% within the savannah zone. The results reveal that there are significant variations of labour and fertilizer as complementary inputs of maize production in the different agro ecological zones. Table 5 further indicates positive relationship between labour and material cost. The values imply that10% rise in the labour input would increase the demand for material inputs by 83% across the zones, by 18% within the coastal zone, by 59% within the forest zone and by 60% within the savannah zone. This also indicates a wide variation of labour and materials as complementary inputs between the zones. The cross elasticities between fertilizer usage and material cost is evidence of strong complementarity among the inputs. Apparently a 10% rise in the cost of fertilizer would increase the demand for material by 5% and in this case the cross elasticity values do not significantly vary between the zones. The economic interpretation of these results is that joint effects of the pairs of these variables (labour and fertilizer, labour and material, and fertilizer and material) contribute significantly to maize production within and across the agro ecological zones.

Table 5: Summary statistics and definition of variables that influence the technical efficiencies of maize farmers across the agro ecological zones.

Variable	Definition	Mean	St dev.
Age	Age of the household farmer in years	48.119	11.072
Education	Education level of the household famer in years	5.635	3.708
Household Size	Household size of the farmer	4.941	2.357
Years of Farming	Number of years engaged in farming activities	15.691	10.590
Farm Size	Farm size cultivated by the household farmer	5.096	2.141

Table 5…

Off-farm income	Income from off-farm activities (GHs)	58.4	27.1
Male Workers Engaged	Number of male workers engaged in farming activities	3.640	1.734
Female Workers Engaged	Number of female workers engaged in farming activities	1.947	1.480
Marital Status	Dummy for marital status (1=married and 0=otherwise	0.801	0.3998
Farm Credit	Access to some form of credit (1=yes and 0=otherwise)	0.0835	0.277
Extension	Extension services (1=yes and 0=otherwise	0.492	0.500
Irrigation	Form of irrigation (1=yes and 0=otherwise)	0.428	0.495
Farmers Assoc	Farmers association (1=member and 0=otherwise)	1.704	0.457
Cropping Pattern	Type of farming practices (1=mix cropping and 0=monocropping)	0.881	0.324
Green Manure	Whether crop residues were left in farm (1=yes and 0=otherwise)	0.391	0.488

Married-80%; Farm Credit-11%; Extension services-49%; irrigation- 42%;

Farmers Association- 29% and Green Manure-26%

#Dummy Variables are expressed in terms of percentages to aid interpretation

The definition and the summary statistics of variables that influence technical efficiencies of maize production across the agro ecological zones are presented in Table 6. Notably the summary statistics for age, education, marital status, household size, years of farming, male workers engaged, female workers engaged, farm size, cropping pattern and off-farm income are on the average, show considerable differences. The standard deviations for variables across the agro ecological zones are lower than their means indicating no significant variations. On the other hand, farm credit, extension, irrigation and green manure have standard deviations higher than their means across the agro zones indicating wide variations. On the average, maize farmers were about 48 years old, had worked on the farm for 15 years, with an average farm size of 5 hectares, and had 6 years of formal education and a mean household size of 5. The off-farm income generating activities are also quite lucrative as farms earned on the average GHs 58 per season across the agro ecological zones. About 80% of the sampled maize farmer across the agro zones were married, 11% had access to farm credit, 49% had received some extension services, 42% had adopted some form of irrigation system to improve their maize yields, 26% were members of communitarian farmers associations and 26% had adopted green manure method of fertilizing their crops by leaving the crop residue on the farm to decompose.

Table 6: Estimates of the socio-economic and farm level factors that influence the technical efficiency of maize farmers across and within agro ecological zones

Variables	ALL	Coastal	Forest	Savannah
Constant	0.683***	0.755***	0.833***	0.523***
	(10.63)	(7.26)	(8.95)	(5.31)
Age	0.135*	0.0501	0.152*	0.122*
	(2.03)	(0.70)	(2.35)	(1.98)
Education	0.0268*	-0.0553*	0.0716*	0.0604*
	(1.88)	(-2.32)	(2.47)	(2.04)
Marital status	0.0372*	-0.0528*	-0.0483	0.0198**
	(2.17)	(-1.72)	(-1.19)	(3.15)
Household size	0.00255	0.0125*	0.00264	0.0144*
	(0.83)	(2.27)	(0.35)	(2.10)
Years of farming	0.00156*	0.00287*	0.00326*	0.00346*
	(1.94)	(2.00)	(1.81)	(2.00)
Male workers Engaged	0.00863*	0.00655	0.00884	0.0263*
	(2.50)	(1.05)	(1.23)	(2.45)
Female workers engaged	-0.0136*	0.0275**	-0.0366***	0.00444
	(-2.54)	(3.22)	(-3.57)	(0.52)
Farm size	0.0113***	0.0126*	-0.0131*	0.0176***
	(4.03)	(2.44)	(-1.96)	(4.61)
Farm credit	0.0384*	0.0239	-0.180***	0.0334*
	(1.81)	(0.47)	(-4.08)	(2.02)
Extension	0.0295*	0.0192	-0.0423	0.0383*
	(1.93)	(0.66)	(-1.16)	(2.15)
Irrigation	0.0149	-0.0185	0.0446	-0.132*
	(1.03)	(-0.75)	(1.18)	(-2.12)
Farmers assoc	0.0281*	0.00608	0.0352	0.0108
	(1.80)	(0.18)	(0.56)	(0.60)
Cropping pattern	-0.0713**	-0.154***	-0.181***	-0.188***
	(-3.18)	(-4.80)	(-3.99)	(-4.00)
Green manure	0.0319*	0.0249	0.0341*	0.00145***
	(2.27)	(1.03)	(1.77)	(3.57)
Off-farm income	0.000742**	-0.000628*	0.00143***	0.0401
	(3.05)	(-1.99)	(3.74)	(1.37)
R-squared	0.3456	0.2954	0.2605	0.3345
N	586	206	196	184

t statistics in parentheses * *$p < 0.1$,* ** *$p < 0.05$,* *** *$p < 0.01$*

Table 6 presents the results of the socio-economic and farm level characteristics that influence technical efficiencies of maize farmers across the agro ecological zones and also within each zone (coastal, forest and savannah). The age variable was expected to have either positive or negative effect on technical efficiency. Older farmers are more experienced and would be more technically efficient than younger farmers. However, with respect to new ideas and techniques of farming older farmers are less likely to adopt innovations and thus might be less technically efficient than younger farmers. In this paper, age has positive signs and significant effects on technical efficiency across the zones and also within the forest and savannah zones. The result of the analysis on age indicates that the maize producers were within an active and productive age group.

The study also observed a positive relation between the level of education of maize farmers and their level of technical efficiency. As compared to those who did not have any formal education, the farmers who had had little education had a positive and significant effect on technical efficiency across the agro ecological zones. With the exception of the coastal zone where education decreased efficiency statistically significant at 10%, forest and savannah had a positive effect on technical efficiency, which was significant at 10%. This implies that increased education led to increased technical efficiency for some farmers across the ecological zones but also decreased efficiency for other farmers in a particular zone. Education might thus be regarded as a factor for increased efficiency among farmers Married status had a positive effect on technical efficiency which was significant at 10% for maize farmers across the zones and with the savannah zone, but negative and statistically significant at 10% for farmers in the coastal zone. This implies that male farmers who were married were more efficient than those who were single across the zones but contradict the findings in the coastal zone, where marital status had negative effect on efficiency. But this is in conformity with studies conducted by Simonyan, (2010). The coefficients of household size were positively and significantly related to technical efficiency at 10% for both coastal and savannah zones. This implies that large household size is a source of labour for most farm operations. The effect of years of farming on technical efficiency was positive and statistically significant at 10% across the zones as well as within all three zones. This finding serves as evidence for human capital since farmers with more years of experience in farming will have more technical skills in management and thus higher efficiency than younger farmers. Greater experience in cultivation may also enhance critical evaluation of the relevance of better production decisions, including efficient utilization of productive resources. This result is in conformity with the findings of Aye et al (2010).

The coefficients for the number of males engaged in the farm were positive and statistically significant at 10% on technical efficiency for maize farmers across the agro ecological zones and for farmers in the savannah zone. Although the variable was not significant for coastal and forest zones it was positive there also. This implies that males engaged in the farming work hard to increase the level of efficiency in their farms. On the other hand, the number of females engaged in the farm had negative and significant effect on the level of efficiency across the zones and also in the forest zone. However this variable was positive and statistically significant at 5% for maize farmer in the coastal zone. It appeared to be central to determining the efficiency of the output. The coefficients for farm size were positive and highly significant at 1% for farms across the zones and for farms in the savannah zone. In the coastal zone the farm size was also positive and statistically significant at 10%. However the farm size was negatively significant at 10% in the forest zone. This might be explained by increased farm size diminishing the timeliness of input use thus leading to a decline in technical efficiency. This inverse relationship confirms the findings of Mungatana, (2010). These results underscore the need to formulate policies that encourage smallholder farmers to continue in production, as they are the backbone of agricultural production and growth in developing countries

The effect of access to credit on farming efficiency was positively significant at 10% across the agro ecological zones and within the savannah zone. This agrees with the finding of Muhammad (2009) and Aye and Mungatana (2010). This result implies that accessibility and availability of credit loosens the production constraints and hence makes it easier for timely purchase of resources thereby increasing productivity through efficiency for savannah farmers. However contrary to that, farmers in the forest zone reported a negative impact of access to credit on technical efficiency, significant at 1%. The extension service contact was expected to have a positive impact on efficiency since farmer's access to extension services enhances their access to information and improved farming techniques. The variable was positive and statistically significant at 10% for farmers across the zones and in the savannah zone, however, it was found to be negative but not significant for farms in the forest zone. This result suggests that extension services delivery is lagging in effectiveness. It therefore becomes imperative for more proactive and effective policy decisions to be taken aimed at improving the service delivery of extension officers. Topmost priority should be given to updating the knowledge base of extension personnel as well as timeliness in disseminating information on modern farming techniques.

Communitarian social capital, measured as membership of a farmer's association, had a positive influence on technical efficiency statistically significant at 10% across the agro zones and insignificant within the zones, but with uniformly the same sign. This finding implies that association members farming can be valuable for small-scale operations, supposedly because it facilitates access to markets and encourages income and agricultural activities. In addition, association membership provides farmers with a secure market for their crops as well as some technical assistance, which enhances farmer technical efficiency. Unexpectedly, we found a detrimental impact of intercropping techniques on efficiency, across the ecological zones and within the three major zones. This was not in line with usual agronomic expectations. The cropping pattern variable had negative impact statistically significant at 5% and 1% across and within the agro zones respectively. This result supports the alternative mono-cropping system, which has high potential for increasing maize production at in the short term. It was found that off/non-farm income influenced maize productivity positively at 5% level of significance across the zones but negatively at 1% level of significance in the coastal and savannah zones. This supports the argument that increased off/non- farm opportunities might either take away farm resources and farmers effort that could otherwise be used for maize production and so reduce maize productivity or they might increase productivity if some of the off farm income is also invested in maize production.

Likelihood Ratio Test

Likelihood ratio tests (LRTs) have been used to compare two nested models. The form of the test is suggested by,

$$LRT = -2\log_e\left(\frac{L(H_o)}{L(H_a)}\right)$$

In the ratio of two likelihood functions; the simple (Cobb-Douglas) model has fewer parameters than the general (translog) model. Asymptotically, the test statistic is distributed as a chi-squared random variable, with degrees of freedom equal to the difference in the number of parameters between the two models. Likelihood ratio tests compare two models provided the simpler model is a special case of the more complex model (i.e., “nested"). LRTs can be presented as a difference in the log- likelihoods and this is often expressed as,

$$\lambda = -2\{\ln[L(H_o)] - [\ln(LH_a)]\}$$

As indicated in the methodology this is to determine whether the data for the agro ecological zone (that is “nested”) could be pooled. The values of relevance computed from the stochastic production functions were:

$$\ln[L(H_o)] = -496.544$$

$$\ln[\text{L}\ (H_a)] = -468.128$$

$$\lambda = -2\{-496.544 + 468.128\}$$

$$\lambda = -2\{-28.416\}$$

$$\lambda = 56.832$$

With 19 degrees of freedom, the chi-squared distribution from the table at 99% confidence level is 43.820. Our estimated value of 56.832 was outside this range. Consequently, we fail to accept the null hypothesis that the maize farmers in the agro ecological zones used similar technology in production. Thus, the data for the agro ecological zones could not be pooled.

Consequently, there was a need to use the metafrontier estimation technique to estimate common technical efficiency scores for the maize farmers across the agro ecological zones

Table 7: Estimates of metafrontier efficiencies (TE*) and technology gap ratios (TGR) for maize farms across the ecological zones

Zone	Variables	Mean	Std. Dev.	Min	Max
All	Group TE	0.620	0.160	0.154	0.910
	Tech Gap Ratio TGR	0.700	0.373	0.007	1.000
	Metafrontier TE*	0.419	0.267	0.004	0.905
Coastal	Group TE	0.628	0.170	0.125	0.898
	Tech Gap Ratio TGR	0.943	0.212	0.013	1.000
	Metafrontier TE*	0.628	0.165	0.154	0.905
Forest	Group TE	0.637	0.189	0.105	0.925
	Tech. Gap Ratio TGR	0.204	0.143	0.007	0.808
	Metafrontier TE*	0.127	0.094	0.004	0.482
Savannah	Group TE	0.524	0.200	0.077	0.931
	Tech Gap Ratio TGR	0.893	0.106	0.146	1.000
	Metafrontier TE*	0.504	0.198	0.045	0.888

Estimated technical efficiencies with respect to the agro zone frontiers and the meta-frontier, together with estimated TGRs, their standard deviations, and the distributions of TGRs by zone are presented in Table 1. The differences in the agro zones are as result of variations in the climatic indicators (temperature, rainfall etc). The value of TGRs ranges from 0.007 to 1. The standard deviation for a mean technical efficiency estimate for a variety is a measure of the dispersion of individual farm technical efficiencies around the mean technical efficiency. From the results, maize farms in the forest zone are the most efficient (64%) as compare to coastal (63%) and savannah (52%). The coastal farms in the maize production achieved highest mean technical efficiencies relative to the metafrontier. However, the mean technical efficiency relative to the metafrontier is very low for farms in the forest zone. The mean values for the TGRs indicate that coastal farmers produce, on the average, about 94.3%, forest farms produce about 20.4% and savannah farms produce about 89.3% of the potential output given the technology available to the whole maize production across the ecological zones. Farms in coastal zone generally lead in terms of technology gap ratio and have the highest variation of TGR. However, TGR ratio of farms within the forest zone has the lowest average TGR ratio hence its average efficiency is reduced from 64% when compared relative to the frontier within zone to 13% when compared to the meta-frontier. The fact that we cannot reject the null hypothesis that there is no one-sided error term in the frontier estimation for the coastal and savannah zones suggest that farms are close enough to the frontier and thus reach the highest possible efficiency score (100%). However, the coastal zone 94% average TGR reduces its average efficiency to 63% relative to the meta-frontier, although still leading among the three zones.

Conversely, maize farms within the forest zone have the lowest potential output given the technology available to the whole maize production. Despite the fact that farms within the forest zone achieved higher mean technical efficiency relative to their group stochastic frontier, they are far from the potential outputs that are defined by the metafrontier function. Both the coastal and savannah zones farms had the maximum value for the TGRs of one, indicating that, the two zones farms and their group stochastic frontiers were tangent to the metafrontier. Hence, it is possible for farms within zones to attain efficiencies under the common technology of the metafrontier. On the other hand, the TGR of the farms in the forest zone is less than one, implying that the farms group stochastic frontier is not tangential to the metafrontier of the maize production across the agro ecological zones. We suggest that, attention should be paid to agricultural extension systems to disseminate agricultural technology and know-how between and within the agro zones. Second, when the ecological difference has limited the diffusion of agricultural technology, institutional variables, such as factor markets should be further examined. Whether efforts should be invested in following leading agro zone within the zones or within the agricultural activity that could be determined by examining the efficiency scores and technology gap ratios. We conclude that climate variability had significantly affected technical efficiency and technology gap in Ghana’s food crop production across the ecological zones.

Table 8: Estimates of the OLS model to verify the determinants of metafrontier efficiencies

Dependent Variable; Metafrontier Technical Efficiency Scores

Variables	**Coefficients**
Constant	0.725***
	(5.49)
Age	-0.144*
	(-2.17)
Education	0.0694**
	(2.61)
Marital status	0.0408
	(1.28)
Household size	0.00631*
	(1.95)
Years of farming	-0.00433**
	(-2.87)
Male workers engaged	0.00241*
	(2.34)
Female workers engaged	0.0211
	(0.74)

Table 8…

Farm size	0.00284**
	(2.53)
Farm credit	-0.0402*
	(-1.83)
Extension	0.0666*
	(2.32)
Irrigation	-0.0185
	(-0.65)
Farmers association	0.0238
	(0.78)
Cropping pattern (monocropping)	-0.122**
	(-2.61)
Rainfall	-0.0948**
	(-2.95)
Temperature	-0.118*
	(-1.94)
Green manure	-0.0504*
	(-1.83)
Off-farm income	-0.00643
	(-0.25)
R-squared	0.3468
VIF	9.743
N	581

t statistics in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$

In order to corroborate the determinants of technical efficiency of maize production across the ecological zones, we estimated Ordinary Least Squares (OLS) regression model using the metafrontier technical efficiency estimates as the dependent variable. The results are presented in Table 8. From the results, the socio-economic and farm level characteristics as well as the climatic indicators (temperature, rainfall etc.) explain technical efficiency of the maize production across the agro ecological zone relative to the metafrontier. The relationships between all these variables and the technical efficiency scores have mixture of positive and negative coefficients. From the results, negative coefficient of the farmers perception about the variability of temperature is statistically significant at 10%, this suggests that movement away from the trend can be damaging for production of maize once temperature cross a certain threshold.

This confirms that high temperature leads to low level of technical efficiency relative to the metafrontier across the agro ecological zones. This means that changes in temperature, amount of carbon dioxide (CO2), and the frequency and intensity of extreme weather could have significant effects on maize yields. Warmer temperatures may make many crops grow more quickly, but warmer temperatures could also reduce yields. Crops tend to grow faster in warmer conditions. However, for some crops such as maize, faster growth reduces the amount of time that seeds have to grow and mature (USGCRP 2009). This can reduce the amount of maize produced from a given land. The effect of increased temperature would depend on the crop's optimal temperature for growth and reproduction. In some areas, warming may benefit the types of crops that are typically planted there. However, if warming exceeds a crop's optimum temperature, yields can decline. Furthermore, extreme temperature and precipitation can prevent crops from growing. Extreme events, especially floods and droughts, can harm crops and reduce yields. The coefficient of rainfall is negatively signed and statistical significant at 10% on technical efficiency relative to the metafrontier. This stands to reason that rainfall variability affect maize yields by reducing length of growing season, especially in the drought years. This variation in rainfall poses a high risk in maize production, as it may become difficult to predict rainfall across the agro zones. The erratic nature of rainfall and infrequent heavy storms also adds to the erosion problem in some of the agro ecological zone. The infiltration capacity of the soils, during such storms is exceeded and the high intensity causes crust formation, which leads to high runoff and soil losses. Hence, low maize yield across the zones.

CONCLUSION

The results of this study reveal variations in technical efficiency in maize production between the three major agro ecological zones (coastal, forest and savannah) in Ghana. The results show maize production in forest zone was on the average more efficient than those in coastal and savannah zones. Although the average maize production was technically more efficient in the forest zone than other zones, all three zones did not achieve maximum technical efficiency. This suggests that opportunities exist for increasing productivity of maize farmers in the study area by increasing the efficiency with which resources are used at the farm level. It was found that household size, extension contact, educational status and credit access were all directly or inversely related to the technical efficiency of farmers across the agro zones while farm size was directly related to the technical efficiency of all farmers within the zone categories. Age was an important factor and it had a mixture of positive and negative significant effect on technical efficiency of farmers across the zones. The cross elasticities between the maize inputs showed that there were significant input complementarities among the maize farmers across the zones

All maize farms across the agro ecological zones are less efficient. However, farms in the forest zone have higher efficiency scores than farms within coastal and savannah zones. Farms in the coastal and savannah zones are closer to their potential output defined by the metafrontier function than farms within the forest zone. The stochastic frontiers for all farms within coastal and savannah zones are tangent to the stochastic metafrontier. Farms within coastal and savannah zones use more advanced technology than farms within the forest zone as indicated by the intercept term in the production function.

RECOMMENDATIONS

- Since the study revealed that an increase in the age of the farmer groups would lead to decline in their technical efficiency, policies that would focus on ways of attracting youths who are agile and stronger to embark on maize production would help to increase technical efficiency and productivity.
- Policies aimed at improving farmers' access to credit and other farm input would be useful in increasing their efficiency which in turn increase the level of food sufficiency among Ghanaians
- Those who are experienced should also be encouraged to continue farming.
- Attention should be paid to agricultural extension systems to disseminate agricultural technology and know-how between and within the agrozones, especially farms in forest zone
- Policy makers should also ensure that climatic conditions prevailing in the different agro ecological zones across the country are taken into consideration while formulating agricultural policy. Since climate variability may have either positive or negative effects on these policies as well as farm technologies used. Also daily temperature and rainfall information should be made available to farmers especially those in the rural communities to enable them have adequate knowledge about the climate variability to guide their farming activities

LIMITATIONS OF THE CURRENT STUDY

Also, since the food crop farmers hardly keep records on their farming activities, the research relied on the respondent's power to recall, and or perceptions to obtain some of the data required for the study. This might have affected the realities of the situations in the study and thus inferences from the findings of the study may reflect situations in the selected communities but not the entire country. Because of the need to rely on farmers' memories, the efficiency analysis is based on certain period (July – August, 2013). Extrapolating the results to other areas, years and season needs to be done with care. Furthermore, factors such as temperature, rainfall, types of capital used and variations in the inputs prices can have an impact on efficiency and technological gaps.

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