REGULAR ARTICLE

ASSESSING THE TECHNICAL EFFICIENCY OF IMPROVED TOMATO PRODUCTION IN GHANA: A TWO- STEP METASTOCHASTIC FRONTIER APPROACH

Adinan Bahahudeen SHAFIWU[1], Samuel A. DONKOH[2], Abdulai ABDUL-MALIK[3]*

[1]Department of Agriculture and Food Economics, University for Development Studies
[2]Department of Economics, University for Development Studies
[3]Department of Applied Economics, University for Development Studies
* Correspondent author: shafiwu@uds.edu.gh

ABSTRACT

Purpose of the Article: This study examines the technical efficiency of tomato farmers in Ghana.
Methods: Using cross-sectional data for the 2019 cropping season and through a multi-stage sampling technique, 508 farmers from three agro-ecological zones were selected and used for the study. Using Metafrontier analysis and a translog functional form, we examined the mean levels and the determinants of Metatechnical efficiencies.
Findings, Value Added and Novelty: The findings of group-specific metafrontier technical efficiencies (MFTEs) and ecological gap ratios (EGRs) showed that tomato farmers in Ghana produced below the group frontier due to limited and inefficient utilization of the available technologies. Farmers in Forest Savannah Transitional Zone (FSTZ) achieved higher mean technical efficiency than those in the Coastal Savannah Zone (CSZ) and the Guinea Savannah Zone (GSZ).respectively. Conventional inputs such as land, seeds, insecticides, and tractor services positively influenced tomato production in GSZ, FSTZ and CSZ while farmers who were: male; formally educated; belonged to an FBO; and had access to extension services, were technically efficient in GSZ and FSTZ. In CSZ, female farmers and farmers producing tomato as a secondary occupation were more technically efficient. The study recommends that the private sector, including financial institutions, value chains, and NGOs as well as the government through MoFA should invest in FBOs, and also assist tomato farmers to access extension services and education to help eliminate technical inefficiencies in tomato production. Government should also help ease farmers 'access to production inputs such as tractor, fertilizer, pesticides, and seed so as to increase tomato production in Ghana.

Keywords: Metafrontier, Ecological zones, Technical Efficiency, Tomatoes, Ghana
JEL Codes:

INTRODUCTION

Tomato (*Lycopersicon esculentum*) is one of the popular and major income-generating vegetables cultivated by small-scale and medium-scale commercial farmers globally **(Aidoo-Mensah D 2018; Naika *et al.*, 2005; Osei et al., 2010; Ayandiji *et al.*, 2011; Singh *et al.*, 2018).** Tomato has a relatively shorter maturity period and a longer production period (usually up to a year), making it economically attractive to many farmers **(Naika *et al.*, 2005).** It flourishes from temperate to hot and humid tropical weather under different crop systems and climatic conditions, **(Naika *et al.*, 2005).** Compared to other vegetables, tomatoes are the most consumed vegetable in Ghana. It is consumed in large quantities daily by most households in various dishes such as soups, sauces and salads **(Aidoo-Mensah D,2018 ; Attoh *et al.*, 2014).** Tomato is an essential source of minerals (iron, phosphorus), lycopene, beta-carotene, vitamins (A and C), large amounts of water, and low calories **(Naika *et al.*, 2005; Abdulai et al., 2017).** Tomatoes help prevent aging-related illnesses such as dementia and osteoporosis **(Freeman and Reimers, 2010),** and can also improve fertility in men by improving sperm quality and swimming speed by reducing the amount of abnormal sperm in men due to their high lycopene content **(Innes, 2014).**
In Ghana, tomato cultivation is a thriving agricultural activity in the savanna and forest-savanna transition zones. Differences in rainfall patterns, access to tractor services and land makes tomatoes production highly seasonal and bring about variation in harvest periods **(Robinson and Kolavalli, 2010).** Two periods (period of abundance and period of scarcity) is created due to seasonality and this reflects in market prices **(Amikuzuno and Ihle, 2010).** In addition, high production costs, poor seed distribution, poor adaptation of a variety to temperature, inadequate use of irrigation water when needed, sub-optimal and/or untimely application of inputs such as fertilizers, lack of access to credit and inadequate control of pests and diseases contribute to low yields and inefficiency of tomato production in Ghana. It is believed that a farmer can obtain the maximum attainable yield levels by using the recommended quantity of fertilizer, improved seeds and other relevant inputs in tomato production **(MoFA, 2010).**
Despite the increase in tomato production, national demand for tomatoes has long outstripped domestic supply, a situation that attracts large imports from neighbouring countries **(Dapaah and Konadu, 2004; Melomey *et al.*, 2022).** In 2017 for instance, some 75,000kg of tomatoes was imported to meet domestic demand. The supply shortfalls are

attributed to low yields **(Attoh, 2017),** which are on average between 63,500kg to 65,500kg. Low agricultural productivity is partly due to resource-used inefficiency in agricultural production and low adoption of improved agricultural technologies including crop varieties **(Owusu *et al*, 2016).** The use of local and poor seed variety limits productivity **(Mohiuddin *et al*., 2007)** and the quality of tomato, which in turn affects pricing **(Horna *et al.*, 2007; Clottey *et al.*, 2009).** Although the crop has many benefits, most developing countries, particularly those in Africa, face many challenges in cultivating it, rendering it unprofitable to produce.

Increasing tomato productivity will not only involve the transformation of some institutions such as the land tenure systems and input and credit provision, but will also require farmers to adopt improved technologies **(Donkoh *et al.*, 2013).** In recent times, the introduction of advanced agricultural technologies has become the focus of the political interests of developing countries. The introduction of improved tomato varieties provides a significant increase in yields by reducing post-harvest losses, which can lead to the creation of processing and export industries, thereby promoting economic development, **(Aidoo *et al.*, 2014).**

Efficiency measurement is continually an area of significant research in the developing countries owing to the inefficiencies in the production processes of developing countries **(Betty 2005).** For instance, some studies **(e.g., Attoh, 2011)** have delved into options for increasing tomato production in Ghana and others (**e.g., Ahmed and Anang, 2019)** have unraveled the drivers of efficiency performances of tomato farmers. However, less of these studies did a country-wide analysis, let alone investigated the effect of improved seed adoption on production efficiency. It is also worth knowing that, efficiency study is location and crop specific, hence results from existing studies elsewhere cannot be generalized.

This study is aimed at identifying the metafrontier technical efficiency, ecological gab ratios (EGRs) and its drivers. Specifically, the study sought to determine the levels and the factors influencing the technical efficiency of tomato farmers and the factors influencing tomato production output in the selected agro-ecological zones of Ghana. The study contributes to filling the gab of regional interventions as a conduct to improving the performance of smallholder farmers. The remaining section of the study in structured as follows: Section 2 literature review, section 3 contains the methodology, which consists of the material and methods and, sections 4 and 5 is devoted to results and discussions and conclusions and recommendations

LITERATURE REVIEW

Efficiency concepts and measurement

Farrell (1957) introduced efficiency measurement, which **Kumar and Gulati (2010)** defined as a measure of operational excellence in the resource utilization process. Productivity is closely related to efficiency. In its most basic form, productivity is calculated by dividing the output by the total physical inputs or resources (land, labor, seed, etc.) used in production. In other words, productivity is simply production efficiency **(Syverson, 2011).** Single factor productivity measures or reflects output units produced per unit of a specific input. When a company fails to maximize its potential output, it is said to be inefficient. A company in the manufacturing process is likely to experience some aspects of productive efficiency, such as technical, allocative, and economic efficiencies. Farmers' output differences can be explained by differences in efficiency. Thus, the production frontier describes the highest attainable output given the smallest number of inputs required to produce a specific output. In other words, the production frontier depicts the maximum attainable output for each input mix. Technical inefficiency refers to a farmer's or firm's failure to achieve the frontier level of output given the level of inputs **(Kumbhakar, 1994).** As a result, inefficiency occurs when the observed output falls below the frontier. Allocative efficiency refers to a company's or farmer's ability to use inputs optimally given their respective prices **(Uri, 2001).** Allocative inefficiency or resource misallocation occurs when a farmer fails to allocate inputs at the lowest possible cost, given the relative input prices. The implication is that misallocating resources will result in higher production costs and, as a result, lower output. Again, a firm or farmer is said to be allocatively inefficient if the marginal rate of technical substitution between any two inputs is not equal to the resulting proportion of factor prices. This could be due to a slow response to price changes and regulatory challenges (**Atkinson & Cornwell, 1994).** In the manufacturing process, a company can be technically efficient but allocatively inefficient, allocatively efficient but technically inefficient, both technically and allocatively efficient, or, at worst, both technically and allocatively inefficient. Economic efficiency attempts to combine technical and allocative efficiencies to depict a firm's or farmer's ability to produce at the lowest possible cost, given an input price and a set of inputs. As a result, attaining technical or allocative efficiency is a necessary but not sufficient condition for achieving economic efficiency. To achieve economic efficiency, a firm or farmer must achieve both technical and allocative efficiencies.

Tomato Production in Ghana

Tomato varieties developed in Ghana have varying levels of resistance to pests and diseases. Resistant varieties have an inherent resistance to pests and diseases that is present in the seed. Varieties of resistant seeds are capable of preventing certain unique diseases, meaning that it is very difficult or unlikely for a plant with these resistant features to get the particular disease. Resistance may be attributed to different characteristics of the plant. A densely covered leaf with hairs prevents certain insects from sitting on such improved trees. Again, some colours are unattractive to certain insects which give such plants resistance ability. Most of these characteristics are noticeable, while features leading to fungal and virus resistance are invisible **(Minot & Ngigi, 2004).** Tomato is a food as well as a cash crop in Ghana. Increasing competitiveness of tomato production can enhance economic growth in Ghana **(Anang *et al.*, 2013).** Despite its potential, tomato production continues to decline, while imports of tomato paste surge at high levels **(Robinson *et al.*, 2012).** The country is ranked as the second largest importer in Africa with about 7,000 Mt of fresh tomatoes and 27,000 Mt of processed tomatoes from the European market **(MoFA, 2017).** Again despite the fact that, tomatoes is one of the most important vegetables produced and consumed in the country, its production shows a pronounced seasonal trend with prices typically varying substantially even within a week.

RESEARCH METHODOLOGY

Study settings

This study was carried out specifically in the Guinea Savannah, Forest Savannah Transition and the Coastal Savannah zones of Ghana. The reason for the selection of these three agro-ecological zones was motivated by a study by **IFPRI (2013)** which identified these zones as having the potential to grow enough tomatoes to meet domestic demand and supply and even have excess for export to the neighboring countries. The study was cross-sectional and employed mainly primary data obtained from farmers using semi-structured questionnaires through a multi-stage sampling technique: the study purposively selected the Guinea Savanna, Forest Savanna Transition and Coastal Savanna based on the aforementioned **(IFPRI, 2013)** study. A simple random and the stratified sampling technique were used in the selection of both the municipality and the communities in each municipality. A proportion-to-size sampling technique was then used to select twenty households from each community, to avoid selectivity bias a simple random technique was employed in the last stage in the selection of individual respondents from each household that engages in tomatoes farming. We employed the Slovin’s formula used by **Rivera (2007)** to determine the sample size for the study. It is expressed as:

$$n = \frac{N}{(1 + Ne^2)} \tag{1}$$

Where n is the sample of farmers to be included in the study, N is the population size (number of potential farmers in Ghana, according to $MoFA(2016) = 2503006$) and e is the margin of error. We used 4.4% as the margin of error also known as precision level. From the above formula a total of 516 farmers regardless of acreage were obtained. Data was collected from the 516 respondents and was later cleaned to arrive at 508 farmers. We employed quantitative techniques in the analysis. The Stata software version 16 was used to provide descriptive statistics, such as the mean, standard deviation and variance of the respondents.’ and to also estimate the maximum likelihood estimates.

Analytical framework

Given that the study involves different ecological zones with differences in rainfall pattern, tractor services and land, we employed Metafrontier stochastic model in determining the drivers of meta-technical inefficiency and the translog production function in determining the factors influencing tomato output. **Barnes and Revoredo (2011)** stated that a metafrontier production function is suitable for studies under different technologies and environmental conditions.
Specifically we employed the two-step stochastic metafrontier model since the sample consists of different ecological zones. The two-step metafrontier, the pooling stochastic metafrontier and the two-step mixed methods all assume that the deviations between the frontier and the observed output are caused by both factors under and beyond the control of the firm (farmer). Unlike the pooling stochastic metafrontier model whose estimates are not exact and the two-step mixed approach also violating the standard regularity property, the new two-step approach to estimating metafrontier technical efficiencies is accurate and exact and meets all the standard regularity conditions **(Haung *et al.*, 2014).**

The New Two-Step Stochastic Metafrontier Models

The proposed new two-step stochastic metafrontier by **Huang et al. (2014)** is the current estimation method for production efficiency analysis. Both the group specific stochastic frontier and the stochastic metafrontier regressions are used. The group specific stochastic frontier regression is specified as:

$$y_i^k = f(x_i, \beta_i^k)\ell^{V_i^k - U_i^k} = \ell^{x\beta_i^k + V_i^k - U_i^k} \tag{2}$$

Where y^k is group k output, x is the vector of inputs, v_i^k and u_i^k are the error terms for firms in group k, β^k is a vector of unknown parameters for group k firms.

From the above model [eq2], the group specific stochastic frontier will be first estimated and the estimated parameters and error terms pooled together for the estimation of the stochastic metafrontier model. This is expressed as:

$$y_i^k = f(x_i, \beta_i^k)\ell^{V_i^k - U_i^k} = y^* = f(x_i, \beta_i^*)\ell^{V_i^* - U_i^*} = \ell^{x_i\beta_i^* + V_i^* - U_i^*} \quad (3)$$

The variables are as defined in (Eq. 2). On the contrary, y^* is metafrontier output and v_i^* and u_i^k are error terms for metafrontier and β^* is the vector of metafrontier parameters.

From equation [2.0] above the group technical efficiency can be derived by dividing the observed output by the frontier output. Both the frontier output and the observed outputs can be used in estimating production performance of a firm. Therefore, the technical efficiency (*T.E (1))* of a group (1) is expressed c as:

$$TE_A^1 = \frac{Observed - output - of - eco\log ical - zone1}{Frontier - output - of - group(1)eco\log y} = \frac{y_A^1}{y^1} = \frac{f_A^1(x, \beta^1)e^{v^1 - u^1}}{f^1(x, \beta)e^{v^1}} = -u^1 \quad (4)$$

For output-oriented efficiency, the ecological gap ratio of farmers in eco1ogical group1 (GSZ) can be estimated as:

$$EGRs(1)\frac{Frontier - output - of - firms - eco\log ical - zone1}{metafrontier - output} - \frac{y^1}{y^*} \quad (5)$$

Finally, the metafrontier technical efficiency *(TE*)* can be measured using the equation

$$TE^* = \frac{Observed - output - of - eco\log ical - zone1}{metafrontier - output} - \frac{y_A^1}{y^*} \quad (6)$$

From the viewpoint of **Huang *et al.* (2014)**, the exact nature of any estimated metafrontier efficiency $MFTE_i^k$ justifies the definition of metafrontier as an envelope of individual frontiers. Hence, the estimated metafrontier is given as:

$$MFTE_i^k = EGR_i^k \times TE_i^k \quad (7)$$

Where $0 \le MFTE_i^k \le 1, 0 \le TE_i^k \le 1 and 0 \le TGR_i^k \le 1$ while $MFTE_i^k$, are all predicted.

For a farmer to be technically efficient or inefficient will depend on some characteristics that are directly or indirectly associated with the farmer. These characteristics could be farmers' socioeconomic or demographic characteristics, farm specific location (FSD), institutional-policy variables (IPV), seed variety adoption (SVA) and the border town effect (BTE). Thus, technical inefficiency of the farmers in *k-th* agro-ecological zone is expressed theoretically as:

$$TI_i^k = U_i^k = \{\delta_o^k + \sum_{m=1}^{m=6}\delta_m^k FSD_{mi}^k + \sum_{m=7}^{m=10}\delta_m^k IPV_{mi}^k + \sum_{11}^{13} SVA_{mi}^k + \sum_{14}^{14}\delta_m^k BTE_{mi}^k + \delta_i^k\} \quad (8)$$

Empirical estimation of the New-Two Step Stochastic Metafrontier Translog Model

Following the new two-step stochastic metafrontier model used by **Huang et al. (2014)**, we first estimated the group specific stochastic translog models. Each of these estimated group specific stochastic translog models are then used in the prediction of tomatoes outputs. The group estimates of tomatoes output (T_i^*) are then pooled together and used for further estimation of the metafrontier model. Also, to obtain a metafrontier technical efficiency ($METE_i$ or TE_i^*), the metafrontier technical inefficiency is subtracted from one (1). Where a metafrontier technical inefficient is given as:

$$TI_i^k = U_i^* = \{\delta_o^* + \sum_{m-1}^{m-6}\delta_m^* FSD_{mi}^* + \sum_{m-7}^{m-10}\delta_m^* IPV_{mi}^* + \sum_{11}^{13} SVA_{mi}^* + \sum_{14}^{14}\delta_m^* BTE_{mi}^* + \delta_i^*\} \quad (9)$$

Implies ($METE_i = TE_i^* = 1 - U_i^*$).

The likelihood ratio test was used in testing for the right functional form while the one-step maximum likelihood estimation procedure was used in the determination of the relationship between tomato output (dependent variable) and input use (socio economic variables influencing tomato output). The generalized likelihood-ratio test was expressed as:

$$K = -2[\ln\{L(H_A)\}/\ln\{L(H_0)\}] = -2[\ln\{L(H_A)\} - \ln\{L(H_0)\}] \quad (10)$$

Where the values of the likelihood function under the alternative and Null hypothesis are $L(H_A)$ and $L(H_0)$. Also, the value of K has a chi-square (χ^2) or the mixed chi-square distribution with the value of degrees of freedom equal to the difference between the number of parameters involved in H_A and H_0.

Table1 Definition of variables

Table1 below shows the variables used in this study and their measurements

Variable	Description	Measurement
Improved Tomato Seed Variety	Tomato Variety	Categorical: Pectomer 1, Power Roma 2 , Pectomer/power roma 3.
Sex	Sex of the farmer	Dummy; 1 if the respondent is male, 0 if otherwise
HH_Size	Household size	No. of people eating from the same pot
Education	Education of the farmer	No. of years in school
Primary_Occupation	Main occupation of the farmer	Dummy; 1 if tomato farming is the main occupation, 0 if otherwise
Income	Annual household income	Ghana cedi
Ext_Access	Access to extension service	Dummy; 1 if the respondent had extension visit (s), 0 if otherwise
Credit_Access	Access to credit	Dummy; 1 if the respondent had credit, 0 if otherwise
Cropping_Type	Type of cropping	Dummy; 1 if the respondent practices mono-cropping, 0 if otherwise
Potential_Yield	Perception about yield	Scale; ranked from 1-7
Availability_Mkt	Perception about market access	Scale; ranked from 1-7
Seed_Access	Perception about access to seed	Scale; ranked from 1-7
Resistance_Pest	Perception about resistance to pest	Scale; ranked from 1-7
Early_Maturity	Perception about early maturity	Scale; ranked from 1-7
Storage_Ability	Perception about good storage ability	Scale; ranked from 1-7
Resistance_BadWeather	Perception about weather condition	Scale; ranked from 1-7
GSZ	Guinea Savannah zone	Dummy; 1 if the respondent is located in GSZ, 0 if otherwise
FTSZ	Forest Transition Savannah zone	Dummy; 1 if the respondent is located in FTSZ, 0 if otherwise
Instrumental variables		
FBO	Membership in FBO	Dummy; 1 if the respondent belonged to an FBO, 0 if otherwise
Insurance	Membership in insurance program	Dummy; 1 if the respondent participated in insurance program, 0 if otherwise

RESULTS AND DISCUSSION

FARMER AND FARM-SPECIFIC CHARACTERISTICS

Table 2 shows the descriptive results of the farmer and farm-specific characteristics, as well as institutional and environmental factors used in the study. As shown in the table, the respondents have a mean age of 40.53 years with a minimum of 22 years and a maximum of 77 years. The mean ages of farmers in GSZ, FSTZ, and CSZ are 41.09 years, 40.97 years, and 39.367 years respectively. These statistics imply that tomato farmers are within their active and economical years and this has the tendency of increasing tomato production in the country. This finding is consistent with **Dasmani *et al.'s* (2020)** study which showed a mean age of 40 years. Also, 89.6% of the respondents are male while the remaining 10.4% are females. The gender distribution in GSZ (73.4%), FSTZ (87.0%), and CSZ (84.1%) also suggest that tomato production is dominated by males. The findings are consistent with **Owusu (2016)**, **Wongnaa and Awunyo-Vitor (2019),** and **Dasmani *et al.* (2020)** who revealed male dominance in farming in the coastal, forest and savannah zones in Ghana. It was also revealed that males (82.10%) domnate cormmercial tomato farming with only a few females (17.90) also into commercial tomato faming. However in the case of small-scale farming majority (91.29%) are female with the remaining (8.71%) being male. This finding does not meet the *a-priori* expectation. Also, the survey results show that 36% of the sampled respondents in the selected agro ecological zones are illiterate while the remaining 64% are literate. The mean formal education is 2.23 years with a minimum of zero and a maximum of seven. The mean educational years also indicate that the highest level of education a respondent has attained on average is primary education (approximately Primary 3). The result is consistent with the **GSS (2016)** finding which indicates that approximately half of Ghana's adults have obtained primary education or completed middle school/JHS. In terms of technology adoption and understanding of market dynamics, this could have some negative influence on agriculture. **According to Minot *et al.* (2006),** education is also a means of accessing extra employment activities, especially in the non-farm sector. Moreover, majority (90%) of the family heads of the selected farmers in the agro ecological zones are without formal education and this may mean that most of these people would not be able to engage in any formal employment except agriculture. The findings are consistent with **Dasmani *et al*. (2020).**

The mean farming experience is 13.01 years. This high level of expertise in farming can be an essential factor for improving the efficiency of resource use in tomato production.

The mean household size is 7.58 persons per household with a minimum of one and a maximum of twenty-three respectively. This average size is slightly above the average of 7 members in Ghana's household **(GSS, 2010)**. **Al-Hassan (2008)** argues that large families enable members of household to earn additional income from non-farm activities and can help minimize marketable surplus through consumption. Furthermore, majority (83.9%) of the farmers are engaged in tomato production as their primary occupation. Table 1 further reveals that the mean land size is 2.51 ha for the pooled sample and 2.95 ha, 2.44 ha, and 2.38 ha in CSZ, FSTZ, and GSZ. Labour is another important variable that is required through the production process. The mean labour for the pooled sample is approximately 133.41 mandays/ha, with a minimum of 10 and a maximum of 1200 mandays. The average quantity of seed planted to one ha was estimated at 18.94 kg for the pooled sample. The mean herbicide and insecticide application rates are 4.654 litres/ha and 3.207 litres/ha for the entire farmers respectively. The average cost of tractor services is GH¢214.03/ha for the pooled sample. The mean output of tomato for the entire sample is estimated at 98.32 crates per ha. A crate was evaluated at 72kg. The table reveals that about 96.5% of the farmers belong to FBOs. Furthermore, about 63.2% of tomato farmers have access to extension services. Also, less than 5.0% of the entire sample belongs to an insurance program.

Hypotheses Tests for the use of Stochastic Frontier and Metafrontier Models

The results of the generalized likelihood ratio (LR) chi-squared tests for determining the appropriate functional form, existence of inefficiency, and the effects of exogenous factors on technical inefficiency are presented in Table 3. The stochastic metafrontier model is estimated using the stochastic production frontier (SPF) estimates of the individual agro-ecological zones (GSZ, FSTZ, and CSZ). According to the table, the null hypothesis that the Cobb-Douglas production function is suitable for the data is rejected at 1% significance level. The transcendental (translog) functional form is used to represent the production structure since the chi-square calculated values are greater than the chi-square critical values. Several recent studies on the production efficiency of farmers also applied the translog SPF model to estimate technical efficiency **(Owusu *et al.*, 2016; Asravor *et al.*, 2019; Wongnaa and Awunyo-Vitor, 2019).** Besides the LR test, the translog production function is adopted because it is said to be flexible and imposes no restrictions on both production (demand) elasticities and elasticities of substitution, compared to the Cobb-Douglas production function which assumes constant returns-to-scale **(Battese and Coelli, 1995).** Also, the null hypothesis that technical inefficiency is absent is rejected at 1% significance level for each of the translog stochastic frontier production (SPF) models. This result generally indicates that the total variation in output or deviation of actual output from the frontier is in part, explained by farmers' inefficiencies **(Belotti *et al.*, 2013; Kidane and Ngeh, 2015).** The presence of technical inefficiency in the data provides a strong justification for the use of the stochastic production frontier model, rather than the Ordinary Least Squares (OLS) or average production response model (APR) which would have produced biased and inefficient estimates **(Onumah *et al.*, 2013 as cited in Mabe, 2018).**

Furthermore, the null hypothesis that none of the exogenous explanatory factors has a significant effect on technical inefficiency is rejected at 1% significance level. Also, the stochastic metafrontier model is used to estimate technical efficiencies of tomato farmers in the three agro-ecological zones on the basis that farmers in each zone operate under different technologies **(Aravindakshan *et al.*, 2018).** To justify the use of the stochastic metafrontier model, the LR chi-squared test was conducted to test the null hypothesis that tomato farmers in the three selected agro-ecological zones operate with similar or homogenous production technologies against the alternative hypothesis that they operate with heterogeneous production technologies. According to the results, the null hypothesis is rejected at 1% significance level, confirming that tomato farmers in the three agro-ecological zones operate with different production technologies. However, by using the stochastic metafrontier model, all potential biases in technical efficiency due to differences in production technologies and capacity imposed by tomato seed variety have been corrected **(Villano *et al.*, 2010)**. The differences in ecological zones production are evident in the results since the translog SPF model for GSZ is nested into translog SPF models for FSTZ and CSZ, whereas at the same time, the translog SPF model for FSTZ is also nested into the translog SPF models for GSZ and CSZ respectively.

Maximum Likelihood Estimates of the New-Two Step Stochastic Metafrontier Translog Model

The dependent variable, output, and the input variables are all mean-corrected to zero and log-transformed, which implies that the first-order coefficient estimates of the model represent the corresponding elasticities. This study interprets partial output elasticity as the percentage change in output as a result of a one-percent change in an input.

The result is presented in table 4 and shows that the estimated returns-to-scale (RTS) is greater than one in GSZ (1.5111) but less than one in FSTZ (0.1194) and CSZ (-6.6092), indicating that farmers in GSZ are operating at increasing returns to scale (IRTS) while farmers in FSTZ and CSZ are operating at decreasing returns to scale (DRTS). The quantity of seed planted by farmers is significant and positive in the GSZ and FSTZ but negative in the CSZ. The coefficient of land, labour, herbicides, and tractor services are also significant in GSZ. Land, herbicides, and tractor services are positive and significant at 1%, 10%, and 1% levels respectively, while labour is negative and significant at 1% level. The positive effect of land and seed agrees with **Asravor et al. (2019)** and **Wongnaa and Awunyo-Vitor (2019)** who reported a positive and significant effect of land and seed on rice and maize production in some selected agro-ecological zones in Ghana. However, the negative effect of labour in this study contradicts **Asravor *et al.* (2019)** but agrees with **Owusu (2016)** and **Wongnaa and Awunyo-Vitor (2019). Owusu (2016)** further found a negative effect of land on maize production in some selected agro-ecological zones in Ghana.

The results show that land has the largest positive (0.4407) impact in tomato production, followed by seed (0.2731), fertilizer (0.1089), tractor services (0.0868), and herbicide (0.0678). In contrast, labour has the largest negative (0.0594) impact on tomato production, compared to insecticide (0.0439). The positive effect of land, fertilizer, and seed is consistent with **Dessale (2019)** in Ethiopia and Oyetunde-Usman and Olagunju in Nigeria who found a positive and significant relationship between farm size and farm output. In addition, the sources of technical inefficiency (TI) of tomato farmers in the various agro-ecological zones were determined and presented in Table 3. Here, TI is the reverse of technical efficiency (TE). This implies that factors that positively influence TI also reduce TE while factors that negatively influence TI also increase TE. The results reveal that the education of farmers, farming experience, membership of FBOs, and access to extension services are found to be significant factors of TI of tomato farmers in GSZ. The coefficient of education is negative (-0.9169) and significant at 1% significance level. This finding is consistent with **Narala and Zala (2010**), **Cramon-Taubadel and Saldias (2014),** in Chile and **Ngango *et al.* (2019)** in Rwanda, but contradicts the findings of **Donkoh et al. (2013)** and **Anang et al. (2016)** in Ghana who found a positive and significant effect of education on TI of small-scale maize farmers. Membership of FBOs was also significant and negative. The finding is consistent with A**nang et al. (2016) and Wongnaa and Awunyo-Vitor (2019)** in Ghana who found that farmers who belong to FBOs are more technically efficient than those who do not belong to FBOs. The results also found that access to extension services reduces TI by 1.1916 and 0.0633, in GSZ and FSTZ respectively. The finding is consistent with previous literature **(Wongnaa and Awunyo-Vitor, 2019).** Contrary to expectation, highly experienced farmers are less efficient, compared to less-experienced farmers. The finding contradicts **Narala and Zala (2010)** in Central Gujarat who found that highly-experienced farmers are more efficient than less-experienced farmers. The coefficient of gender is significant and negatively related to TI in FSTZ, but positively correlated with TI in CSZ. The negative effect of gender on TI is consistent with **Donkoh *et al.* (2013) and Anang *et al.* (2016)** while the positive effect of gender on TI is in agreement with **Wongnaa and Awunyo-Vitor (2019).** Furthermore, farmers whose primary occupation is tomato farming are less technically efficient compared to those who engage in tomato production as their secondary occupation. This result is contrary to expectation.

Determinants of Technical Inefficiency across the Agro-Ecological Zones

Having examined the determinants of TI of tomato farmers, we proceed to estimate the determinants of metafrontier inefficiency. Table 5 presents the results on the determinants of the metafrontier inefficiency. Results from the estimation revealed education, farming experience, and farming type positively and significantly influence TI while access to extension negatively and significantly influences TI of tomato farmers in Ghana. The results show that the educated, highly-experienced farmers and farmers who practice mixed cropping are less technically efficient while farmers who have access to extension services are more technically efficient.

Summary Statistics of Metafrontier Technical Efficiencies and Ecological Gap Ratios

The study further looked at the ecological gap ratio (EGRs) on farm metafrontier technical efficiency. The results of on-farm metafrontier technical efficiency (MFTE) and ecological gap ratio (EGRs) of tomato farmers are presented in Table 5. MFTE scores are calculated by taking the ratio of actual output to the frontier output. The mean MFTE of the stochastic metafrontier is 77.19%, with a minimum of 15.76% and a maximum of 96.47%. The MFTEs for farmers in the FSTZ range from 4.69% to 100.00% with a mean of 98.17%. Also, MFTEs for tomato farmers in GSZ range from 23.49% to 99.61% with a mean of 77.44% whereas MFTEs for tomato farmers in the CSZ range from 17.29% to 99.99%, with an estimated mean of 86.51%. The findings imply that on average, tomato farmers in GSZ, FSTZ, and CSZ produce at 22.56%, 1.83%, and 13.49% below their respective frontiers. However, the MFTE scores indicate that farmers in FSTZ perform better than their colleagues in GSZ and CSZ. Also, a MFTE score of 100% was recorded among the farmers in FSTZ. In rice production, **Mabe (2018)** also reported that TE scores of rice farmers in GSZ and CSZ are lower when compared with MFTE scores of farmers in FSTZ.

EGRs is estimated to show the productivity potential and gap between each agro-ecological zone frontier and the metafrontier given that all farmers in any of the agro-ecological zone have the potential access to the best available technology for tomato production. EGRs of 1 implies that each group-specific frontier is tangential to the metafrontier whereas EGRs <1 implies that each group-specific frontier is not tangential to the metafrontier. EGRs> 1 indicates better returns from technology. The results in Table 4.6 reveal a mean EGRs of 81.14% (16.48), ranging from 37.77% to 146.54%. This indicates that on average, tomato farmers in Ghana achieve 81.14% of the potential output given the technology available to overall tomato production. The mean EGRs for farmers in GSZ is 86.89% (11.69), ranging from 53.33% to 152.17%. The mean EGRs for farmers in FSTZ is 75.26% (18.45) with a minimum of 15.76% and a maximum of 104.45% whereas EGRs for farmers in CSZ is on average 76.05% (18.51), ranging from 37.77% to 146.54% respectively. The findings imply that, on average, about 13.11%, 24.74% and 23.95% of the EGRs in GSZ, FSTZ, and CSZ are farther below the metafrontier.

Table 2 Descriptive statistics of the sample's characteristics

	GSZ (n=250)		**FSTZ (n=158)**		**CSZ (n=100)**		**Pooled (n=508)**	
Variables	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Farmer characteristics								
Sex (dummy)	0.896	0.306	0.734	0.443	0.870	0.338	0.841	0.366
Age (years)	41.092	11.054	39.367	8.554	40.970	11.854	40.532	10.522
Household size (count)	7.488	3.662	6.677	10.693	9.250	4.774	7.583	6.874
Education (years)	2.208	2.426	2.741	1.130	1.500	1.806	2.234	2.027
Farming experience (years)	14.060	9.809	11.285	7.451	13.090	10.744	13.006	9.406
Primary occupation (dummy)	0.848	0.360	0.930	0.255	0.670	0.473	0.839	0.368
Policy variables								
Membership in FBO (dummy)	0.984	0.126	0.962	0.192	0.920	0.273	0.965	0.185
Membership in insurance policy (dummy)	0.080	0.272	0.050	0.219	0.000	0.000	0.049	0.217
Extension service (dummy)	0.436	0.497	0.816	0.388	0.830	0.378	0.632	0.483
Access to credit (dummy)	0.184	0.388	0.038	0.192	0.100	0.302	0.122	0.328
Production variables								
Land size (ha)	2.375	1.693	2.441	1.534	2.946	2.382	2.508	1.814
Farming type (dummy)	0.252	0.435	0.481	0.501	0.500	0.503	0.372	0.484
Labour (mandays/ha)	86.400	66.374	207.278	217.504	134.200	90.265	133.406	145.583
Seed (kg/ha)	23.956	97.998	14.430	4.879	13.500	4.263	18.935	68.936
Tractor service(GH¢/ha)	278.720	600.017	74.057	177.951	273.456	603.349	214.029	516.3036
Fertilizer (kg/ha)	252.204	251.348	410.127	404.149	239.010	381.616	298.724	340.120
Herbicides (litres/ha)	6.562	12.035	3.425	4.155	1.824	0.975	4.654	8.973
Insecticides (litres/ha)	3.847	4.155	3.134	2.618	1.725	0.907	3.207	3.376
Output (crates/ha)	94.060	70.524	98.070	67.778	109.350	89.909	98.317	74.005

Environmental factors								
Annual rainfall (mm)	984.1	870	1150	1000	841.3	800	1024	800
Annual temperature (ºC)	28.5	27.8	26.7	26	24.6	24	27.1	24

Source: Authors' Constract, 2020

Table 3 Hypotheses Tests for the use of Stochastic Frontier and Metafrontier Models

Null hypothesis	**(n)**	**Df**	**Chi-Square Test**		
Cobb-Douglas functional form is appropriate			$\chi^2 - Cal$	$\chi^2 - Crit$	$\rho - Values$
GSZ	250	21/49	114.54	34.39	0.000
FSTZ	158	21/49	43.62	34.39	0.0012
CSZ	100	21/49	40.11	34.39	0.0016
Metafrontier	508	21/49	230.37	34.39	0.0000
No inherent inefficiency					
GSZ	250	38/39	128.37	29.41	0.0000
FSTZ	158	38/39	58.76	29.41	0.0000
CSZ	100	38/39	53.95	29.41	0.0005
Metafrontier	508	38/49	117.54	29.41	0.0000
Homogeneous Ecological Zones					
There are no differences in ecological	508	38/49	121.12	65.81	0.0002

Source: Authors' Constract, 2020

Table 4 Maximum Likelihood Estimates of the New-Two Step Stochastic Metafrontier Translog Model

Variables	GSZ Model		FSTZ Model		CSZ Model		Metafrontier Model	
	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE
lnLand	0.4979***	0.1623	-0.1269	0.2851	-0.3311	0.6931	0.4407***	0.0467
lnLabour	-0.6396***	0.0219	-0.0273	0.0741	-0.6299	0.7131	-0.0594***	0.111
lnFertilizer	0.1284	0.1197	0.0965	0.1040	-0.5287	0.5057	0.1089***	0.248
lnSeed	1.3840**	0.5060	0.1477**	0.0616	-3.4764*	6.4874	0.2731***	0.0731
lnHerbicide	0.0712*	0.0387	0.1095	0.6493	-0.9949	0.7429	0.0678***	0.0185
lnInsecticide	-0.0257	0.0403	-0.0925	0.8210	-0.8538	0.5700	-0.0439**	0.0206
lnTractor	0.0949***	0.0322	0.0124	0.1217	0.2056	0.1444	0.0868***	0.0154
$lnLand^2$	0.1726	0.1931	0.2181	0.1738	0.0906	0.2206	0.2956***	0.0495
$lnLabour^2$	0.0145	0.0226	0.0784	0.0752	0.1727	0.1222	0.0259***	0.0078
$lnFertizer^2$	-0.0533	0.0499	-0.0421	0.2663	-0.0844	0.1054	-0.0244*	0.0139
$lnSeed^2$	0.0732	0.1715	0.0814	0.2675	-1.4432	1.0007	0.0089	0.0619
$lnHerbicid^2$	0.0073	0.0726	0.1048	0.9760	-1.6352*	0.8491	0.0453	0.0387
$lnInsecticide^2$	0.1213	0.0922	-0.2545	1.2279	-0.7336	0.7743	0.0884**	0.0437
$lnTractor^2$	0.0256***	0.0068	-0.0088	0.0237	0.0281	0.0246	0.0204***	0.0032
lnLand×Labour	0.2530**	0.0957	-0.0996	0.1873	0.0702	0.1728	-0.0536*	0.0297
lnLand×Fertilizer	0.1479*	0.0794	0.2710	0.1773	0.2465*	0.1455	0.1824***	0.0276
lnLand×Seed	-0.3893**	0.1546	0.0187	0.3322	-0.5451	0.5721	-0.0246	0.0611
lnLand×Herbicide	-0.0112	0.0889	-0.8811*	0.5311	0.1466	0.4816	-0.0308	0.0369
lnLand×Insecticide	-0.1336*	0.0773	1.0159*	0.5844	-0.6699	0.4558	-0.0421	0.0372
lnLand×Tractor	-0.0143	0.0141	-0.0105	0.0233	-0.0315	0.0333	-0.0067	0.0052
lnLabour×Fertilizer	-0.1252*	0.0727	0.0056	0.1719	-0.6516***	0.1538	-0.1007***	0.0204
lnLabour×Seed	-0.2856**	0.1323	0.2399	0.4762	-0.9347**	0.4428	-0.2482***	0.0506
lnLabour×Herbicide	-0.0115	0.0732	0.0098	0.4832	-0.0745	0.2363	-0.0115	0.0296
lnLabour×Insecticide	0.1478*	0.0874	-0.2419	0.4930	0.7013**	0.3004	0.1223***	0.0342
lnLabour×Tractor	-0.0019	0.0171	0.0405	0.0438	0.0798**	0.0298	0.0191***	0.0054
lnFertilizer×Seed	0.2735*	0.1553	0.4277	0.2863	-0.3029	0.3955	0.1076**	0.0498
lnFertilizer×Herbicide	-0.0279	0.0752	0.5146	0.4681	0.2584	0.2442	0.0509*	0.0295
lnFertilizer×Insecticide	-0.0784	0.0786	-0.5348	0.4681	-0.9198**	0.3369	0.0713**	0.0298
lnFertilizer×Tractor	0.0197	0.0132	-0.0396	0.0271	0.0006	0.0239	0.0069*	0.0036
lnSeed×Herbicide	-0.0376	0.1228	0.2308	0.5953	-0.4629	0.6514	0.0140	0.0539
lnSeed×Insecticide	0.1155	0.1411	-1.1960	0.9271	-1.9599*	1.1544	0.1175*	0.0604
lnSeed×Tractor	-0.0134	0.0108	0.0468	0.0379	-0.0306	0.0602	0.0157**	0.0068
lnHerbicide×Insecticide	-0.0772	0.0773	0.0711	1.1257	0.3766	0.3617	-0.0157	0.0357
InHerbicide×Tractor	0.0134	0.0108	0.0300	0.9517	0.0039	0.0345	-0.0233***	0.0042
InInsecticide×Tractor	-0.0065	0.0117	-0.0431	0.1111	0.0744	0.0538	0.0058	0.0045
Constant	-0.0327	0.2499	-0.5494	0.9459	-2.7645*	1.6365	0.0340	0.0872

RTS	1.5111	0.1194	-6.6092	
Log-Lik	139.7159	104.9329	74.4009	79.0894
Wald $\chi^2(35)$	193.46***	67.60***	78.92***	795.22

Note: ***, **, and * indicate significance levels at 1%, 5%, and 10% respectively
Source: Authors' Constract, 2020

Table 5 Determinants of Technical Inefficiency across the Agro-Ecological Zones

Variables	**GSZ Model**		**FSTZ Model**		**CSZ Model**		**Metafrontier Model**	
	Coeff.	**SE**	**Coeff.**	**SE**	**Coeff.**	**SE**	**Coeff.**	**SE**
ln (σv^2)	-2.0953***	0.1844	-1.6448***	0.1291	-1.4744***	1.6193	-3.3802***	0.2192
Sex	-1.1111	0.6940	-2.4081**	1.0461	5.8368**	2.7453	0.0105	0.2377
Age	0.0275	0.0203	0.0790	0.0492	-0.1074	0.0741	-0.0081	0.0092
Education	-0.9169*	0.5256	2.8475	1.9228	1.5353	2.1419	0.3597*	0.2172
Household size	-0.5399	0.8289	3.6567	2.5807	-1.3413	2.8821	0.2720	0.4069
Marital status	-0.0874	0.0729	3.4863	4.2894	-2.2479	1.4213	0.0182	0.5953
Occupation	0.5019	0.4541	-3.7965	3.4559	3.3556*	2.0218	-0.0174	0.2349
Farming experience	0.3737**	0.1589	-0.0631	0.3389	-0.22750	0.6491	0.2291***	0.0658
Farming type	-0.0736	0.4264	-1.4818	1.0661	1.3671	1.3867	0.7663***	0.1994
Membership in FBO	-1.7440**	0.6522	2.0110	2.5760	-3.0353	5.1542	-0.6399	0.4170
Access to credit	0.4102	0.5427	0.4087	2.5760	-0.4888	4.7024	-0.1059	0.4031
Access to extension	-1.1916**	0.5127	-0.0633***	0.0188	2.8829	1.8977	-0.7404**	0.2753
Constant	-0.3929	1.4224	-5.2248	3.7797	-6.6865	5.7682	-2.0111**	0.7718

Legend: ***, **, and * indicate significance levels at 1%, 5%, and 10% respectively
Source: Author's construct, 2020

Table 6 Summary Statistics of Metafrontier Technical Efficiencies and Ecological Gap Ratios

Central Tendencies	GSZ		FSTZ		CSZ		Metafrontier	
	MFTE	EGRs	MFTE	EGRs	MFTE	EGRs	MFTE	EGRs
Mean	0.7744	0.8689	0.9817	0.7526	0.8651	0.7605	0.7719	0.8114
St. Deviation	0.1731	0.1167	0.0939	0.1845	0.1729	0.1851	0.1446	0.1648
Minimum	0.2349	0.5333	0.0469	0.1576	0.2298	0.3777	0.1559	0.1576
Maximum	0.9961	1.5217	1.0000	1.0445	0.9999	1.4654	0.9647	1.5217
Sample Size	250		158		100		508	

Source: Authors' Constract, 2020

CONCLUSION AND RECOMMENDATION

This study sought to determine the levels and the factors influencing the technical efficiency of tomato farmers in selected ecological zones of Ghana using the metafrontier model and a translog functional form. The findings of the study revealed that land, seeds, insecticides, and tractor services significantly increased tomato output in FSTZ and CSZ while decreased tomato output de GSZ. Also, education, membership in FBOs, and access to extension services significantly reduced technical inefficiencies while farming experience significantly increased technical inefficiencies in GSZ. Females and farmers with access to extension services had higher technical inefficiencies in FSTZ. In addition, farmers who engaged in tomato production as their primary occupation in CSZ were found to be technically inefficient compared to FSTZ and GSZ. Metafrontier technical efficiency (MFTE) and ecological gap ratios (EGRs) of tomato farmers of the stochastic production metafrontier were estimated to be above 80%. However, farmers in FTSZ achieved the highest mean MFTEs and EGRs, followed by CSZ and GSZ. Similarly, farmers in FTSZ achieved the highest mean technical efficiency, compared to farmers in CSZ and GSZ.

Tomato farmers in Ghana produced below the group frontier due to limited and inefficient utilization of the available technologies. There were also technical inefficiencies in tomato production, especially in GSZ and CSZ compared to FSTZ whose farmers were the most technically efficient.

The policy implication of the study is that government should also help ease farmers' access to production inputs such as tractor, fertilizer, pesticides, and seed so as to increase tomato production in Ghana Also, the private sector, including financial institutions, value chains, and NGOs as well as the government through MoFA should invest in FBOs, and also assist tomato farmers to access extension services and education to help eliminate technical inefficiencies in tomato production

Conflict of Interest: Competing Interests Disclaimer

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge.

REFERNCES

ABDULAI, A. & HUFFMAN, W. (2000). Structure Adjustment and Economic Efficiency of Rice Farmers in Northern Ghana. *Economic Development and Cultural Change,* 503-519.

ABDULAI, S. NKEGBE, K. P. & DONKOH, A. S. (2013). Technical efficiency of maize production in Northern Ghana. *African Journal of Agricultural Research*, 8(43), 5251-5259. DOI: 10.5897/AJAR2013.7753

AHMED, H., & ANANG, B. T. (2019). Impact of improved variety adoption on farm income in Tolon district of Ghana. *Agricultural Socio-Economics Journal*, *19*(2), 105-115.

AIDOO, R., DANFOKU, R. A. & MENSAH, J. O. (2014). Determinants of postharvest losses in tomato production in the Offinso North district of Ghana. *Journal of development and agricultural economics*, 6(8), 338-344.

AIDOO-MENSAH, D. (2018). Determinants of income patterns of tomato farmers in Ghana. *Review of Agricultural and Applied Economics (RAAE)*, *21*(1340-2018-5181), 58-70.

AIGNER, D. J., LOVELL, C. A. K. & SCHMIDT, P. (1977). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics*, 6, 21-37.

AKHILOMEN, L. O., BIVAN, G. M., RAHMAN, S. A. & SANNI, S. A. (2015). Economic efficiency analysis of pineapple production in Edo State, Nigeria: a stochastic frontier production approach. *Journal of Experimental Agriculture International*, 267-280.

AL-HASSAN, S. (2004). *Farm-Specific Technical Efficiency, Resource Use and Employment: An Analysis of Smallholder Rice Farmers in the Upper East Region of Ghana [Doctoral Thesis]*. University of Ghana, Legon.

AMIKUZUNO, J., & IHLE, R. (2010). *Seasonal asymmetric price transmission in Ghanaian tomato markets: Adapting Johansen's estimation method* (No. 308-2016-5005).

ANANG, B. T., BÄCKMAN, S. & SIPILÄINEN, T. (2016). Technical efficiency and its determinants in smallholder rice production in northern Ghana. *The Journal of Developing Areas*, 50(2), 311-328.

ARAVINDAKSHAN, S., ROSSI, F., AMJATH-BABU, T. S., VEETTIL, P. C. & KRUPNIK, T. J. (2018). Application of a bias-corrected metafrontier approach and an endogenous switching regression to analyze the technical efficiency of conservation tillage for wheat in South Asia. *Journal of Productivity Analysis*, 49(2-3), 153-171.

ASRAVOR, J., WIREDU, A. N., SIDDIG, K., & ONUMAH, E. E. (2019). Evaluating the environmental-technology gaps of rice farms in distinct agro-ecological zones of Ghana. *Sustainability*, *11*(7), 2072.

ATKINSON, S. E., & CORNWELL, C. (1994). Parametric estimation of technical and allocative inefficiency with panel data. *International Economic Review*, 231-243.

ATTOH, C., MARTEY, E., KWADZO, G. T. M., ETWIRE, P. M., & WIREDU, A. N. (2014). Can farmers receive their expected seasonal tomato price in Ghana? A probit regression analysis.

AYANDIJI, A., ADENIYI, O. D., & OMIDIJI, D. (2011). Determinant post harvest losses among tomato farmers in Imeko-Afon local government area of Ogun State, Nigeria. *Global Journal of Science Frontier Research*, *11*(5), 23-27.

BARNES, A. P., REVOREDO-GIHA, C., & SAUER, J. (2011). *A metafrontier approach to measuring technical efficiencies across the UK dairy sector* (No. 705-2016-48310).

BATTESE, G. E. & COELLI T. J. (1995). A model for Technical Efficiency Effects in a Stochastic Frontier Production Function for Panel Data. *Empirical Economics*, 20, 325-332.

BELOTTI, F., DAIDONE, S., ILARDI, G. & ATELLA, V. (2013). Stochastic frontier analysis using Stata. *The Stata Journal*, 13(4), 719-758.

BETTY, S. (2005). The Growing Evidence for Demonic Possession: What Should Psychiatry's Response be?. *Journal of religion and health*, *44*(1), 13-30.

BURTON-FREEMAN, B., & REIMERS, K. (2011). Tomato consumption and health: emerging benefits. *American Journal of Lifestyle Medicine*, *5*(2), 182-191.

CLOTTEY, V. A., KARBO, N., & GYASI, K. O. (2009). The tomato industry in northern Ghana: Production constraints and strategies to improve competitiveness. *African Journal of Food, Agriculture, Nutrition and Development*, *9*(6).

DASMANI, I., DARFOR, K. N., & KARAKARA, A. A. W. (2020). Farmers' choice of adaptation strategies towards weather variability: Empirical evidence from the three agro-ecological zones in Ghana. *Cogent Social Sciences*, *6*(1), 1751531.

DESSALE, M. (2019). Analysis of technical efficiency of small holder wheat-growing farmers of Jamma district, Ethiopia. *Agriculture & Food Security*, *8*(1), 1-8.

DONKOH, S. A., AYAMBILA, S. & ABDULAI, S. (2013). Technical efficiency of rice production at the Tono irrigation scheme in northern Ghana. *American Journal of Experimental Agriculture*, *3*(1), 25-42.

DONKOH, S. A., TACHEGA, M. & AMOWINE, N. (2013b). Estimating technical efficiency of Tomato Production in Northern Ghana. *American Journal of Experimental Agriculture*, 3(1), 56-75.

FARAYOLA, C. O., AKINTARO, O. S., YAHAYA, A. A. & ONI, O. O. (2013). Determinants of Marketing Efficiency among Small-Holder Cocoa Marketers in Oyo State, Nigeria. *Int. J. mgt. soci. Resc*, *2*(11), 38-43.

FARRELL, M. (1957). The measurement of productivity efficiency. *Journal of Royal Statistical Society*, 120, 253-290.

GHANA STATISTICAL SERVICE. (2010). *2010 Population and housing census: Summary report of final results*. Accra: Ghana Statistical Service.

HORNA, J. D., SMALE, M., & VON OPPEN, M. (2007). Farmer willingness to pay for seed-related information: rice varieties in Nigeria and Benin. *Environment and Development Economics*, *12*(6), 799-825.

HUANG, N. E. (2014). *Hilbert-Huang transform and its applications* (Vol. 16). World Scientific.

INNES, M. (2014). Signal crimes. *Social Reactions to Crime, Disorder, and Control*.

KIDANE, A., & NGEH, E. T. (2015). A comparative analysis of technical efficiency of smallholder tobacco and maize farmers in Tabora, Tanzania. *Journal of development and agricultural economics*, *7*(2), 72.

KUMAR, S., & GULATI, R. (2010). Measuring efficiency, effectiveness and performance of Indian public sector banks. *International Journal of Productivity and Performance Management*.

KUMBHAKAR, S. C. (1994). Efficiency estimation in a profit maximising model using flexible production function. *Agricultural Economics*, *10*(2), 143-152.

MABE, F. N., DONKOH, S. A. & AL-HASSAN, S. (2018). Accounting for rice productivity heterogeneity in Ghana: The two-step stochastic metafrontier approach.

MELOMEY, L. D., AYENAN, M. A., MARECHERA, G., ABU, P., DANQUAH, A., TARUS, D., & DANQUAH, E. Y. (2022). Pre-and Post-Harvest Practices and Varietal Preferences of Tomato in Ghana. *Sustainability*, *14*(3), 1436.

MENSAH, A. & BRÜMMER, B. (2016). Drivers of technical efficiency and technology gaps in Ghana's mango production sector: A stochastic metafrontier approach. *African Journal of Agricultural and Resource Economics*, 11(2), 101-117.

MINISTRY OF FOOD AND AGRICULTURE (MoFA), Agriculture in Ghana: Facts and Figures Statistics, Research and Information Directorate (SRID), Ministry of Food and Agriculture, Ghana, 2010.

MINOT, N., & NGIGI, M. (2004). *Are horticultural exports a replicable success story? Evidence from Kenya and Côte d'Ivoire. EPTD*. MTID discussion paper, IFPRI, Washington, DC.

MOHIUDDIN, M., UDDIN, M. S., RASHID, M. H., HOSSAIN, K. M. F., & MATIN, M. A. (2007). Adoption and profitability of improved tomato variety in the Chittagong Region of Bangladesh. *Journal of Soil and Nature*, *1*(3), 52-58.

NAIKA, S., DE JEUDE, J. V. L., DE GOFFAU, M., HILMI, M., & VAN DAM, B. (2005). Cultivation of tomato. *Production, processing and marketing, Agromisa/CTA. Revised edition*.

NARALA, A., & ZALA, Y. C. (2010). Technical efficiency of rice farms under irrigated conditions in Central Gujarat. *Agricultural Economics Research Review*, *23*(347-2016-16935), 375-382.

NGANGO, J., LEE, J., & KIM, S. G. (2019). Determinants of technical efficiency among small-scale coffee farmers in Rwanda.

NKEGBE, P. K. (2012). Technical efficiency in crop production and environmental resource management practices in northern Ghana. *Environmental Economics*, 3(4), 43-51.

OGUNNIYI, L. T., & OLADEJO, J. A. (2011). Technical efficiency of tomato production in Oyo State Nigeria. *Agricultural Science Research Journal*, 1(4), 84-91.

ONUMAH, E. E., OPPONG, B. A. & ASUMING-BEMPONG, S. (2014). *Stochastic Frontier Modeling of Maize Production in Brong Ahafo Region of Ghana*: AGRIS On-line Papers in Economics and Informatics, 6(2), 67-75

OWUSU, S. B., KWOSEH, C. K., STARR, J. L., & DAVIES, F. T. (2016). Grafting for management of root-knot nematodes, Meloidogyne incognita, in tomato (Solanum lycopersicum L.). *Nematropica*, *46*(1), 14-21.

ROBINSON, E. J. Z. & KOLAVALLI, S. L. (2010). *The Case of Tomato in Ghana: Processing*. Working Paper #21. Accra, Ghana: International Food Program.

SINGH, R., UPADHYAY, A. K., CHANDRA, P., & SINGH, D. P. (2018). Sodium chloride incites reactive oxygen species in green algae Chlorococcum humicola and Chlorella vulgaris: implication on lipid synthesis, mineral nutrients and antioxidant system. *Bioresource technology*, *270*, 489-497.

SYVERSON, C. (2011). What determines productivity?. *Journal of Economic literature*, *49*(2), 326-65.

URI, N. D. (2001). Technical efficiency, allocative efficiency, and the implementation of a price cap plan in telecommunications in the United States. *Journal of Applied Economics*, *4*(1), 163-186.

VILLANO, R., MEHRABI, B. H. & FLEMING, E. (2010). When is metafrontier analysis appropriate? An example of varietal differences in pistachio production in Iran. *J. Agr. Sci. Tech., 12* (1), 379-389.

VON CRAMON-TAUBADEL, S., & SALDIAS, R. (2014). Access to credit and determinants of technical inefficiency of specialized smallholder farmers in Chile. *Chilean journal of agricultural research, 74*(4), 413-420.

WONGNAA, C. A., & AWUNYO-VITOR, D. (2019). Scale efficiency of maize farmers in four agro ecological zones of Ghana: A parametric approach. *Journal of the Saudi Society of Agricultural Sciences*, *18*(3), 275-287.