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Research Article

Technical efficiency and production risk of maize production: Evidence from Ghana

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Abstract
The paper performs an investigation of maize production efficiency in Ghana by the stochastic frontier model with flexible risk properties using a cross section of 232 farms from the Brong-Ahafo Region. The findings of the study are the translog model is best fit for the mean output function, whilst the input variables: seed, herbicide, land, labor and cost of intermediate inputs positively influence maize output at decreasing returns to scale. The study also finds that seed and labor inputs are negatively related to production risk, whilst land and cost of intermediate inputs are classified as risk increasing inputs. The average technical efficiency estimate is 62% and the combined farm specific factors explain the variation in technical efficiency. The study concludes that 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 contribute to produce maize optimally.

Keywords
Maize–Resources–Optimization–Productivity–Food Security–Ghana

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1. Introduction

World production of maize amounts to 875, 226,630 tons in 2012 mainly from United States, China and Brazil (Ranum et. al 2014) whilst Africa contributes minor fraction of the total supply (FAO 2015). But maize consumption per capita is highest in Africa between 52 to 328 g/person/day to become a major staple food. Ghana's Per capita consumption of mainly white maize, increase from 38.4 kg in 1980 to 43.8 kilograms in 2011 (MoFA 2012). Thus maize has greater industrial use in the major producing countries. The current average yield of maize in Ghana is estimated to be 1.9 t/ha (FAO, 2015) 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 respectively and over the decade maize yields have being very erratic (FAO 2015). However in Asia and other parts of Africa yields are consistently increasing in Ethiopia, Angola, and South Africa. At the worst yields are decreasing in Kenya, Morocco and Rwanda whilst population is growing meanwhile the crop constitute about 5-51% of calorie intake. Thus the extent of deviation of observed maize yields from the achievable yield is worst in Africa due to constraints limiting yield growth as a result of physical structures, weather, pest and disease incidence and socio economic characteristics of the farmers. The persistence of this trend cannot create the supply to meet its higher demand from growing population, meat and dairy consumption from growing affluence and expected biofuel consumption in 2050 (Ray et al 2013).

Technical efficiency analysis is of paramount importance to promote the role of the crop towards food security and income generation. But, aside technical inefficiency, production risk in inputs also influences the production structure and subsequently the technical efficiency estimates (Just and Pope 1978; Tiedemann and Latacz-Lohmann 2012; Ogundari & Akinbogun 2010; Villano et al 2005; Bokusheva and Hockmann 2006). Thus the conventional stochastic frontier model neglects the role of the inputs towards risk. This area of production risk in input and technical efficiency of maize production has not been properly addressed in Ghana. Meanwhile a number of these studies have contributed to policy on maize production (Oppong et al. 2014; Crenstil & Essilfie 2014; Al-hassan, S. (2008); Abdulai, et al 2013; Awunyo-Vitor et al 2013; Al-hassan, 2012; Onumah, et al 2010; Essilfie, et al 2001). The study then assesses together technical efficiency and production risk of maize farms in Ghana.

2. Materials and Method

2.1 Study Area

The study is based on farm level data on maize cultivation in the Brong-Ahafo Region of Ghana. The crops mainly cultivated in the region are cocoa, teak, oil palm, maize, yam and cassava. 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 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. 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 effectively and efficiently.

2.2 Theoretical Framework

The method of analysis proposed for this study is consistent with the stochastic frontier approach which is independently proposed by Aigner et al. (1977) and Meeusen and Van Den Broeck (1977). However, this model proposes the inputs have similar effect on mean and variance of output. Therefore, if an input influences output positively, it is expected to influence output variance positively and vice versa. But, Just and Pope (1978), production function proposes a separate effect of the inputs on the mean output and the variance of output or output risk whilst Kumbhakar (2002) further incorporates technical inefficiency model to explain the variation in technical inefficiency. Following kumbhakar (2002) the production process is represented below as;

$$Y_i = f(X_i;\beta) + g(X_i;\psi)V_i - q(Z_i;\delta)U_i \quad (1)$$

Y_i refers to the observed output produced by the i-th farm, $f(X_i;\beta)$ is the deterministic output function, $g(X_i;\psi)$ is the output risk function, ψ are the estimated coefficients of production risk function, X_i are the input variables, β are the estimated coefficients of the mean output function, $q(Z_i;\delta)$ represents the technical inefficiency model, δ are the estimated effect of the explanatory variables in the technical inefficiency model,V_i represents the random noise in the data, representing production risk and U_i represents farm specific technical inefficiencies. Given the values of the inputs, and the inefficiency effects, , the mean output of the i-th farmer is given by:

$$E(Y_i/x_t, u_i) = f(x_{t,\beta}) - g(X_i;\psi)U_i \quad (2)$$

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

$1 - \frac{g(x_i:\psi)u_i}{f(x_i:\beta)}$

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,

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

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

Thus, $\frac{\partial g^2(x,\psi)}{\partial x_j} \prec 0 \Rightarrow$ Risk decreasing of the jth 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 $\lambda = \sigma_u^2/\sigma_v^2 \geq 0$ (Aigner et al., 1997).

2.3 Empirical Model Specification

The empirical application of this study is consistent with models developed by Aigner et al. (1977) and Meeusen and Van Den Broeck (1977), Just and Pope (1978) and Kumbhakar (2002). Translog model is assumed for the deterministic part of the production frontier in equation (1).

$$Iny_i = \beta_0 + \sum_{j-1}^{5} \beta_j Inx_{ji} + 0.5 \sum_{j-1}^{5} \sum_{k-1}^{5} \beta_{jk} Inx_{ji} Inx_{ki} + \varepsilon_i \quad (8)$$

β_j denotes the unknown true values of the technology parameters. If, $\beta_{jk} = 0$ then the translog stochastic frontier model reduces to the Cobb-Douglas model given as: + The composed error term is given as;

$$\varepsilon_i = g(x_i;\psi)v_i - q(z_i;\delta)u_i \quad (9)$$

Wales 2000). The sum total of the output elasticity from the input variables is the estimated scale elasticity

Table 1. Variable Description of the Input Variables in the Maize Production Process

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

(K) which is defined as the percentage change in output as a result of 1% change in all input factors. When $(K) \succ 1 \Rightarrow$ increasing returns to scale (IRS), $(K) \prec 1 \Rightarrow$ decreasing returns to scale (DRS), and $(K) = 1 \Rightarrow$ Constant returns to scale (CRS) Following Battese and Broca (1997), the scale elasticity in this study is the frontier output elasticity. Man days for labour is calculated with the formula; one adult male working for one day (8 hours) equals one man day; one female and one child (< 18years) working for one day (8 hours) equals 0.75 and 0.5 man days respectively. The following researchers applied the above method for the calculation of man-days: Coelli and Battese (1996) and Onumah et al (2010). The linear production risk function is specified as;

$$g(x_i;\psi) = \psi_0 + \sum_{m-1}^{5} \psi_m x_{mi} \tag{10}$$

Where $x_m^{'S}$ represent the input variables, as described in Table 1. $\psi_m^{'S}$ represent the unknown true coefficients of the risk model parameters and the $v_i^{'S}$ are the pure noise effects. Where $\psi_m^{'S}$ becomes negative, the respective input reduces output variance and vice versa. (Just and Pope, 1978). The technical inefficiency effects are given by;

$$q(z_j,\delta) = \delta_0 + \sum_{j-1}^{9} \delta_j z_{ij} \tag{11}$$

Where $\delta_j^{'S}$ denote the unknown true values of the parameters of the technical inefficiency model and $z_j^{'S}$ are the exogenous explanatory variables.

Ranking of level of formal schooling for the study follows the study of Onumah & Acquah, (2011) 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

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

2.4 Statement of Hypothesis

The following hypotheses are considered for investigation; $H_0 : \beta_{jk} = 0$, the coefficients of the second-order variable in the translog model are zero to become 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 $H_0 : \delta_1 = \delta_2 = ... = \delta_9 = 0$; the exogenous variables do not explain variation in technical inefficiency.

2.5 Data and Sampling Technique

The study uses cross sectional data from 232 maize farms, which is a fair representation of the maize farms in the region. Multi-stage sampling procedure is 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 zone and semi-deciduous zones where 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 ranged between (337.5 – 6750) kg/ha at the mean of 1957.506 kg/ha and standard deviation of 1027.74 kg/ha (Table 1). The maize producers obtained yields within the range of 5.5-6tons/ha to make the production technology fairly represented because the maximum yield of maize of about 5.5-6tons/ha on the average is represented for the region. The average yield of 1957kg/ha of maize means that most of the farmers produce below the maximum yield per hectare but considering all the inputs in the production process the frontier output is not known and this study seeks to estimate the determinants of technical efficiency.

Table 3. Summary Statistics of Output and Input Variables

Variables	Unit	Minimum	Mean	Maximum	SD
Output	Kilograms/ha	337.5	1957.51	6750	1027.74
Seed	Kilograms/ha	4.85	21.35	43.13	6.54
Herbicide	Liters/ha	0.1	8.57	40	5.82
Land	Hectares	0.4	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

3.2 Testing of Hypothesis

The translog model is an adequate representation of the data, given the specifications of it. 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 inefficiency is explained by the exogenous variables (Table 2).

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
$H_0 : \beta_{jk} = 0$	-107.17	71.1	37.7	Reject H_0
$H_0 : \psi_1 = \psi_2 = ...\psi_5 = 0$	-88.8	35.74	20.52	Reject H_0
$H_0 : \lambda = 0$	-96.81	50.38	9.50a	Reject H_0
$H_0 : \delta_1 = \delta_2 = ... = \delta_9 = 0$	-93.71	44.78	32.91	Reject H_0

Value of test of one sided error. The correct x^2 value for the hypothesis of the one sided error is obtained from table 1 of Kodde and Palm (1986, p. 1246), whilst the rest are obtained from chi-square table. All the variables are significant at 1% level.

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. Land contributes to output by gains in technical efficiency as found in Ngwenya et al (1997). At the scale elasticity of 0.8%, output does not respond proportionally to input change. But, Abdulai, et al (2013) results of maize production in Northern Ghana indicated an increasing return to scale (Table 4&5).

Table 5. Maximum likelihood estimates of translog mean output function

Variables	Parameters	Estimates	Standard Errors
Constant	$\beta 0$	0.40***	0.01
Lnseed	$\beta 1$	0.219***	0.057
Lnherbicide	$\beta 2$	0.073**	0.024
Lnland	$\beta 3$	0.136***	0.037
Lnlabour	$\beta 4$	0.074***	0.019
Lncost	$\beta 5$	0.280***	0.017
0.5Ln(seed)^2	$\beta 6$	1.514***	0.356
0.5Ln(herbicide)^2	$\beta 7$	0.048*	0.027
0.5Ln(land)^2	$\beta 8$	0.910***	0.242
0.5Ln(labour)^2	$\beta 9$	0.452***	0.113
0.5Ln(cost)^2	$\beta 10$	0.006	0.034
Lnseed*Lnherbicide	$\beta 11$	0.133*	0.071
Lnseed*Lnland	$\beta 12$	-1.045***	0.232
Lnseed*Lnlabour	$\beta 13$	-0.398***	0.08
Lnseed*Lncost	$\beta 14$	-0.365***	0.925
Lnherbicide*Lnland	$\beta 15$	-0.146***	0.019
Lnherbicide*Lnlabour	$\beta 16$	-0.107***	0.085
Lnherbicide*Lncost	$\beta 17$	-0.006	0.018
Lnland*Lnlabour	$\beta 18$	-0.115	0.137
Lnland*Lncost	$\beta 19$	0.357*	132
Lnlabour*Lncost	$\beta 20$	0.017	0.053
Lambda	λ	1.67***	0.087

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

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: Authors computation. All the input variables are significant at 1 percent

3.4 Production Risk

Production risk in inputs has been significant in the production process with the exception of herbicide. Seed and labor reduce risk because seed as an input factor had the favorable characteristics to support its growth into maturity. This contradicts with what Picazo-Tadeo and Wall (2003) found in which seed was a risk increasing-input in rice production. Labour is used to perform 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 Bokusheva and Hockmann (2006), Picazo-Tadeo and Wall (2011) and Ogundari and Akinbogun (2010). 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. Tiedemann and Latacz-Lohmann (2012) study reveals greater area cultivated led 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, Picazo-Tadeo and Wall (2011) 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 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: Authors computation. ***, **,* indicate 1%, 5% and 10% 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. Maize production has also not being efficient in some areas of Ghana (Essilfie et al. 2011: Abdulai et al 2013). Quite significant number of farmers obtains relatively higher efficiency scores (Fiqure 1).

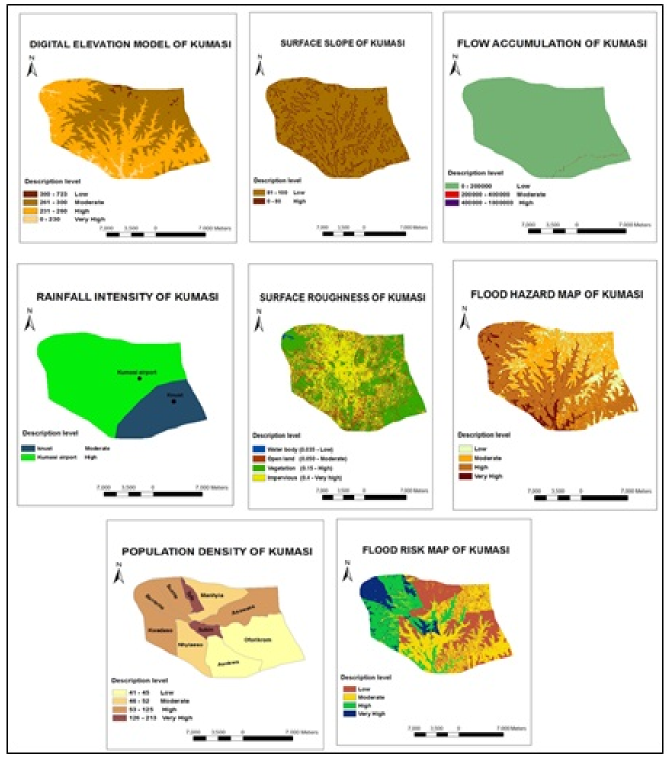

Figure 1. Technical Efficiency Distribution
Source: Authors Construction

3.6 Determinants of Technical Inefficiency

Farm size did not tend to influence the physical relationship with output only but it also reduced inefficiency. The reason might be that such farmers adopted the best farm practices so as to achieve the frontier output (Ahmad, et al. 2002; Nehring et al 2014). Solís et al., (2006) 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 in Sunyani West is significantly lower than the other districts. Similarly the efficiency of cocoa production varied by region in Ghana (Dzene 2010) as well as rice production in South Korea (Mohammed & Saghaian 2014).

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**	0.33
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: Authors computation. ***, **, indicate 1%, and 5% level of significance respectively

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 (Tiedemann and Latacz-Lohmann 2012; Ogundari and Akinbogun 2010; Villano et al 2005).

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 the locality are recommended. Lastly, it is appropriate to incorporate production risk in technical efficiency analysis if the inputs have flexible risk properties.

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