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Scale efficiency of maize farmers in four agro ecological zones of Ghana: A parametric approach

Camillus Abawiera Wongnaa *, Dadson Awunyo-Vitor

Department of Agricultural Economics, Agribusiness and Extension, Kwame Nkrumah University of Science and Technology, Private Mail Bag, University Post Office, Kumasi, Ghana

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ABSTRACT

The study analyzed scale efficiency parametrically for Ghana's smallholder maize farms. The data used was obtained through a cross-sectional survey of 576 maize farmers in the Guinea Savannah, Transition, Forest and Coastal Savannah zones of Ghana using structured questionnaire. Descriptive statistics and Ray's (1998) proposed stochastic frontier analysis approach were the methods of analysis employed. The results showed that the mean scale efficiencies were 86%, 91%, 89% and 86% for the Guinea Savannah, Transition, Forest and Coastal Savannah zones respectively, indicating that generally, scale inefficiencies existed in maize farms in the four agro ecological zones. The results further showed that most maize farmers in each zone exhibit increasing returns to scale, indicating that their outputs fall below efficient levels and therefore their output could be increased for optimal scales to be reached. Finally, the results revealed that scale efficiency is explained by educational level, maize farming experience, access to good roads and ready markets, group membership, extension contact, household size, land fragmentation as well as uses of fertilizer, pesticides and improved seeds. For scale efficiency to be improved, maize farmers in the various agro ecological zones of Ghana are encouraged to employ more of the production inputs available to them. For the farmers to be able to employ more of these inputs, cost of production inputs could be subsidized and credit could be given to them by government.

1. Introduction

Accounting for over 50% of total cereal production, maize is the second most important staple food in Ghana, next to cassava (Angelucci, 2013). With Ghana achieving self-sufficiency in starchy staples like plantain, yam and cassava, production of maize is nowhere near demand (EIU, 2007; RoG, 2007). With a greater proportion of maize supply going into food consumption in Ghana, an increase in its productivity is undoubtedly crucial for achieving food security in the country. Also, as a major constituent of livestock and poultry feed, the productivity and development of the poultry and livestock industries depend on the maize value chain.

In spite of the aforementioned economic importance of maize, the average maize yield in Ghana is low and remains one of the lowest in the world, much lower than the average for Africa south of the Sahara (Ragasa et al., 2014). For instance, land productivity is estimated at a third of its potential yield per hectare (OECD, 2008 cited in Wolter, 2008). In the year 2014, the International Food Policy Research Institute (IFPRI) and Ghana's Ministry of Food and Agriculture (MOFA) also estimated the average yields of maize under rain fed conditions for smallholder maize farmers in Ghana to be 1.73 metric tonnes/ha and 1.92 metric tonnes/ha respectively (MOFA, 2015; Andam et al., 2017). These yields are less than 35% of the estimated potential yield of 5.5 metric tonnes/ha for the same year. With a decline in productivity, there will be a decline in aggregate maize production which will have a negative impact on food security and the development of the poultry and livestock subsectors. Thus there is the need to find the sources of low yields in maize production in Ghana. The existence of scale inefficiencies in Ghana's maize farms is often speculated to be one of the major causes of the low yields. Therefore, estimation of scale efficiency of the farmers is necessary in formulating policies that will help address their productivity challenges. Also farmers may/may not be efficient and productive depending on which agro ecological zone they operate. This is because different agro ecological zones have different soil and climatic conditions that may/may not

* Corresponding author.
E-mail address: wongnaaa@yahoo.com (C.A. Wongnaa).

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support maize production. It is therefore possible that maize farmers in different agro ecological zones will have different efficiencies and yields. Therefore, for farmers in Ghana to make the best out of maize production, it is important for them to operate in the ideal place for maize production in the country.

By way of methodology, a common task in agricultural economics is to estimate scale efficiency non-parametrically within the framework of Data Envelopment Analysis (Wadud and White, 2000; Wu et al., 2003; Bravo-Ureta et al., 2007; Minh and Long, 2009; Błażejczyk-Majka et al., 2012). Other studies calculated technical efficiency using both parametric and non-parametric approaches, but estimation of scale efficiency was carried out exclusively adopting a non-parametric technique (Andreu and Grunewald, 2006; Vu, 2006; Bojnec and Latruffe, 2008). Parametric approaches to estimating scale efficiency is limited and evolving. Ray (1998) proposed a parametric methodology for estimating scale efficiency in which scale efficiency is calculated from the parameters estimated in the production function under the assumption of variable returns to scale and from estimation of scale elasticity. This methodology is friendly and does not need further econometric work. It is manageable and easy to implement, and has the advantage of being suitable for flexible functional forms, such as the translog. Despite these advantages, few scale efficiency studies have employed the methodology. The first empirical application of this methodology was by Pantzios et al. (2002) to analyse the technical and scale efficiencies of EU cotton farming using Greek Cotton Growers. This was followed by the work of Karagiannis and Sarris (2005) which employed Ray's (1998) methodology to measure and explain the scale efficiency of Greek tobacco growers. Madau (2010) and Madau (2012) also employed the methodology to estimate technical and scale efficiencies in Italian citrus farming. Added to this is the work of Karagiannis et al. (2012) which employed parametric procedures in estimating scale efficiency in organic and conventional dairy farming in Austria. Finally, and recently, Abdulai and Abdulai (2016) moved away from the non-parametric Data Envelopment Analysis methodology and estimated allocative and scale efficiencies for Zambian maize farmers using a parametric zero efficiency stochastic frontier approach. Although Ray's methodology was not employed, zero efficiency stochastic frontier approach is parametric.

This paper adds to the literature on parametric estimation of scale efficiency by examining the scale efficiencies of maize production in four agro ecological zones of Ghana (Guinea savannah, Transition, forest and coastal savannah zones) using Ray's (1998) proposed parametric approach. To the best of our knowledge, this is the first application of Ray's methodology to scale efficiency estimation in African agriculture. Also, the results of this study would help government make specific policies aimed at improving the productivity of maize production in specific agro ecological zones.

2. Materials and methods

2.1. Study area

The study was conducted in four agro ecological zones of Ghana, namely, Guinea savannah, Transition, Forest and Coastal Savannah zones. The Guinea Savannah zone is located along the North eastern corridor of the Northern Region with a total land area of about 125,430 square kilometres. The tropical continental climate and Guinea Savannah vegetation type are seen in this area. The Transition zone, which is located around the middle portion of the Brong Ahafo Region and the Northern part of Ashanti Region, covers a total land area of about 2300 square kilometres. The zone is characterized by wet semi-equatorial climate while the vegetation is the Savannah woodland and a forest belt. The forest zone, covering an area of about 135,670 km^2, is floristically divided into rain forest and semi-deciduous forest and has a population of about 134,354. The climate is the semi equatorial type while the vegetation is semi-deciduous forest zone with clay, sand and gravel deposits. The Coastal Savannah occupies about 20,000 km^2, and comprises the Ho-Keta Plains, the Accra Plains and a narrow strip tapering from Winneba to Cape Coast. The main climatic factor is rainfall, which comes in two peaks. March–July is the main season and September–October, the minor rainy season. August is a dry but cloudy break during which bright sunshine may be less than two to four hours per day.

2.2. Data collection

Data used in the study which was mainly primary, was obtained through a cross-sectional survey conducted to collect farm level data for the 2014 rainy season from 576 maize producers using structured questionnaire. Multi-stage sampling technique was employed in selecting the respondents for the study. Two districts/municipalities were purposively selected from each of the agro-ecological zones based on the level of maize production at the first stage. In the second stage, nine (9) villages or communities were randomly selected from each of the sampled districts/municipalities. Stage three involved random sampling of eight (8) maize farmers from a list of maize farmers in each of the villages or communities with the aid of agricultural extension agents.

2.3. Analytical framework

The study employed descriptive statistics in presenting socioeconomic characteristics of the respondents. Also, a parametric methodology proposed by Ray (1998) and applied by Pantzios et al. (2002), Karagiannis and Sarris (2005), Madau (2010) and Madau (2012) within the framework of the stochastic frontier production function was employed to estimate the scale efficiency of maize production in the four agro ecological zones. Aigner et al. (1977) and Meeusen and Van den Broeck (1977) independently proposed the stochastic frontier production function as follows:

$$y_i = f(x_i;\beta) + e_i \quad where\ i = 1, 2, \ldots, N \tag{1}$$

$$e_i = v_i - u_i \tag{2}$$

where y_i represents the level of output of the ith maize farmer; $f(x_i;\beta)$ is an appropriate production function of vector,x_i, of inputs for the ith maize farmer and a vector, β, of parameters to be estimated. e_i is an error term which comprises two components: v_i which is a random error with zero mean and is specifically associated with random factors like measurement errors in production as well as weather factors that the maize farmer cannot control and it is assumed to be symmetric and independently distributed as $\mathrm{N}(0;\sigma^2 v)$, random variables and is independent of u_i. Conversely, u_i which ranges from zero to one, is a *non-negative* truncated half normal, $\mathrm{N}(0;\sigma^2 u)$, random variable and is linked to farm specific characteristics, which leads to the ith maize farm not achieving maximum production efficiency. N is the number of maize farmers that took part in the cross sectional survey. The stochastic frontier production function can be estimated by the maximum likelihood estimation (MLE) technique (Greene, 2005).

The generalized likelihood ratio test was used to test the hypothesis of whether the Cobb-Douglas or translog functional form is an adequate representation of the data given the assumptions of the stochastic frontier translog production function. The test allows evaluation of a restricted model with respect to an adopted model. The statistic associated with this test is defined as:

$$\lambda = -2\left[\ln\frac{L(H_0)}{L(H_1)}\right] = -2[\ln L(H_0) - \ln L(H_1)] \quad (3)$$

where $L(H_0)$ and $L(H_1)$ are the log-likelihood values of the adopted and the restricted models respectively. The test statistic λ has approximately a mix chi-square distribution with a number of degrees of freedom equal to the number of parameters (restrictions), assumed to be zero in the null-hypothesis. When λ is lower than the corresponding critical value (for a given significance level), the null-hypothesis cannot be rejected. The main hypothesis tested here is to find out whether the Cobb-Douglas functional form is an adequate representation of the maize production data collected, given the specification of the translog functional form. The test results showed that the translog functional form was more appropriate (Table 4). Therefore, the translog functional form is adopted in this study. The stochastic frontier translog production function is specified as:

$$\ln y_i = \beta_0 + \sum_{k=1}^{m}\beta_k \ln x_{ki} + \frac{1}{2}\sum_{k=1}^{m}\sum_{j=1}^{m}\beta_{kj}\ln x_{ki}\ln x_{ji} + v_i - u_i \quad (4)$$

where y_i = Total quantity of output measured in kilogramme, x_i = Vector of inputs which includes *SED* = Quantity of seed used, measured in kilogramme per hectare (kg/ha), *LANDSZ* = Area of land cultivated with maize, measured in hectares (ha), *LAB* = Quantity of labour employed in maize production, measured in Man-days, *CAP* = Capital used in maize farm, measured as depreciated charges on farm tools and implements, *FET* = Quantity of fertilizer used in maize production, measured in Kilogrammes per hectare (kg/ha), *MAN* = Quantity of manure used in maize production, measured in Kilogrammes per hectare (kg/ha), *PET* = Quantity of pesticides used in maize production, measured in litres per hectare (litres/ha), *HEB* = Quantity of herbicides used in maize production, measured in litres per hectare (litres/ha), m = number of production inputs, ij = Positive integers $(i \neq j)$, $\beta's$ = Vector of parameters to be estimated, $v_i and u_i$ have their usual meanings. The inefficiency model is also specified as:

$$u_i = \delta_0 + \sum_{n=1}^{q}\delta_n z_i \quad (5)$$

where z_i is a vector of farmer characteristics in the inefficiency model (Table 1), δ is a vector of parameters to be estimated, n is a constant representing the parameter of a specified characteristic and q is the total number of farmer characteristics in the inefficiency model.

Ray (1998) suggested a parametric approach to estimating scale efficiency from the estimated coefficients of the stochastic frontier production function and from estimation of scale elasticity. For instance, for a stochastic frontier translog production function and with the assumption of output-oriented approach to estimating technical efficiency, farm level scale elasticity is obtained by taking the partial derivative of y_i with respect to x_{ki} in Eq. (4) and substituting the sample input means. That is,

$$E_i = \sum_{k=1}^{m}\left(\beta_k + \sum_{j=1}^{1}\beta_{kj}x_{ji} + \beta_{ji}\right) \quad (6)$$

where x, m, k, β, j and i have their usual meaning as explained for Eq. (4) and E_i is the farm level scale elasticity. Referring to Ray (1998) for a comprehensive explanation of the parametric methodology, farm level scale efficiency (SE^0) can be calculated as follows:

$$SE_i^0 = \exp\left[\frac{(1-E_i)^2}{2\beta}\right] \quad (7)$$

where

$$\beta = \sum_{k=1}^{m}\sum_{j=1}^{m}\beta_{kj} \quad (8)$$

with β, which is hypothesized to be negative definite in order to be sure that $0 < SE_i^0 \leqslant 1$. It is however important to note that even though negative definiteness of β is a sufficient condition, it is not a necessary condition (Ray, 1998). The aforementioned output-oriented scale efficiency assesses the importance of scale in shaping technical efficiency. For a resource combination that does not exhibit constant returns to scale, the average productivity of a farm differs from those of optimum levels. The implication, according to Karagiannis and Sarris (2005) is that scale efficiency corresponds to the relative expansion in output by operating efficiently. That is, from the Frisch's (1965) definition, scale efficiency estimates the distance to maximum efficiency.

According to Ray (1998), scale efficiency (Eq. (7)) and scale elasticity (Eq. (6)) are both equal to one only at the most productive scale size (MPSS). That is, at the point where there is constant returns to scale. There may also be variations in their values and $SE_i^0 < 1$ no matter $E_i < or > 1$. This implies that, away from the MPSS, scale elasticity does not reveal anything about SE_i^0 levels. It is important to note that the sub-optimal scale corresponds to increasing returns to scale. With increasing returns to scale, $E_i > 0$ and SE_i^0 rises with a rise in output. That is, the output level should be expanded in order to operate in an optimal scale. Conversely, for a farm that exhibits decreasing returns to scale or supra-optimal scale $(E_i < 0)$, there should be a contraction in output in order for optimal scale to be achieved.

Table 1
The variables and their description and expected signs.

Variable	Description	Expected Sign
ROAD	Access to good roads, measured as a dummy (1 for access to good road and 0 otherwise)	+
SEX	Gender of maize farmer, measured as a dummy (1 for male and 0 for female)	+
AGE	Age of maize farmer, measured in years.	+/–
EDU	Educational level of maize farmer, measured in years of schooling	+
HOSIZE	Household size, measured as number of family members living with maize farmer	+/–
EXP	Maize farming experience, measured in number of years in maize farming	+
MGROUP	Membership of a farmer association, measured as a dummy (1 for membership of an association and 0 otherwise)	+
CREDIT	Access to credit, measured as a dummy (1 for access to credit and 0 otherwise)	+
INCOME	Previous year's maize income, measured in Ghana Cedis.	+
NPLOTS	Land fragmentation, measured as a dummy (1 for owning only one plot and 0 otherwise)	+/–
NOEXTVI	Extension contact, measured in number of meetings of maize farmer with agricultural extension agents.	+
REDYMKT	Access to ready maize market, measured as a dummy (1 for available maize market and 0 otherwise)	+
FERTus	Use of inorganic fertilizer, measured as a dummy (1 for use of inorganic fertilizer and 0 otherwise)	+
PESTus	Use of pesticides, measured as a dummy (1 for use of pesticides and 0 otherwise)	+
SEDtyp	Seed variety planted by maize farmer, measured as a dummy (1 for improved variety and 0 for traditional variety)	+
LANDSZ	Area cultivated with maize, measured in hectares	+/–

For farm level scale efficiency variations to be explained, a two-stage methodology was used by Karagiannis and Sarris (2005). Firstly, Eq. (7) was used to estimate SE_i^0 s which was followed by a regression of SE_i^0 scores against a vector of explanatory variables in the second stage. In the second stage of the parametric approach, the stochastic frontier function is estimated by the maximum likelihood technique (Reinhard et al., 2002) according to the following equations:

$$\ln SE_i^0 = m_i + \varepsilon_i \quad \text{with} \tag{9}$$

$$m_i = Z(z_i, \rho) \quad \text{and} \tag{10}$$

$$\varepsilon_i = v_i^* - u_i^* \quad i = 1, 2, \ldots N \tag{11}$$

where z_i comprises the same inefficiency variables in technical efficiency estimation (Eq. (5)), ρ are the parameters that will be estimated, ε_i is the error term which is twofold, viz: v_i^* which stands for statistical noise and is identically and independently distributed with $N(0, \sigma^2_{v^*})$ random variable truncated at $-m_i$, u_i^* stands for the conditional scale inefficiency that remains even after variation in the z_i has been taken into consideration $(u_i^* \sim N(-m_i, \sigma^2_{u^*}))$ and *RAINamt* is the amount of rainfall recorded in the area where maize farmer lives (expected to have a positive effect on scale efficiency) and all other variables have their usual meanings as explained in Table 1 for determinants of technical efficiency. Many authors including Battese and Coelli (1995), Kumbhakar and Lovell (2000) among others have criticized the two-stage approach for estimating technical efficiency because it is not consistent in its assumption concerning independence of the inefficiency effects. This is because the specification of the second stage regression in which the technical efficiency scores are hypothesized to be related to the explanatory variables disagrees with the hypothesis that u_i's are independently and identically distributed. Nonetheless, it is possible to use a two-stage approach on condition that the efficiency scores are estimated from the parameter estimates of the first stage regression rather than estimating it econometrically in stage one (Reinhard et al., 2002). For the scale efficiency estimation procedure explained above, there is no such assumption made about the dependent variable SE_i^0 because SE_i^0 scores are calculated from the estimated parameters and the estimated scale elasticity of the first stage regression. The two-stage approach was therefore recommended by Reinhard et al. (2002) for farm level scale efficiency estimations.

3. Results and discussions

3.1. Descriptive analysis

Table 2 presents the socioeconomic characteristics of maize farmers in the agro ecological zones. Table 3 also presents the descriptive statistics of farmers' characteristics and quantities of inputs and outputs. The results showed that in the Guinea Savannah zone, 88.2% of the farmers were males while 11.8% were females. The Transition zone also recorded 76.4% for males and 23.6% for females. As shown in Table 2, similar results were found in the Forest and Coastal Savannah zones. The implication is that maize production in each zone is dominated by males. This finding agrees with those of Kuwornu et al. (2013) as well as Addai and Owusu (2014) that also reported on the dominance of males in maize production. The ages of the respondents ranged from 20 to 75 years with a mean age of 43.2 years for the Guinea Savannah zone (Table 3). Also, Table 2 shows that majority of maize farmers in the Guinea Savannah zone (64.6%) are within the age bracket of 18–45 years while 19.4% are from 46 to 60 years and 16% are above 60 years of age. The results found in the other agro ecological zones are not different from the Guinea Savannah zone. For example, the mean ages obtained in the Transition, Forest and Coastal Savannah zones were 44.7, 47.1 and 45.5 respectively. Similar results were obtained by Ogundari et al. (2006) in a study into the economies of scale and cost efficiency in small scale maize production in Nigeria. The implication is that maize farmers in all zones are relatively old. This condition may have an influence on the efficiency of maize production (Bempomaa and Acquah, 2014; Addai and Owusu, 2014).

For the sampled maize farmers who had access to extension service, the average number of times extension agents visited them per season were calculated to be 1, 2, 1 and 7 times for the Guinea Savannah, Transition, Forest and Coastal Savannah zones respectively, an indication of poor provision of extension service to the farmers (Table 3). This may prevent farmers from operating at optimal scale (Sienso et al., 2013). Also 63.9% of maize farmers in the Guinea Savannah zone did not belong to any farmer association as against 36.1% that were members of farmer associations. This runs through the rest of the agro ecological zones, especially in the forest zone where only 11.1% of the sampled maize farmers belonged to a farmer association (Table 2). This could have an adverse effect on the scale efficiency of maize production in the study area since extension agents are used to disseminating efficiency enhancing technologies through farmer based organizations (Kuwornu et al., 2013). Generally, maize farmers in all agro ecological zones had no access to credit. For example, 83.3% and 84.0% of maize farmers in the Forest and Coastal Savannah zones respectively never received any form of credit. Poor access to credit is a potential source of scale inefficiency in maize production since credit allows farmers to acquire efficiency enhancing inputs (Addai and Owusu, 2014).

With a mean of 9.7, the household size ranged from 1 to 32 for maize farmers in the Guinea Savannah zone. Similarly, maize farmers in the Transition, Forest and Coastal Savannah zones recorded mean household sizes of 7.8, 6.5 and 6.4 respectively. Also, Table 3 shows that on average, farmers in the Guinea Savannah zone had 18.6 number of years of experience in maize farming. With the exception of maize farmers in the Forest zone where farmers had an average of 7.9 years of farming experience, similar high levels of farming experience where recorded in the Transition and Coastal Savannah zones of the country. This corroborates the findings of Ogundari et al. (2006) in economies of scale and cost efficiency studies for maize farmers in Nigeria. With high levels of farming experience, the productivities and efficiencies of maize farmers in the Guinea, Transition and Coastal Savannah zones are expected to be on the higher side since experienced farmers could predict appropriate agronomic practices for efficient maize production (Abdulai et al., 2013; Sienso et al., 2013).

The mean maize outputs recorded in the Guinea Savannah, Transition, Forest and Coastal Savannah zones were 2.2 metric tonnes/ha, 4.2 metric tonnes/ha, 1.1 metric tonnes/ha and 3.5 metric tonnes/ha respectively. The results imply that maize yield is relatively higher in the Transition zone and therefore maize farmers in this zone may be more efficient than those in the other zones. The aforementioned outputs are relatively lower than the estimated potential output of 5.5 metric tonnes/ha for Ghana (MOFA, 2015). The outputs are also relatively lower when compared to 6.3 metric tonnes/ha obtained by Abdulai and Abdulai (2016) for Zambian maize farmers. The mean quantities of labour used were 75.6 man-days, 80.8 man-days, 48.4 man-days and 71.6 man-days for the Guinea, Transition and Coastal Savannah zones respectively. Again with the labour intensive nature of maize production, it is not surprising that labour quantity was higher in the Transition zone. This could be the reason behind the relatively higher outputs recorded in the Transition zone. The mean farm size cultivated

Table 2
Socioeconomic characteristics of Maize Farmers in the Agro ecological zones. *Source:* Survey, 2015.

Variable	Guinea savannah zone		Transition zone		Forest zone Zone		Coastal savannah zone	
	Freq	%	Freq	%	Freq	%	Freq	%
Sex								
Male	127	88.2	110	76.4	113	78.5	96	66.7
Female	17	11.8	34	23.6	31	21.5	48	33.3
Total	144	100	144	100	144	100	144	100
Age group (Years)								
18–45	93	64.6	76	52.8	69	47.9	90	62.5
46–60	28	19.4	53	36.8	56	38.9	43	29.9
Greater than 60	23	16	15	10.4	19	13.2	11	7.6
Total	144	100	144	100	144	100	144	100
Educational level								
No formal education	98	68.1	24	16.7	15	10.4	70	48.6
Primary school	8	5.6	33	22.9	23	16	20	13.9
Middle school/JSS/JHS	19	13.2	69	47.9	67	46.5	45	31.2
SSS/SHS	13	9	13	9	36	25	7	4.9
Training college/Tertiary	6	4.2	5	3.5	3	2.1	2	1.4
Total	144	100	144	100	144	100	144	100
Association membership								
No	92	63.9	103	71.5	128	88.9	113	78.5
Yes	52	36.1	41	28.5	16	11.1	31	21.5
Total	144	100	144	100	144	100	144	100
Access to credit								
No	116	80.6	118	81.9	120	83.3	121	84
Yes	28	19.4	26	18.1	24	16.7	23	16
Total	144	100	144	100	144	100	144	100

Table 3
Descriptive statistics of farmers' characteristics and quantities of inputs and outputs *Source:* Survey, 2015.

Variable	Guinea savannah zone				Transition zone				Forest zone				Coastal savannah zone			
	Min	Max	M	SD	Min	Max	M	SD	Min	Max	M	SD	Min	Max	M	SD
Age (Years)	20.0	75.0	43.2	14.3	21.0	72.0	44.8	11.7	18.0	78.0	47.1	10.8	27.0	71.0	45.5	18.0
Education (Years)	0.0	18.0	4.0	6.0	0.0	17.0	7.2	3.9	0.0	15.0	8.3	3.7	0.0	15.0	4.4	0.0
Experience (Years)	1.0	50.0	18.6	13.3	1.0	50.0	13.9	10.4	1.0	45.0	7.9	7.6	3.0	40.0	15.8	1.0
Farm size (ha)	0.4	11.6	2.7	1.7	0.4	70.0	3.4	4.7	0.2	54.5	3.3	24.9	0.4	7.2	2.0	0.2
Number of plots	1.0	5.0	1.5	0.7	1.0	5.0	1.9	4.1	0.4	5.0	1.4	0.7	0.8	7.0	1.4	0.4
Extension visits	0.0	4.0	1.2	1.5	0.0	20.0	2.2	3.7	0.0	13.0	1.0	2.9	0.0	26.0	6.6	0.0
Fertilizer (kg/ha)	0.0	600	481	644	0	490	465	649	0	155	141	254	0	380	313	0
Herbicide (Litres/ha)	0.0	48.0	6.2	8.1	0.0	60.0	4.9	7.9	0.0	60.0	4.5	8.5	0.0	24.0	5.1	0.0
Pesticide (Litres/ha)	0.0	6.0	0.1	0.7	0.0	11.0	0.2	1.4	0.0	3.0	0.02	0.3	0.0	1.0	0.01	0.0
Seed (kg/ha)	0.0	117	28.4	19.1	0.0	720	59.7	79.2	2.5	120	22.3	17.9	6.0	144	39.1	6.0
Labour (man–days/ha)	0.0	1020	75.6	106.5	0.0	1096	80.8	139.2	0	380	48.4	51.0	9.0	363	71.6	9.0
Manure (kg/ha)	0.0	6000	41.7	500	0.0	750	9.4	75.3	0.0	500	41.0	124	0.0	1400	25.0	0.0
Capital (Gh¢/ha)	100	3500	697	637	150	10000	899	1232	0.0	3000	328	322	0.0	2000	307	40.0
Size of household	1.0	32.0	9.7	6.5	0.0	34.0	7.8	5.1	1.0	25.0	6.5	3.1	1.0	15.0	6.4	2.0
Output (Mt/ha)	0.1	8.6	2.2	1.6	0.2	20.0	4.2	5.4	0.2	6000	1.1	1.0	0.01	1.2	3.5	0.01

Note: Min = Minimum, *Max* = Maximum, *M* = Mean and *SD* = Standard Deviation.

were 2.7 ha, 3.4 ha, 3.3 ha and 2.0 ha for maize farmers in the Guinea Savannah, Transition, Forest and Coastal Savannah zones respectively. These farm sizes are relatively small and therefore imply that maize production activities in each zone are on a small scale. The same could be said for maize farmers in other African countries. This is because similar results were obtained by Mulwa et al. (2009) for maize producers in Kenya and Abdulai and Abdulai (2016) for maize farmers in Zambia. The mean fertilizer usage was higher for maize farmers in the Guinea savannah zone (481 kg/ha) followed by the Transition zone (465 kg/ha). The high usage of fertilizer in the Guinea savannah zone could be the results of the provision of subsidies on production inputs by the Savannah Agricultural Development Authority (SADA) as well as the fertilizer subsidy programme that operated in the northern part of the country.

3.2. Fitness of adopted model

Maximum likelihood estimates of the stochastic frontier production function and the inefficiency model were estimated simultaneously using the STATA software package. Estimates for the preferred frontier models were obtained after testing various null hypotheses in order to evaluate suitability and significance of the adopted models using the generalized likelihood ratio statistic. The test results for the four agro ecological zones showed that the rather popular but inflexible Cobb-Douglas functional form should be rejected since at least one of the interaction terms is statistically different from zero, making the translog functional form the best fit for the data. That is, the null hypothesis that $\beta_{kj} = 0\ (k, j = 1, \ldots, 8)$ is rejected at the 5% level of significance for data from all zones (Table 4).

Table 4
Results of hypotheses test for the adopted model *Source:* Survey, 2015.

Restriction	Guinea savannah zone				Transition zone				Forest zone				Coastal savannah zone			
	L(H_0)	λ	χ^2	D	L(H_0)	λ	χ^2	D	L(H_0)	λ	χ^2	D	L(H_0)	λ	χ^2	D
H_0: β_{ij}	−85.3	24.2	9.8	R	−99.4	52.5	11.9	R	−81.3	44.1	8.3	R	−112.2	62.8	12.7	R
$\delta_m = 0$	−178.3	45.8	12.2	R	−83.4	31.2	16.4	R	−94.8	21.7	8.1	R	−138.7	34.4	18.9	R

Note: Critical values are at 5% significance level and are obtained from χ^2 distribution table. L(H_0) = Log likelihood function, λ = Test statistic, D = Decision on whether hypothesis accepted or rejected, R = Hypothesis is rejected, NR = Hypothesis is not rejected.β_{ij} = Parameters in the square and cross terms and δ_m = Parameters in the inefficiency term.

Table 5 presents the variance parameters for the stochastic frontier production function for maize farmers in each agro ecological zone. The high gamma (γ) values of 1, 0.999999, 1 and 1 for maize farmers in the Guinea savannah, Transition, forest and coastal savannah zones indicate the presence of technical inefficiencies among the sampled farmers. This shows that technical inefficiency should be taken care of in the production function for these farmers, making the stochastic frontier production function an appropriate model. This is further confirmed by the extremely high values of the lambda parameter representing each zone. The values of λ and sigma squared (σ^2) and the fact that they are significantly different from zero implies good fits and the correctness of the specified distributional assumptions. Table 5 also presents statistically significant Wald chi-square statistics of 8.37×10^8 ($p < 0.01$), 1629.3 ($p < 0.05$), 3.40×10^7 ($p < 0.05$) and 8.61×10^8 ($p < 0.1$) for maize farmers in the Guinea savannah, Transition, Forest and Coastal savannah zones respectively. This shows that each model was jointly significant. The variables included in each model were tested for multicollinearity using Variance Inflation Factor (VIF). The mean VIF calculated for the models representing maize farmers in the Guinea savannah, Transition, Forest and Coastal savannah zones were 1.459, 2.146, 1.736 and 2.546 respectively. The VIFs are small (<5), indicating the absence of multicollinearity in the models (Edriss, 2003). In addition, Breusch Pagan (BP) tests revealed safety of heteroskedasticity as justified by statistically insignificant values of 0.9147, 0.4851, 0.6145 and 0.9545 for the models representing maize farmers in the Guinea savannah, Transition, Forest and Coastal savannah zones respectively.

3.3. Determinants of maize output in various agro ecological zones

Table 6 presents the results of the maximum likelihood estimation of the stochastic frontier production functions for maize production in the four agro ecological zones. In the Guinea savannah zone, the coefficients of the variables representing each of fertilizer ($p < 0.01$), pesticide ($p < 0.1$), manure ($p < 0.01$) and land ($p < 0.01$) were positively related to the output of maize, indicating farmers will record higher output levels when higher amounts of these inputs are employed in their maize production. Capital ($p < 0.01$) however had a negative sign. For maize farmers in the Transition zone, whereas fertilizer ($p < 0.01$), pesticide ($p < 0.01$), land ($p < 0.05$) and manure ($p < 0.01$) were found to be positively related to the output of maize, herbicide ($p < 0.01$), seed ($p < 0.01$) and capital ($p < 0.01$) were found to be inversely related to maize output. In the Forest zone, fertilizer ($p < 0.05$), herbicide ($p < 0.05$), pesticide ($p < 0.05$), seed ($p < 0.01$) and land ($p < 0.01$) were found to be positively related to maize output and therefore are the determinants of maize output in this zone. Finally, in the Coastal savannah zone, the coefficients of the variables representing each of fertilizer ($p < 0.01$), pesticide ($p < 0.1$), seed ($p < 0.01$) and manure ($p < 0.01$) were found to be positively related to the output of maize, indicating farmers will see an increase in output levels when higher amounts of these inputs are employed in their maize farms. The production input elasticities for the various agro ecological zones are also presented in Table 7. For instance, the results showed that a 1% rise in the levels of fertilizer, pesticide, manure and land in the Guinea savannah zone has the effect of increasing output levels by 0.52%, 0.004%, 0.064% and 0.14% respectively. This supports the findings of Oppong et al. (2016) that also found maize output to be influenced by quantities of seed, herbicide, land, labour and cost of intermediate inputs.

3.4. Technical efficiency of maize farmers in various agro ecological zones

Table 8 presents the minimum, maximum, mean and standard deviation of technical efficiency scores for maize farmers in the various agro ecological zones considered in the current study. Specifically, the mean technical efficiencies were 61.2%, 70.2%, 49.9% and 66% for maize farmers in the Guinea savannah, Transition, Forest and Coastal savannah zones respectively. With technical efficiency scores estimated as output-oriented measures, the results imply that the outputs of maize farmers in the Guinea

Table 5
ariance parameters for the stochastic frontier production function *Source:* Survey, 2015.

Variable	Guinea savannah zone	Transition zone	Forest zone	Coastal savannah zone
Sigma squared $\sigma^2 = \sigma_u^2 + \sigma_v^2$	0.36***	0.21**	0.26**	0.37*
Gamma $\gamma = \sigma_u^2/\sigma^2$	1***	0.99***	1***	1***
Lambda $\lambda = \sigma_u/\sigma_v$	1007194***	1438535***	52521.56***	153917.1***
Log likelihood	17.72	21.19	32.21	64.89
Number of farmers	139	135	135	139
Wald	8.37×10^8***	1629.3**	3.40×10^7**	8.61×10^8*
Mean VIF	1.459	2.146	1.736	2.546
Breusch Pagan stat	0.9147	0.4851	0.6145	0.9545

Note: The asterisks indicate levels of significance.
*** Significant at 1%.
** Significant at 5%.
* Significant at 10%.

Table 6
Maximum likelihood estimates of stochastic frontier production function *Source:* Survey, 2015.

Variable	Guinea savannah zone		Transition zone		Forest zone		Coastal savannah zone	
	Coeff	Std. Err	Coeff	Std. Err	Coeff	Std. Err	Coeff	Std. Err
Constant	6.841	0.373	10.280***	0.505	11.176		9.154	
lnFET	0.175***	0.023	0.032***	0.008	0.028**	0.012	0.077***	0.015
lnHEB	0.358	0.046	−0.385***	0.075	1.549**	0.770	0.190	0.199
lnPET	0.044*	0.004	0.192***	0.048	0.012**	0.011	0.001*	0.002
lnSED	−0.030	0.048	−0.101***	0.018	2.607***	0.783	0.070***	0.010
lnLAB	−0.363	0.005	−0.183	0.001	0.123	0.466	−1.617***	0.200
lnMAN	0.045***	0.009	0.150***	0.040	0.011	0.011	0.050***	0.003
lnLAD	0.708***	0.161	0.548**	0.244	2.658***	0.339	−0.507	0.351
lnCAP	−0.295***	0.052	−0.199***	0.063	−0.461	0.577	−0.217**	0.091
lnFETxlnFET	−0.013***	0.003	−0.022***	0.003	−0.001	0.005	0.050***	0.002
lnPETxlnPET	−0.072	0.063	−0.001	0.013	−0.069***	0.019	−0.085***	0.008
lnHEBxlnHEB	−0.215***	0.023	−0.147***	0.043	0.063	0.047	0.064***	0.006
lnSEDxlnSED	−0.055***	0.021	−0.082**	0.032	0.314	0.263	−0.100**	0.046
lnLABxlnLAB	0.010	0.013	−0.032***	0.007	−0.062**	0.027	0.221***	0.013
lnMANxlnMAN	−0.002***	0.005	−0.053***	0.006	−0.008**	0.003	−0.019***	0.001
lnLADxlnLAD	0.099**	0.047	−0.130	0.109	0.129**	0.064	−0.581***	0.101
lnCAPxlnCAP	0.009**	0.004	−0.003*	0.002	0.001	0.005	−0.018***	0.004
lnFETxlnPET	−0.019**	0.010	0.008	0.011	0.012	0.010	−0.096***	0.003
lnFETxlnHEB	−0.014***	0.004	0.002*	0.001	0.001	0.005	−0.019***	0.001
lnFETxlnSED	0.051**	0.024	−0.042**	0.013	0.075***	0.012	−0.084***	0.014
lnFETxlnLAB	0.008	0.025	0.032**	0.013	−0.005***	0.002	−0.038***	0.008
lnFETxlnMAN	−0.053***	0.008	0.016***	0.003	0.017**	0.008	0.006***	0.002
lnFETxlnLAN	−0.099***	0.022	0.001	0.002	0.006**	0.003	0.014***	0.010
lnPETxlnCAP	0.015***	0.001	0.035***	0.006	−0.007	0.005	−0.011***	0.001
lnPETxlnHEB	0.026*	0.014	0.110***	0.008	−0.018	0.012	−0.019***	0.003
lnSEDxlnLAB	0.035	0.026	−0.083***	0.013	0.087	0.172	0.122	0.085
lnSEDxlnMAN	0.109***	0.015	−0.111***	0.017	−0.021**	0.010	−0.012	0.032
lnSEDxlnLAD	0.028	0.039	0.105***	0.052	−0.518**	0.227	0.763***	0.090
lnSEDxlnCAP	0.038***	0.011	0.100***	0.028	0.217	0.191	0.205***	0.052
lnSEDxlnHEB	0.015	0.019	0.124***	0.011	0.481*	0.250	0.170***	0.011
lnLABxlnMAN	0.086***	0.026	−0.055***	0.013	−0.031	0.023	0.071***	0.010
lnLABxlnLAD	0.042	0.021	0.272***	0.023	−0.015	0.187	−0.321***	0.065
lnLABxlnCAP	0.041**	0.018	−0.014	0.009	−0.006	0.016	−0.048*	0.029
lnLABxlnHEB	−0.099***	0.013	−0.002	0.018	0.057	0.048	0.025	0.050
lnMANxlnLAD	0.334	0.013	0.309***	0.108	0.002	0.032	−0.015***	0.003
lnMANxlnCAP	0.079***	0.008	0.016**	0.007	0.002	0.002	0.033***	0.010
lnMANxlnHEB	0.111***	0.012	−0.022***	0.004	−0.003	0.016	−0.007	0.005
lnLADxlnCAP	−0.003	0.014	−0.105***	0.028	−0.233	0.166	−0.062	0.040
lnLADxlnHEB	−0.005***	0.001	−0.093***	0.013	−0.533**	0.272	−0.343***	0.043
lnCAPxlnHEB	0.002	0.002	−0.012	0.001	−0.011**	0.005	−0.127***	0.011
lnFETxlnCAP	−0.005**	0.002	−0.017***	0.002	−0.041**	0.012	0.014***	0.003
lnPETxlnSED	−0.012***	0.003	−0.014***	0.001	−0.008***	0.001	−0.001*	0.001
lnPETxlnLAB	0.003***	0.001	0.004***	0.001	−0.002*	0.001	0.002**	0.001
lnPETxlnMAN	0.037	0.057	0.138***	0.007	−0.042***	0.015	−0.048***	0.003
lnPETxlnLAD	−0.018	0.043	−0.021***	0.003	0.013**	0.005	0.007***	0.002

Note: The asterisks indicate levels of significance.
*** Significant at 1%.
** Significant at 5%.
* Significant at 10%.

Table 7
Input elasticities *Source:* Survey, 2015.

Variable	Elasticity			
	Guinea savannah zone	Transition zone	Forest zone	Coastal savannah zone
Fertilizer	0.519	0.588	0.668	0.934
Herbicide	0.435	0.746	0.550	0.017
Pesticide	0.004	0.009	0.001	2.1×10^{-5}
Seed	0.019	1.672	0.151	0.361
Labour	0.893	0.598	0.786	0.830
Manure	0.064	0.004	0.081	0.015
Land	0.142	3.553	4.158	0.012
Capital	0.214	0.424	0.301	0.021
Scale elasticity	**2.29**	**7.594**	**6.696**	**2.19**

savannah zone, Transition zone, Forest zone and Coastal savannah zone can be increased by 38.8%, 29.8%, 50.1 and 34% respectively if they are able to use the resources available to them more efficiently. The results are in line with previous similar studies (Abdulai et al., 2013; Addai and Owusu, 2014; Bempomaa and Acquah, 2014; Oppong et al., 2016). However, with the exception

Table 8
Technical efficiency scores of maize farmers in Ghana *Source:* Survey, 2015.

Agro ecological zone	Minimum (%)	Maximum (%)	Mean (%)	Standard Deviation (%)
Guinea savannah zone	11.8	99.9	61.2	26.8
Transition zone	7.3	99.9	70.2	22
Forest zone	10.3	99.9	49.9	25
Coastal savannah zone	0.6	99.9	66	20.3

of the results obtained for the Forest belt of Ghana, the rest of the results contradict the results of Chirwa (2007) that found smallholder maize farmers in Malawi to be overly inefficient with an average technical efficiency score of 46.23%.

The distribution of technical efficiency scores among maize farmers in each of the agro ecological zones considered in this study is also presented in Fig. 1. The figure showed that in the Guinea savannah zone, most of the maize farmers (72%) had their technical efficiencies in the 41–60% range, indicating that, at least 40% of their potential output is lost to inefficiency. Over 60% of the respondents in the Transition zone however had their technical efficiencies in the range of 61–80%, implying that at least 20% of farmers' potential maize output is lost to factors that the farmer can control. Also, the distribution of technical efficiencies of farmers in the Forest zone is similar to those of the Guinea savannah zone, as 57% of the farmers in this zone had their technical efficiencies in the 41–60% range. Finally, for maize farmers in the Coastal savannah zone, over half of the respondents (52.5%) had their technical efficiencies in the range of 61–80%, while only 9.4% obtained the lowest technical efficiencies in the range of 0–20%. The implication is that most maize farmers in the Coastal Savannah zone of Ghana have at least 20% of their potential outputs lost to inefficiency.

From the technical inefficiency model presented by Table 9, a negative coefficient implies an increase in the variable concerned would increase technical efficiency and productivity and vice versa. For maize farmers in the Guinea savannah zone, whereas male gender ($p < 0.01$), age ($p < 0.05$), maize farming experience ($p < 0.01$), income ($p < 0.01$), extension contact ($p < 0.05$), membership of a farmer association ($p < 0.1$), access to credit ($p < 0.01$) as well as uses of fertilizer ($p < 0.05$), pesticides ($p < 0.05$) and improved seeds ($p < 0.05$) were found to be positively related to technical efficiency, farm size ($p < 0.01$) and land fragmentation ($p < 0.05$) were found to exert negative effects. In the Transition zone, the coefficients of the variables representing each of male gender ($p < 0.01$), age ($p < 0.01$), educational level ($p < 0.05$), household size ($p < 0.05$), farming experience ($p < 0.05$), income ($p < 0.01$), extension contact ($p < 0.01$), membership of a farmer association ($p < 0.01$), access to credit ($p < 0.01$) and ready market ($p < 0.01$) as well as uses of fertilizer ($p < 0.01$), pesticides ($p < 0.01$) and improved seeds ($p < 0.01$) were found to be positively related to technical efficiency, indicating an increase in these variables will improve technical efficiency. For maize farmers in the Forest zone, while male gender ($p < 0.1$), household size ($p < 0.1$), farming experience ($p < 0.05$), farm size ($p < 0.01$), income ($p < 0.01$), group membership ($p < 0.01$), access to credit ($p < 0.05$) and fertilizer use exerted positive effects on technical efficiency, land fragmentation exerted a negative effect. Finally, with male gender ($p < 0.01$), age ($p < 0.01$), educational level ($p < 0.01$), household size ($p < 0.01$), farm size ($p < 0.05$), income ($p < 0.01$), extension contact ($p < 0.05$), group membership ($p < 0.01$), access to ready market ($p < 0.01$) and fertilizer use ($p < 0.01$) having positive effect on technical efficiency, land fragmentation had a negative effect for maize farmers in the Coastal savannah zone of Ghana.

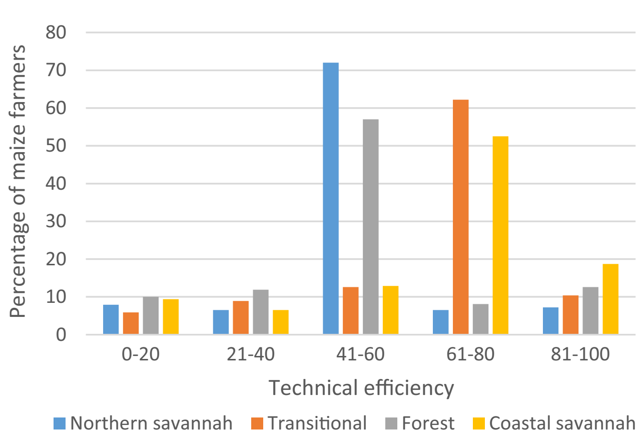

Fig. 1. Distribution of predicted technical efficiencies in agro ecological zones. *Source:* Survey, 2015.

3.5. Scale efficiency of maize farmers in various agro ecological zones of Ghana

Table 10 presents the results of the estimated scale elasticities and scale efficiencies of maize farmers in the various agro ecological zones. The table showed that the overall mean scale efficiencies were 86%, 91%, 89% and 86% for maize farmers in the Guinea Savannah zone, Transition zone, Forest zone and Coastal Savannah zone respectively. The results imply that generally, maize farmers in all agro ecological zones are not scale efficient. That is, observed maize farms in the aforementioned zones could have further increased their outputs by about 14%, 9%, 11% and 14% respectively if they had operated at an optimal scale. These findings corroborate the results of some recent studies (Minh and Long, 2009; Rasmussen, 2010; O'Donnell, 2012; Abatania et al., 2012; Umanath and Rajasekar, 2013; ShiWei, 2015; Abdulai and Abdulai, 2016). With most respondents in all agro ecological zones having no access to credit (Table 2), it was not surprising that scale inefficiencies existed in the farms since acquisition and application of required quantities of production inputs would be difficult. Also, access to extension service was very poor among the farmers and therefore, there was a likelihood of productivity enhancing technologies not reaching them and this is a potential source of scale inefficiency among the farmers. This is because, according to Abdulai and Abdulai (2016), inefficiency is explained by the level of education, access to extension services, distance to markets and access to credit. Similarly, the results from Table 10 showed that the average scale elasticities were 2.29, 7.59, 6.70 and 2.19 for maize farmers in the Guinea Savannah, Transition, Forest and Coastal Savannah zones respectively, indicating that even though some few farmers in the zones may have exhibited decreasing returns to scale (supra-optimal scale) and constant returns to scale (optimal scale), on average, most maize farmers in all agro ecological zones exhibited increasing returns to scale (sub-optimal scale). The implication is that the outputs of maize farms in all zones would have increased if more of the inputs were employed. The results corroborate those of Oppong et al. (2016) that also found maize output to be influenced by quantities of seed, herbicide,

Table 9
Sources of technical efficiency among smallholder maize farmers *Source:* Survey, 2015.

Variable	Guinea savannah zone		Transition zone		Forest zone		Coastal savannah zone	
	Coeff	Std. Err	Coeff	Std. Err	Coeff	Std. Err	Coeff	Std. Err
Constant	18.367	11.898	3.723	3.174				
ROAD	−0.525	0.566	3.354	0.478	−0.816	0.515	1.664	0.571
SEX	−2.877***	0.740	−1.083***	0.410	−0.225*	0.514	−1.589***	0.337
AGE	−0.035**	0.018	−0.106***	0.018	0.004	0.029	−0.159***	0.033
EDU	−0.047	0.038	−0.062**	0.053	−0.014	0.067	−0.150***	0.040
HOSIZE	−0.056	0.034	−0.005**	0.047	−0.079*	0.099	−0.291***	0.096
EXP	−0.061***	0.022	−0.043**	0.021	−0.110**	0.049	−0.115***	0.030
LANDSZ	0.418***	0.136	0.364***	0.039	−1.509***	0.345	−0.358**	0.162
NPLOTS	328436**	0.449	0.029	0.031	1.040**	0.430	0.234***	0.179
INCOME	−0.001***	0.001	−0.004***	0.001	−0.002***	0.001	−0.002***	0.001
NOEXTVI	−1.298**	0.596	−0.497***	0.095	−1.395	1.033	−1.007**	0.460
MGROUP	−0.105*	0.753	−1.536***	0.472	−2.838***	0.904	−1.929***	0.718
CREDIT	−3.604***	0.668	−6.471***	0.549	−1.272**	0.609	0.567	0.599
REDYMKT	−0.651	0.579	−2.910***	0.417	−0.933	0.768	−2.252***	0.778
FERTus	−1.909***	0.728	−1.792***	0.501	−1.633**	0.698	−1.735***	0.475
PESTus	−2.567***	0.931	−2.994***	0.823	−0.715	0.001	0.019	0.459
SEDtyp	−1.247**	0.517	−6.323***	0.711	−1.239	0.502	0.058	0.460

Note: The asterisks indicate levels of significance.
*** Significant at 1%.
** Significant at 5%.
* Significant at 10%.

Table 10
Estimated scale elasticity and scale efficiency in agro ecological zones of Ghana.

Type of scale	Guinea Savanna zone		Transition zone Zone		Forest zone Zone		Coastal Savanna Zone	
	E	SE	E	SE	E	SE	E	SE
Supra-optimal scale	0.57	0.89	0.71	0.95	0.59	0.9	0.54	0.88
Optimal scale	1	1	1	1	1	1	1	1
Sub-optimal scale	1.60	0.82	1.46	0.87	1.48	0.88	1.56	0.84
Maximum	2.96	0.99	8.75	0.99	7.50	0.99	2.76	0.99
Minimum	−0.31	0.20	0.18	0.28	−0.38	0.40	−0.36	0.28
Mean	2.29	0.86	7.59	0.91	6.70	0.89	2.19	0.86
Std. Dev	0.66	0.18	0.51	0.14	0.57	0.15	0.63	0.17

Note: E = Scale elasticity and *SE* = Scale efficiency.

land, labour and cost of intermediate inputs just that this time, it was at decreasing returns to scale.

Table 11 also presents the scales distribution among maize farmers in different agro ecological zones of Ghana. The results showed that for maize farmers in the Guinea Savannah zone, 55.71% of them exhibited increasing returns to scale, 35.71% exhibited decreasing returns to scale and 8.58% operated under optimal scale. Results from the Transition zone of Ghana also revealed that 55.15%, 37.5% and 7.35% of maize farmers in that zone exhibited increasing returns to scale, decreasing returns to scale and constant returns to scale respectively. Similarly, the percentages of maize farmers in the Forest belt of the country that operated under sub-optimal, supra-optimal and optimal scales were 59.57%, 35.46% and 4.97% respectively. The situation was not all that different for maize farmers in the Coastal savannah zone as 66.66%, 27.78% and only 5.56% of maize farmers in that zone exhibited increasing returns to scale, decreasing returns to scale and constant returns to scale respectively. Also, the mean scale efficiencies of maize farmers operating in supra-optimal scales (89.5% for the Guinea Savannah zone, 95.2% for the Transition zone, 89.9% for the Forest zone and 88.1% for the Coastal Savannah zone) suggest that the margins that separate such farmers from the optimal scale are not that wide. The implication is that most maize farmers in all agro ecological zones operate under a sub-optimal scale. This means that their outputs fall below efficient levels and therefore potentials exist for outputs to be increased for optimal scales to be reached by increasing the size of their operation. The results are expected since generally, farmers in all agro ecological zones were found to have poor access to credit with which they could have purchased production inputs. Also, most of them did not

Table 11
Distribution of maize farmers according to scale efficiency *Source:* Survey, 2015.

Type of scale	Guinea savannah zone		Transition zone		Forest zone		Coastal savannah zone	
	Freq	%	Freq	%	Freq	%	Freq	%
Supra-optimal scale	50	35.71	51	37.5	50	35.46	40	27.78
Optimal scale	12	8.58	10	7.35	7	4.97	8	5.56
Sub-optimal scale	78	55.71	75	55.15	84	59.57	96	66.66
Total	140	100	136	100	141	100	144	100

belong to farmer based organizations where most efficiency enhancing technologies and practices are normally discussed (Table 2). The results corroborate those of previous studies including Coelli et al. (2002), Karagiannis and Sarris (2005), Latruffe et al. (2005), Cisilino and Madau (2007), Madau (2010), Błażejczyk-Majka et al. (2012), Madau (2012) and Umanath and Rajasekar (2013) that reported that most small scale farmers operate under increasing returns to scale. According to them, these small-sized farms are generally adversely affected by capital, structural and infrastructural challenges in the form of huge land fragmentation, use of simple farming implements, inadequate knowledge of modern production technologies as well as insignificant availability of land markets. As a result, these farmers do not reach their efficient sizes.

3.6. Determinants of scale efficiency of maize farmers in various agro ecological zones

Table 12 presents the maximum likelihood estimates of the stochastic frontier scale efficiency function. The coefficient of the variable representing age is negatively related to scale efficiency and statistically significant at the 5%, 10%, 1% and 10% levels for maize farmers in the Guinea savannah zone, Transition zone, Forest zone and Coastal savannah zone respectively. The effect of age means that younger maize farmers are more scale efficient than older ones. This is because younger farmers are more aware of current technology and tend to acquire more knowledge about technological advances. This finding agrees with the results of some recent efficiency studies (Alam et al., 2012; Khan and Ali, 2013; Bidzakin et al., 2014). It however disagrees with the findings of Karagiannis and Sarris (2005) and Madau (2012) that reported that older farmers are more scale efficient than farmers who are relatively young. Madau (2012) further stated that the small value of the coefficient of farmers' age implies the variable does not have much influence on the observed variations in scale efficiency and therefore even though significant, the variable does not really explain the magnitude of scale efficiency. The coefficient of age for the current study is even lower than that of Madau (2012) and therefore its effect in this study cannot be taken seriously.

The coefficient of education is positive and significant at the 10%, 5% and 1% levels for maize farmers in the Guinea savannah, Forest and the Coastal savannah zones respectively. The effect of education means that acquisition of one more year of education by a maize farmer has the effect of making the farmer operate close to an optimal scale. This is because education will give farmers adequate knowledge of a balanced input mix required for producing at optimal levels. The results corroborate the results of Khan and Ali (2013) as well as Abdulai and Abdulai (2016) that also found a positive relationship between years of education and efficiency of agricultural production in Pakistan and Zambia respectively. The relationship between household size and scale efficiency is positive and is significant at the 5%, 10% and 5% levels for maize famers in the Guinea savannah, Transition and Coastal savannah zones respectively. The implication is that maize farm families with many members experience less scale inefficiencies as compared to those with few members. This is because large household sizes will increase the labour available to such farm families which will make them carry out required agronomic practices on time and therefore operate close to an optimal scale. This finding is in line with the results obtained by Bidzakin et al. (2014) that examined efficiency of small scale maize production in northern Ghana. An increase in labour input is required since at least 55% of maize farmers in each of the agro ecological zones have been found to exhibit increasing returns to scale (Table 11). That is most farmers operate below the optimal scale.

Farm size, with positive coefficients and statistically significant at the 10%, 5% and 5% levels for maize farmers in the Transition zone, Forest zone and Coastal savannah zone are expected. This means that maize farmers who cultivated large farm plots have higher levels of scale efficiencies than those with small land holdings. This result is in line with the findings of Madau (2012) that reported that scale efficiency improvement is mostly conditioned by increase in farm size. Karagiannis and Sarris (2005) also observed that notwithstanding the fact that no solid correlation between technical efficiency and area cultivated can be statistically established, a statistically significant positive correlation is obtained between scale efficiency and area cultivated. According to the study, farmers with small farm sizes normally have financial challenges and therefore have inadequate access to production resources. Also, farmers operating small farms may have other sources of income, which to them, are more important and therefore little effort is put into farming vis-a-vis farmers with larger

Table 12
Maximum likelihood estimates of stochastic frontier scale efficiency function *Source:* Survey, 2015.

Variable	Guinea savannah zone		Transition zone		Forest zone		Coastal savannah zone	
	Coeff	Std. Err	Coeff	Std. Err	Coeff	Std. Err	Coeff	Std. Err
Constant	−0.384		0.098		0.013		−0.043	
ROADS	0.022**	0.010	0.015	0.007	0.001*	3.4×10^{-5}	8.61×10^{-5}***	0.003
SEX	0.046	0.016	−0.010	0.005	0.002	2.22×10^{-5}	−0.007	0.036
AGE	−0.001**	0.001	−0.001*	0.001	−0.001***	2.25×10^{-6}	−0.001*	0.001
EDU	0.002*	0.002	0.001	0.001	0.001**	2.78×10^{-6}	0.001***	0.001
HOSIZE	0.002**	0.001	0.004*	0.001	0.001	3.20×10^{-6}	0.003**	0.001
EXP	0.001**	0.001	0.001	0.001	0.001***	3.23×10^{-6}	0.001**	0.001
LANDSZ	−0.008	0.008	0.006*	0.001	0.001**	6.55×10^{-7}	0.004**	0.005
NPLOTS	−0.005**	0.014	−0.001*	0.001	0.001	1.49×10^{-5}	−0.006**	0.010
NOEXTVI	0.004***	0.022	0.007	0.002	0.017*	4.07×10^{-5}	0.002*	0.002
MGROUP	0.004*	0.017	0.030	0.001	0.019**	9.07×10^{-5}	0.021*	0.012
CREDIT	0.004*	0.034	0.008	0.014	0.004**	5.9×10^{-5}	0.014**	0.008
REDYMKT	0.003	0.005	0.002*	0.011	0.002	3.06×10^{-5}	0.091	0.011
RAINamt	0.001**	0.001	0.001	0.001	0.001*	5.14×10^{-8}	-1.6×10^{-5}	1.62×10^{-5}
FERTus	0.004	0.023	0.012**	0.001	0.003*	3.98×10^{-5}	0.003**	0.026
PESTus	0.001*	0.007	0.002**	0.002	0.001	5.1×10^{-5}	0.008**	0.001
SEDtyp	0.005	0.026	0.057***	0.001	0.001*	4.11×10^{-5}	0.004	0.011

Note: The asterisks indicate levels of significance.
*** Significant at 1%.
** Significant at 5%.
* Significant at 10%.

farms. It is worthy of note that the influence of cultivated area on scale efficiency is still being argued. This is because, according to Błażejczyk-Majka (2012), larger farms appear more scale efficient by exploiting scale economies. Conversely, larger farms may also have challenges in undertaking their activities at the optimal time and therefore will not be efficient in the use of the resources available to them (Brambilla and Guido, 2009).

Use of fertilizer in maize production in the Transition zone, Forest zone and Coastal savannah zone is positively related to scale efficiency and is significant at the 5%, 10% and 5% levels respectively (Table 12). This means that maize farmers who used fertilizer in their maize production achieved higher scale efficiency scores than those who did not use fertilizer. This is because fertilizer adds required plant nutrients to the soil and therefore its usage will make farmers operate close to an optimal scale. The relationship between seed variety and scale efficiency is positive and is statistically significant at the 1% and 1% significance levels for maize farmers in the Transition and Forest zones respectively. The implication is that maize farmers who used improved varieties are more scale efficient than those who used traditional varieties. This is because most improved seeds are high yielding and this will give adopters of such varieties higher yields than non-adopters. The aforementioned results confirm those of Chiona (2011) that also revealed positive relationships between usage of fertilizer and improved seed variety on the efficiency of maize production in Zambia. The influence of use of pesticides on the scale efficiency of maize farmers in each of the agro ecological zones is positive and statistically significant at the 5% significance level for each zone. This implies that scale efficiencies of farmers who used pesticides are higher than those who did not use pesticides. Notwithstanding the fact that none of the respondents complained of army worm infestation, positive relationships were found between pesticides and scale efficiency of maize farmers in the study area. This could be due to the presence of some other unknown pests of maize that farmers are not aware of. This therefore calls for research in this area that will help identify such unknown pests so that stringent measures could be devised to help control their infestation. Access to good road has a positive effect on the achievement of optimal scale and is statistically significant at the 5%, 10% and 1% levels for maize farmers in the Guinea savannah, Forest and Coastal savannah zones respectively. This is because good road network around maize farms allows free flow of inputs and outputs. The net result is that farms are timely and adequately supplied with required production inputs and farm outputs do not go bad as they reach consumers on timely basis. This result is in agreement with the finding of Li and Liu (2009) as well as Abdulai and Abdulai (2016) that reported that transportation infrastructure played the most substantial positive role on the efficiency of agricultural production in China and Zambia respectively. The coefficients of the variable for land fragmentation is inversely related to scale efficiency and is significant at 5%, 10% and 5% for maize farmers in the Guinea savannah, Transition and Coastal savannah zones respectively. This means that maize farmers who farm on more than one plot of land are less scale efficient than those farming on single lands. This is because, even though land fragmentation may be used as a risk strategy by maize farmers, it increases cost of production. For instance, transportation cost will definitely increase because farmers have to be moving from farm plot to farm plot that may be far apart. Monchuk et al. (2010) as well as Latruffe and Piet (2014) also reported similar results for the effect of land fragmentation on the scale efficiency of agricultural production. The coefficients of the variable representing contact with extension service is positively related to scale efficiency and is

statistically significant at 1%, 10% and 10% for maize farmers in the Guinea savannah zone, Forest zone and Coastal savannah zone respectively. This is because extension allows maize farmers to know and learn new production technologies as well as the correct combination of production inputs in production. Similar results on the effect of extension contact on efficiency were reported by previous efficiency studies that reported a positive correlation between efficiency of agricultural production and extension visits (Sibiko et al., 2012; Alam et al. 2012; Khan and Ali, 2013; Abdulai and Abdulai, 2016).

The effect of the variable representing membership of a farmer association on scale efficiency is positive and statistically significant at 10%, 5% and 10% for maize farmers in the Guinea savannah zone, Forest zone and Coastal savannah zone respectively. The implication is that members of such associations benefit through the provision of credits and subsidies on production inputs by the association. Added to this is the fact that agricultural extension agents mostly disseminate agricultural production technologies through seminars organized for members of farmer based organizations. This finding is in consonance with the findings of Masuku et al. (2014) and Mwaura (2014) even though it contradicts that of Addai et al. (2014). Finally, access to farm credit was also found to have a positive influence on the scale efficiency of maize farmers and is statistically significant at 10%, 5% and 5% significance levels for maize farmers in the Guinea savannah, Forest and Coastal savannah zones respectively. The effect of access to credit means that maize farmers with access to credit are more scale efficient than those with no access to credit. This is because acquisition of credit by maize farmers reduces their liquidity constraints and allows them to be able to purchase required production inputs for their input mixes and consequently, they operate at an optimal scale. This is in line with the finding of Khan and Ali (2013) as well as Abdulai and Abdulai (2016) that also found a positive relationship between farmers' access to credit and efficiency of agricultural production.

3.7. Conclusion and recommendation

This study analyzed scale efficiency of maize farmers in the Guinea Savannah, Transition, Forest and Coastal Savannah zones of Ghana by the parametric approach. The study found that the mean scale efficiencies for maize production in the Guinea Savannah, Transition, Forest and Coastal Savannah zones of Ghana were 86%, 91%, 89% and 86% respectively. The implication is that observed maize farms in each of the aforementioned zones could have further increased their outputs by about 14%, 9%, 11% and 14% respectively if they had operated at an optimal scale. The study concludes that maize farmers in each agro ecological zone are scale inefficient. The inefficiencies were observed to have emanated from farms exhibiting increasing returns to scale. Optimal scales will therefore be achieved if more production inputs (fertilizer, pesticide, manure and land) are employed by these farms. Also, the findings suggest that with scale efficiencies exceeding technical efficiencies in all agro ecological zones, the implication is that a greater percentage of total inefficiency among the farmers might depend more on producing below the production frontier than on operating at an inefficient scale. Therefore, the room for improving technical efficiencies in the various agro ecological zones is huge vis-à-vis the margin due to scale inefficiencies. Furthermore, for farmers in Ghana to operate at an optimal scale, there is the need for increase in educational level, maize farming experience, access to good roads and ready markets, group membership, extension contact as well as uses of fertilizer, pesticides and improved seeds. However, an increase in land fragmentation would decrease the scale efficiency of the farmers.

For scale efficiency to be improved, maize farmers in the various agro ecological zones of Ghana are encouraged to employ more of the production inputs available to them. For the farmers to be able to employ more of these inputs, cost of production inputs could be subsidized and credit could be given to them by government. Incentives aimed at encouraging farmers to use more fertilizer, pesticides and improved seeds are recommended for optimal scale of production. It is also worthy of note that policy makers through the Ministry of food and Agriculture and other stakeholders in the maize industry should create incentives for extension agents so that their commitment to delivery of agricultural extension services to maize farmers would be improved. Moreover, extension officers should encourage maize farmers to join farmer groups and in places where there are no such groups, farmers should be assisted to team up and form such organizations. This is because agricultural technologies that improve scale efficiency are normally disseminated through farmer groups and therefore farmers who belong to such groups will more likely have knowledge of suggested technologies than those who are not members of such associations. Furthermore, given that the scale efficiency of maize farmers is higher than their technical efficiency, agricultural productivity improvement policies such as assisting farmers to purchase and use improved inputs aimed at addressing the efficiency challenges of maize farmers in Ghana should be targeted more at improving technical efficiency than scale efficiency. Finally, the current study mainly used cross-sectional data. It did not use farm-level panel data, as it was not available. Cross-sectional data analysis is fraught with challenges, such as inability to trace the dynamics of scale efficiency of farmers over a period. Therefore, the current study suggests that future researchers could undertake scale efficiency analysis using farm-level panel data in order to be able to track the dynamics of farmer efficiency over time.

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