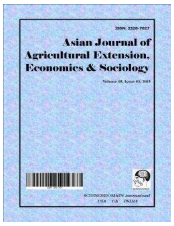

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Technical Efficiency and Production Risk of Maize Production: Evidence from Ghana

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Authors' contributions

This work was carried out in collaboration between all authors. Author BAO prepared the manuscript under the supervision of authors EEO and SAB. All authors read and approved the final manuscript.

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ABSTRACT

This paper analyzed maize production efficiency in Ghana due to differences in efficiency. The stochastic frontier model with flexible risk properties is applied with 232 farms from the Brong-Ahafo Region. Findings of the study were the translog model best fits the mean output function, whilst the input variables: seed, herbicide, land, labour and cost of intermediate inputs influenced maize output at decreasing returns to scale. The study also found seed and labor inputs reduced production risk, whilst land and cost of intermediate inputs increased the risk. The average technical efficiency estimate was 62% and the combined farm specific factors explained the variation in technical efficiency. This study concludes, on the average 38% of potential output is lost due to technical inefficiency and production risk in inputs and the use of the best farm practices produce maize efficiently.

Keywords: Maize; technical efficiency; resources; optimization; productivity; food security; Ghana.

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1. INTRODUCTION

World production of maize amounted to 875, 226,630 tons in 2012 mainly from United States, China and Brazil [1]. Africa contributes small fraction of the total supply [2]. Maize consumption per capita is highest between 52 to 328 g/person/day as a staple in Africa. Ghana's per capita consumption of mainly white maize, increased from 38.4 kg in 1980 to 43.8 kilograms in 2011 [3]. The current average yield of maize in Ghana is estimated to be 1.9 t/ha [2] against achievable yields of 6t/ha. Similarly maize yields for Burkina Faso, Togo, Cote D'Ivoire are 1.59t/ha, 1.19t/ha and 2.06 t/ha and this have been very erratic over the years [2]. The worst yields are decreasing in Kenya, Morocco and Rwanda whilst population is growing meanwhile the crop constitute about 5-51% of calorie intake. But in Asia and other parts of Africa yields are consistently increasing that is Ethiopia, Angola, and South Africa. Thus, in some parts of Africa deviation of observed maize yields from the achievable yield is worst due to constraints from poor physical structures, weather, pest and disease incidence and socio economic characteristics of the farmers. Consequently, the supply of maize is not enough to meet its higher demand from growing population [4].

Technical efficiency analysis is of paramount importance to increase maize productivity and contribute to the attainment of food security and income generation. In addition, production risk in inputs influences the production structure and subsequently the technical efficiency estimates [5,6,7,8,9]. However, the conventional stochastic frontier model neglects the role of the inputs towards risk. A comprehensive analysis of production risk in input and technical efficiency of maize production has not been properly addressed in Ghana. Such studies could contribute to policy formulation on maize production [10,11,12,13,14]. The study assessed technical efficiency and production risk of selected maize farms in Brong-Ahafo Region of Ghana.

2. MATERIALS AND METHODS

2.1 Study Area

The study was based on farm level data on maize production in the Brong-Ahafo region of Ghana. Maize is grown in two seasons but mostly cultivated in the first season with the onset of rains. Major season cultivation usually starts from March to June and a short dry-spell which occurs in July provides suitable conditions for harvesting and sun-drying. The minor season follows in August till November. Nkoranza, Kintampo North and South, Wenchi Districts as part of the study area are found in the transition zone of Ghana whereas Sunyani West and Berekum Districts are located in the semi-deciduous forest zone.

2.2 Theoretical Framework

The method of analysis proposed for this study is consistent with the stochastic frontier approach which was independently proposed by [15] and Meeusen and [16]. However, this model proposes inputs have similar effect on mean and variance outputs. But, [17], production function proposed separate effects of the inputs on the mean and variance outputs whilst [5] further incorporates technical inefficiency model.

Following [5] the production process is represented below as;

$$Y_i = f\left(x_i;\beta\right) + g\left(x_i;\psi\right)v_i - q\left(z_i;\delta\right)u_i \quad (1)$$

Y_i refers to the observed output produced by the i-th farm, $f\left(x_i;\beta\right)$ is the deterministic output function, $g\left(x_i;\psi\right)$ is the output risk function, ψ are the to be estimated coefficients of production risk function, x_i are the input variables, β are the to be estimated coefficients of the mean output function, $q\left(z_i;\delta\right)$ represents the technical inefficiency model, δ are the to be estimated parameters in the technical inefficiency model, v_i is the random noise, representing production risk and u_i denotes farm specific technical inefficiencies. Given the values of the inputs, the inefficiency effects, u_i, the mean output of the i-th farmer is given by:

$$E\left(Y_i / x_i, u_i\right) = f\left(x_{i;}\beta\right) - g\left(x_i;\psi\right)u_i \quad (2)$$

The technical efficiency of the i-th farm is given by equation (3) which is consistent with [5] specification of technical efficiency.

$$TE_i = \frac{E(Y_i/x_i,u_i)}{E(Y_i/x_i,u_i=0)} = \frac{f(x_{i;}\beta) - g(x_i;\psi)u_i}{f(x_i:\beta)} = 1 - \frac{g(x_i:\psi)u_i}{f(x_i:\beta)} \quad (3)$$

And technical efficiency becomes;

$$TE_i = 1 - TI_i \quad (4)$$

The technical inefficiency, TI is represented as:

$$TI_i = \frac{g(x_i:\psi)u_i}{f(x_i:\beta)} \quad (5)$$

The variance of output or production risk is given by,

$$Var(Y_i / x_i, u_i) = g^2(x_i;\psi). \quad (6)$$

The marginal effect of the input variables on the production risk is given as;

$$\frac{\partial V(Y)}{\partial x_j} = \frac{\partial g^2(x;\psi)}{\partial x_j} = 2g(x;\psi)g_j(x;\psi) \quad (7)$$

Thus, $\frac{\partial g^2(x;\psi)}{\partial x_j} \prec 0 \Rightarrow$ Risk decreasing of the j-th input, $\frac{\partial g^2(x;\psi)}{\partial x_j} = 0 \Rightarrow$ Risk neutral of the jth input and $\frac{\partial g^2(x;\psi)}{\partial x_j} \succ 0 \Rightarrow$ Risk increasing of the jth input. Based on the distributional assumptions of the random errors a log likelihood function for the observed farm output is parameterized in terms of $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\lambda = \sigma_u^2 / \sigma_v^2 \geq 0$ [15].

2.3 Empirical Model Specification

The empirical application of this study is consistent with models developed by [5,15,16,17] Deterministic part of the production frontier in equation (1) assumed a translog model in equation (8).

$$Lny_i = \beta_0 + \sum_{j=1}^{5}\beta_j Lnx_{ji} + 0.5\sum_{j=1}^{5}\sum_{k=1}^{5}\beta_{jk} \text{Ln} x_{ji} Lnx_{ki} + \varepsilon_i \quad (8)$$

β_j's denote the unknown true values of the technology parameters. If, $\beta_{jk} = 0$ then the translog stochastic frontier model reduces to

Cobb-Douglas model specified as:

$$Lny_i = \beta_0 + \sum_{j=1}^{5}\beta_j Lnx_{ji} + \varepsilon_i \quad (9)$$

The error term is specified as;

$$\varepsilon_i = g(x_i;\psi)v_i - q(z_i;\delta)u_i \quad (10)$$

Table 1. Variable description of the input variables in maize production process

Variable	Variable description	Measurement
y_i	Output	Kilograms
x_{1i}	Seed	Kilograms
x_{2i}	Herbicide	Litres
x_{3i}	Land	Hectares
x_{4i}	Labour	Mandays
x_{5i}	Cost of intermediate inputs	Cedis

Output and input variables have been normalized by their respective means. The scale elasticity (κ) if $(\kappa) \succ 1 \Rightarrow$ increasing returns to scale (IRS), $(\kappa) \prec 1 \Rightarrow$ decreasing returns to scale (DRS), and $(k) = 1 \Rightarrow$ Constant returns to scale (CRS). Following [17] the (κ) is equivalent to the frontier output elasticity. Man days for labour have been calculated with the formula in line with [18] and [19]. One adult male working for 8 hours equals one man day; one female and one child (< 18years) working for 8 hours equals 0.75 and 0.5 man days respectively.

The linear production risk function is specified as;

$$g(x_i;\psi) = \psi_0 + \sum_{m=1}^{5}\psi_m x_{mi} \quad (11)$$

Where x_m's represent the input variables, as described in Table 1. ψ_m's are the unknown true coefficients of the risk model parameters and the v_i's are the pure noise effects. If ψ_m's becomes negative, the respective input reduces output variance and vice versa [17].

The technical inefficiency effects were given by;

$$q\left(z_j, \delta\right) = \delta_0 + \sum_{j=1}^{9} \delta_j z_{ij} \quad (12)$$

Where δ_j's denote the unknown true values of the parameters of the technical inefficiency model and z_j's are the variables.

Table 2. Variable description of exogenous variables

Variable	Variable description	Measurement
z_{1i}	Land size	Hectares
z_{2i}	Age squared	Years
z_{3i}	Highest educational level	Ranked
z_{4i}	Number of extension visit	Number
z_{5i}	Ploughed field	Yes = 1 No = 0
z_{6i}	Berekum District	Yes = 1 No = 0
z_{7i}	Nkoranza District	Yes = 1 No = 0
z_{8i}	Kintampo District	Yes = 1 No = 0
z_{9i}	Wenchi District	Yes = 1 No = 0

Ranking of level of formal schooling for the study follows the study of [20] is outlined as: None_0; Primary level_1; Junior Secondary/Middle School level_2; Senior Secondary/Vocational level_3; Polytechnic level_4; University (bachelor) level_5.

2.4 Statement of Hypothesis

The following hypotheses were considered for investigation; $H_0 : \beta_{jk} = 0$, the coefficients of the second-order variable in the translog model are zero in favor of the Cobb-Douglas model; $H_0 : \psi_1 = \psi_2 = ...\psi_5 = 0,$ production risk in inputs is insignificant in the production process; $H_0 : \lambda = 0$ inefficiency effects are absent from the model. Therefore the variance of the inefficiency term is zero and deviations of the observed output from the frontier output are entirely due to pure noise effect. On the other hand if $\lambda > 0$ then technical inefficiency is present in the data and deviations from the frontier output are as a result of technical inefficiency and pure noise $H_0 : \delta_1 = \delta_2 = ... = \delta_9 = 0$; this implies the exogenous variables do not account for technical inefficiency.

2.5 Data and Sampling Technique

This study used cross sectional data from 232 maize farms, which is a fair representation of the maize farms in the region. Multi-stage sampling procedure was employed for the farm survey to obtain the data on the relevant variables for the study including output and input variables as well as the farm specific variables. Within each district three major communities with varying intensity of maize production were selected from which the maize farm households are selected randomly. The farmers are distributed within the districts as 50, 50, 47, 39 and 46 for Sunyani West, Nkoranza South, Kintampo North and South Wenchi and Berekum districts respectively which occur in the transition and semi-deciduous zones as soil and weather characteristics are favorable for optimum maize production.

3. RESULTS AND DISCUSSION

3.1 Summary Statistics of the Output and the Input Variables

The study demonstrated that output range between (337.5 – 6750) kg/ha at the mean of 1957.506 kg/ha with standard deviation of 1027.74 kg/ha (Table 1). Maize producers obtained yields of 3.3-6tons/ha of which the production technology becomes fairly represented for the region. The average yield of 1957 kg/ha of maize implies significant number of farmers obtain yields below the maximum yield per hectare but considering all the inputs in the production process the frontier output is not known thus, this study seeks to estimate the determinants of technical efficiency.

3.2 Testing of Hypothesis

The translog model is an adequate representation of the data, given its specification. Production risk in inputs and technical inefficiency are present and the estimated lambda is 1.7. Thus the variations in output due to technical inefficiency are relatively larger than the deviations in output from pure noise component of the composed error term. The study finds technical inefficiencies are explained by exogenous variables (Table 2).

3.3 Frontier Estimates

The effects of the inputs conform to expectation on output. Output is mainly contributed by cost of intermediate input and seed. Additionally, land contributes technical efficiency gains as found in [21]. At the scale elasticity of 0.8%, output does not respond proportionally to input change. But, [12] results of maize production in Northern Ghana have indicated an increasing return to scale (Tables 4 and 5).

3.4 Production Risk

Production risk in inputs is significant in the production process with the exception of herbicide. Seed and labor reduce risk because seed as an input factor has the favorable characteristics to support its growth into maturity. This contradicts with what [22] found in which seed was a risk increasing-input in rice production. Labour performs the best farm practices to support the farmer to achieve the expected output as way of reducing risk in the production process. This result is consistent with the findings of [7,8,22]. Risk averse farmers in pursuit of reducing their risk are expected to use more of seed and labour to better their situation which can alter the technical efficiency score.

Land and cost of intermediate inputs are positively related to production risk. Land might increase the risk of exposure of the crops from unfavorable weather conditions especially during the dry season. [9] study reveals greater area cultivated lead to increased output variability, possibly suggesting that larger farms are less able to react quickly to unfavourable weather conditions at harvest or planting times. On the other hand, [22] found land to be a risk-reducing input because the rice farmers had parceled their land into plots such that losses from one plot are compensated by gains in another due to differences of weather at the different plots.

Table 3. Summary statistics of output and input variables

Variables	Unit	Minimum	Mean	Maximum	SD
Output	Kilograms/ha	337.50	1957.51	6750.00	1027.74
Seed	Kilograms/ha	4.85	21.35	43.13	6.54
Herbicide	Liters/ha	0.10	8.57	40	5.82
Land	Hectares	0.40	3.23	20	2.59
Labour	Man-days/ha	13.06	67.95	236.86	35.11
Cost	Cedis/ha	6.54	170.98	1598.75	160.93

Source: Field survey, 2012

Table 4. Hypothesis test for model specification and statistical assumptions of stochastic frontier model with flexible risk properties

Null hypothesis	Loglikelihood value	Test statistic (λ)	Critical value	Decision
1. $H_0 : \beta_{jk} = 0$	-107.17	71.10	37.70	Reject H_0
2. $H_0 : \psi_1 = \psi_2 = ...\psi_5 = 0,$	-88.80	35.74	20.52	Reject H_0
3. $H_0 : \lambda = 0$	-96.81	50.38	9.50[a]	Reject H_0
4. $H_0 : \delta_1 = \delta_2 = \delta_3 = \delta_4 = ...\delta_9 = 0$	-93.71	44.78	32.91	Reject H_0

[a]*Value of test of one sided error . The correct* χ^2 *value for the hypothesis of the one sided error is obtained from table 1 of [23], whilst the rest are obtained from chi-square table. All the variables are significant at 1% level*

Table 5. Maximum likelihood estimates of translog mean output function

Variables	Parameters	Estimates	Standard errors
Constant	β_0	0.40***	0.01
Lnseed	β_1	0.219***	0.057
Lnherbicide	β_2	0.073**	0.024
Lnland	β_3	0.136***	0.037
Lnlabour	β_4	0.074***	0.019
Lncost	β_5	0.280***	0.017
0.5Ln(seed)^2	β_6	1.514***	0.356
0.5Ln(herbicide)^2	β_7	0.048*	0.027
0.5Ln(land)^2	β_9	0.910***	0.242
0.5Ln(labour)^2	β_8	0.452***	0.113
0.5Ln(cost)^2	β_{10}	0.006	0.034
Lnseed*Lnherbicide	β_{11}	0.133*	0.071
Lnseed*Lnland	β_{12}	-1.045***	0.232
Lnseed*Lnlabour	β_{13}	-0.398***	0.080
Lnseed*Lncost	β_{14}	-0.365***	0.925
Lnherbicide*Lnland	β_{15}	-0.146***	0.019
Lnherbicide*Lnlabour	β_{16}	-0.107***	0.085
Lnherbicide*Lncost	β_{17}	-0.006	0.018
Lnland*Lnlabour	β_{18}	-0.115	0.137
Lnland*Lncost	β_{19}	0.357*	0132
Lnlabour*Lncost	β_{20}	0.017	0.053
Lambda	λ	1.67***	0.087

*Source: ** and *** correspond with 5% and 1% level of significance respectively*

3.5 Technical Efficiency Estimates

Maize production in the region is not technically efficient. The lowest efficiency score is 8% which is incomparable to the highest at 99%. On the average the farmers produce about 62% of the frontier output. Quite significant number of farmers obtains relatively higher efficiency scores (Fig. 1). The results might be similar to other areas of Ghana [10,12]. The study found that farmers in Nkoranza have a higher rate of technical efficiency due to their ability to apply the best farm practices more efficiently.

Table 6. Elasticity of production and returns to scale

Variables	Elasticities
Seed	0.22
Herbicide	0.07
Land	0.14
Labour	0.07
Cost	0.28
RTS	0.8

Source: All the input variables are significant at 1 percent

Table 7. Maximum likelihood estimates of the linear production risk function

Variables	Parameters	Estimates	Standard errors
Constant	ψ_0	-19.46***	7.02
Seed	ψ_1	-0.083**	0.395
Herbicide	ψ_2	0.067	0.064
Land	ψ_3	3.220**	1.405
Labour	ψ_4	-0.048*	0.027
Cost	ψ_5	0.005**	0.002

*Source: ***, **, * indicate 1%, 5% and 10% level of significance respectively*

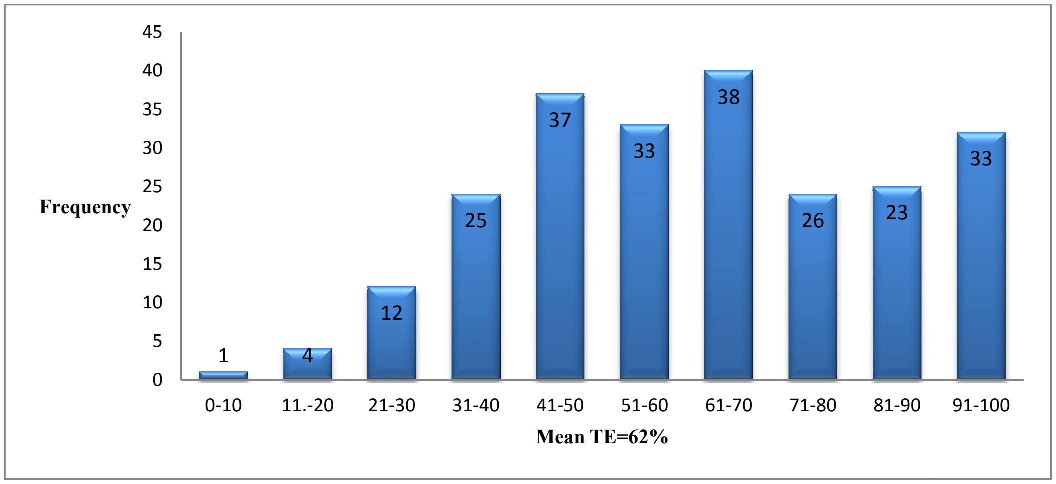

Fig. 1. Technical efficiency distribution
Source: Field data

Table 8. Maximum likelihood estimates of the technical inefficiency model

Variables	Parameters	Estimates	Standard errors
Constant	δ_0	0.23	0.44
Landsize	δ_1	-0.284***	0.055
Age2	δ_2	0.0001	0.00009
Education	δ_3	-0.018	0.097
Numvisits	δ_4	0.046	0.071
Dumplough	δ_5	0.668**	0.330
bkdistrict	δ_6	-0.312**	0.321
Nkoransa	δ_7	-1.054**	0.457
Kintampo	δ_8	-0.749**	0.384
Wenchi	δ_9	-0.813**	0.376

*Source: ***, **, indicate 1%, and 5% level of significance respectively*

3.6 Determinants of Technical Inefficiency

Farm size reduces inefficiency in the production process. The reason might be such farmers adopted the best farm practices so as to achieve the frontier output [24,25]. [26] study indicated that soil conservation practices result to higher levels of technical efficiency among farmers but ploughing affected technical inefficiency positively. Location has been an important factor to determine efficiency because the level of efficiency at Sunyani West is significantly lower than the other districts. Similarly the efficiency of cocoa production varied by regions of Ghana [27] as well as rice production in South Korea [28].

3.7 Risk and Technical Efficiency

Technical efficiency estimates for the maize farms when production risk component is excluded ranged from 13% to 97%, with a sample mean of 76%. However, when the stochastic frontier model with flexible risk properties was considered, the technical efficiency estimates ranged from 8% to 99% with a mean of 62%, which is significantly different from the 76%. Thus the technical efficiency estimates may be compromised when the production technology of the maize farms in the study area is modeled without the flexible risk component [5,6,8,9].

4. CONCLUSIONS AND POLICY RECOMMENDATIONS

This study has estimated stochastic frontier model with flexible risk properties. It revealed the input factors determined maize output as well as production risk. On average, maize production in the region has been technically inefficient and is dependent upon the application of best farm practices. It further predicted technical efficiency to reveal that technical efficiency estimates may be compromised when the production technology is modeled without the flexible risk component. Farmers consider their land sizes before applying best farm practices. The study recommends policy to promote the application of best farm practices on small land holdings as well as bridging the gap in district level efficiency. Again efficient methods of ploughing to suit local conditions are recommended. Lastly, it is appropriate to incorporate production risk in technical efficiency analysis if the inputs are non-neutral in risk.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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