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Abstract

Agriculture in Ethiopia is characterized by low productivity for most crops including teff which is gaining prominence as both a food and income crop. The low productivity is mostly attributed to inefficiencies. To solve this, improving efficiency of the farmer has received the greatest attention as it is more cost effective than introducing new technologies. This study was undertaken in southwest Ethiopia to assess productivity and technical, allocative and economic efficiencies of teff farmers and identifies factors that determine productivity and inefficiencies. Cross sectional data from a random sample of 323 teff producing farmers collected during 2018/19 production season were used for the analysis. A Cobb-Douglas production function was employed to assess teff productivity and factors conditioning productivity. In addition, stochastic production frontier model was used to estimate technical, allocative and economic efficiency level where as OLS regression was used to identify factors affecting inefficiencies level. The result depicted that productivity of teff was significantly influenced by the use of seed, fertilizer, and labor. The estimated mean values of technical, allocative and economic efficiencies were 69, 60 and 56% respectively, which indicate the presence of inefficiency in teff production in the study area. The OLS model results revealed that education levels, age, soil fertility and frequency of extension contact had a significant negative effect on technical inefficiency. Similarly, education levels, participation in off/non-farm activities, soil fertility and frequency of extension were found to have negative effect on allocative inefficiency while education levels, participation in off/non-farm activities and soil fertility had negative influence on economic inefficiency. Hence, policies and strategies of the government should be directed towards the above mentioned determinants.

Keywords: Stochastic frontier analysis; Cobb-Douglas; Efficiency; Teff; Ethiopia.

1 Background

In developing countries like Ethiopia, smallholder agriculture dominates a large proportion of the population and poor reside in rural areas. The agricultural sector is the most important sector in the Ethiopian economy that features strongly in the overarching economic policy of the country-agricultural development led industrialization (ADLI). It serves as source of income and employment for the majority of the country's population. Currently, agriculture is contributes over 35.8 percent to the national GDP, almost 90 percent of export and 72.7 percent of employment (CIA, 2018). However, the production, productivity and efficiency status of the sector is well below world average. Mostly the farmers with the same resources are producing different per hectare output, because of management inefficiency inputs, limited use of modern agricultural technologies, obsolete farming techniques, poor complementary services such as extension, credit, marketing, and infrastructure; poor and biased agricultural policies in developing countries like as Ethiopia (FAO and WFP, 2012; ATA, 2016).

Cereals are the major food crops both in terms of the area coverage and volume of production and accounts for 95 percent of agricultural production in Ethiopia and contributed 87.48 percent of the grain production (CSA, 2018). Of them, teff (Eragrostis tef) is a warm-season annual cereal crop that belongs to the grass family Poaceae is endemic to Ethiopia and has been widely cultivated for centuries (Teklu and Tefera, 2005). It is the most important economic crop cultivated by 43 percent of small holder farmers in Ethiopia, covering around 32 percent of the total annual acreage and 21 percent of the total grain production (Birrara, 2017). In addition, teff is the second most important cash crop next to coffee, which generates about 500 million USD per year for local farmers in Ethiopia (Minten et.al. 2013). Nutritionally, 100 gram of teff grains has 357 kcal, similar to that of wheat and rice (Cheng et.al. 2017). As the crop has high protein and amino-acid content and gluten-free and low on the glycemic index, which makes them suitable for people with type 2 diabetes, the recognition of teff has spurred global research interest by nutritionists and food scientists (FAO, 2015).

In Ethiopia, the main teff producing areas have been concentrated in the northwestern and central highlands of Ethiopia. Oromia region is the most important teff producing area in the country; and its share in total national production is estimated to be as high as 48 percent (Ibrahim et.al, 2018). According to the report of Central Statistical Agency, for the crop year of

2018/2019, from the total land allocated for cereal crops in Oromia region, teff stands in first by covering 29.46 percent of the total areas. In the production year, the total area covered by teff was 1.43 million hectares with a production of 2.56 million tonne and yield of 1.79 t/ha from 2.57 million holders (CSA, 2019). The total production of teff in Jimma zone for the year 2016/17 was 0.26 million tonnes produced by 0.55 million private peasant holders who were engaged in wheat cultivation on 0.18 million hectare. The average productivity was registered as 1.51 t/ha (CSA, 2017).

Cereal crops sector in general and the teff producing in particular face serious challenges in Ethiopia. The most common challenges are lack of, efficiency production system; climatic factors, improved varieties, production inputs, improved management practices, soil fertility management as well as weed and pest management (Mihiretu & Abebaw; Fikadu et.al. 2019). Despite the aforementioned importance and area coverage, teff productivity is much less at national, regional and local levels due to factors like lack of high yielding cultivars, poor management practices and low input utilization (FAO, 2016). Moreover, the erratic and uneven distribution of rainfall is becoming a threat to produce late maturing local teff varieties due to frequent moisture stress at flowering and grain filling stages thus leading to either lower yield or total crop failure (Setotaw, 2011). Study by Crymes (2015) shows 25-30 percent of teff would be lost before and after harvest, and lodging may contribute to the yield loss up to 30 percent. The high losses along the production processes can reduce the available quantity of teff by up to 50 percent. The average productivity of teff in Ethiopia is 1.75 t/ha at smallholder farmer level which is very low (CSA, 2019). However, through research and applying improved agricultural technologies, teff yield can be raised to 5 t/ha (Wassie, 2014).

To improve efficiency of smallholder farmers, the existing levels of resource allocation must be known. According to previous researches in Ethiopia, there also exists a wide teff yield gap among the farmers that might be attributed to many factors such as suboptimal genetic gain, low access to seeds of improved varieties, poor agronomic practices and lodging (Bekele et al., 2019; Abraha et al., 2017). Though there have been various empirical studies conducted to measure efficiency of agricultural production in Ethiopia, (for example, Dessale, 2019; Wassihun et al. 2019; Ayele et.al, 2019; Gela et.al, 2019; and Tenaye, 2020), to the best of the author's knowledge, there were no similar studies undertaken on productivity and efficiency of teff producing household in the study area. Moreover, since social development is dynamic, it is imperative to update the information based on the current productivity and efficiency levels of farmers.

For most developing countries, enhancing the total production and productivity is not an option rather it is a necessity and the first concern in their policies. Theoretically; there are two possible alternatives to increase total production and productivity. The first method is through increased use of inputs and/or improvement in technology at certain level of input. The other option is to develop the efficiency of producers or farmers. The measurement of efficiency has remained an area of important research, especially in developing countries, where resources are scanty and opportunities for developing by inventing or adopting better technologies are dwindling (Wassie, 2014). Though there is the high potential in teff production in the study area, how much to produce and what are the efficiency levels of producers were hardly studied. Based on the above statement, the study was intended to empirically answer the following three key research questions: (1) What is the productivity level of teff production? (1) Are the producers efficient in teff production? (2) What factors influence the inefficiency levels of teff producers in the study area? Therefore, the present study was designed to determine the productivity of teff production and assess the technical, allocative and economic efficiency of teff producer farmers and identify its determinant factors in southwest, Ethiopia.

2 Research methodology

2.1 Description of the study area

The study was conducted in Jimma zone of southwest of Ethiopia which is located 335 km far from Addis Ababa. According to the Central Statistical Agency (CSA, 2007) census report, the zone has a total population of 2,495,795 of whom 1,255,130 are men and 1,240,665 women. Jimma zone lies between latitudes 7°15´ N and 8°45´ S, and longitudes 36° 00´ E and 37°40´ E. The zone generally lies with the altitude ranges between 900 and 3334 m above sea level and is characterized by a tropical highland climate with heavy rainfall, warm temperatures and a long wet period. The mean annual rainfall ranges between 1,200 mm and 2,500 mm. Jimma zone bordered with east Wollega zone in the north, with east Shewa zone and southwest Shewa zone in the northeast, with SNNPR administration in the southeast and south part, and with Illubabor zone in the west (Debebe et.al, 2015). Farming system of the zone is mixed crop-livestock farming. The study area is one of the major cereal crops growing areas of Ethiopia. Teff is the most important crop grown in terms of area coverage and the volume of production in the zone.

2.2 Data types, sources and methods of data collection

Both primary and secondary data sets were used for this study. The primary data was collected from farmers through an interview with the help of pre-tested structured questionnaire 2018/2019 cropping season. The questionnaire used was designed to contain questions on socioeconomic variables, on quantities of inputs and outputs and their respective prices, and on factors that can influence farm efficiency teff producers. The comprehensive data were collected from March 2020 to May 2020 through trained enumerators who were capable of speaking the Afaan Oromo as well as English and supervisors using structured questionnaire. The data cleaning process involved conducting preliminary descriptive analysis to identify irregularities and inconsistencies in data entry, which were correcting by crosschecking on the questionnaires. Secondary data was collected from published and unpublished sources to support the primary data. Informal methods such as focus group discussion and key informants interviews were made with farmers, development agents, concerned agricultural professionals and administration offices at all levels by the researchers were also used to compliment the formal method.

2.3 Sampling technique and sample size determination

In order to select sample households, multi-stage sampling techniques were employed. In the first stage, the Jimma zone was purposively selected based on the extent of teff production. In the second stage, teff producing districts in the zone were identified based on the extent of teff production and three teff producing districts namely Omo Nada, Seka Chekorsa and Kersa were selected randomly. Thirdly, the lists of teff producer farmers in the production year 2018/19 in the selected *kebeles*[1] were identified in collaboration with districts' agricultural and development office experts. Finally, totally of 323 sample farmers were selected from the three districts by using simple random sampling technique. The sample size for the study was determined based on the following formula given by Cochran (1977).

$$n = \frac{Z^2pq}{e^2} \tag{1}$$

where n is the sample size; Z is the confidence level (Z = 1.96); p is the proportion of population containing major interest (p = 0.7 and q = 1 − p) and e is allowable error (e = 0.05).

2.4 Methods of data analysis and specification of analytical models

Various data analysis methods such as descriptive statistics and econometric model were used to analyze the data. Descriptive statistics such as means, frequencies, and percentages were used to examine the socio-economic, institutional and demographic characteristics of sampled teff producers.

2.4.1 Analytical framework

The economic theory of production has provided the analytical framework for most empirical research on productivity and efficiency measurement. The cornerstone of the theory is the production function, which postulates a well-defined relationship between output and factor inputs. Productivity can be achieved from two sources; first, through technological change of using improved practices of production such as ploughs, fertilizers, pesticides, improved seeds, etc which pushes the production frontier upward; and second, if the farmer has got further skills in using the existing techniques of production, productivity will increase (Ayele et al. 2006).
The microeconomic theory of production provides the theoretical framework for most empirical research on efficiency (Tabe-Ojong and Molua, 2017) and simply defines production as the transformation of inputs to outputs. Productivity on the other hand is just an index of the value of output to that of inputs employed in agricultural production.

Generally, a production function is defined by the following equation

$$Y = f(x_1,\ x_2\ , x_3 \ldots \ldots ., x_n) \tag{2}$$

where Y is output and x_i, i=1, 2…, n are the levels of inputs that determine the level of output.

But in reality and practice there other unobservable variable inputs which determine the level of output in the production process. These inputs are known as random effects and are represented by v_i. Adding the term v_i to equation (2) modifies it to probabilistic expression (Palanisami *et al.,* 2002):

$$Y = f(x_1,\ x_2\ , x_3 \ldots \ldots ., x_n) + v_i \tag{3}$$

Moreover, farmers may be inefficient in production which reduces the potential output of the farm in addition to random shocks (v_i). The stochastic production frontier analysis assumes that this inefficiency is specified as follows:

$$Y = f(x_1, x_2, x_3 \ldots \ldots, x_n) + v_i - \mu_i \tag{4}$$

where μ_i the non-negative random inefficiency variables

2.4.2 Specification of econometric model

The paper of Farrell (1957) led to the development of numerous approaches in analyzing productivity and efficiency (Abdul-Salam and Phimister, 2015). The two common methods used in literature are the Stochastic Frontier Analysis (SFA) and the Data Envelope Analysis (DEA). According to Toma et al. (2017), both methods achieve highly correlated results. The stochastic frontier approach was proposed by Aigner, Lovell, and Schmidt (1977) and Meeusen and van den Broeck (1977), later modified by Jandrow, Lovell, Materov, and Schmidt (1982). The potential for the misspecification of functional form resulting in biased estimates of inefficiency is considered to be a weakness of the stochastic frontier approach relative to nonparametric approaches such as DEA. The DEA technique first introduced by Farell (1957) and further developed by Charnes et al. (1978) employs a nonparametric approach to estimate efficiency. However, the main criticism of this technique as underscored in the literature is that it ignores the effect of stochastic error and ascribes all deviation from the frontier to inefficiency (Kopp and Smith 1980; Thiam et al. 2001; Murillo-Zamorano 2004). Moreover, the non-inclusion of a disturbance term makes it difficult to perform statistical tests.

Agricultural production (typically rain-fed) is usually pruned to shocks like weather and climate risks, the incidence of pests and diseases, and other downside risk measures. Furthermore, because many farmers are smallholders whose farm operations are managed by family members, therefore keeping of accurate records is not always a priority. Thus much data available on production are likely to be subject to measurement errors (Coelli and Battese, 1996). Ignoring this and attributing all to inefficiency is a strong assumption with a possibility of biasing our analysis. Thus, present study adopts the SFA in estimating the efficiency of teff farmers in southwest Ethiopia since it differentiates deviation from the frontier into the two components of inefficiency and the idiosyncratic error. The general stochastic frontier model in which an additional random error, vi, is added to the non-negative random variable, μ_i, is specified as follows:

$$ln(y) = x_i\beta + v_i - \mu_i\,, \qquad i = 1, 2, \ldots N \tag{5}$$

Several functional forms have been developed to measure the physical relationship between input and output. The most common functional forms are Cobb–Douglas and transcendental logarithmic (translog) function, each having their merits and demerits. Both models overwhelmingly dominate the applications literature in stochastic frontier and econometric inefficiency estimation (Coeil et al., 2005). For this study Cobb-Douglas functional form was selected using log likelihood test (see Equation 11).

2.4.3 Estimation approach

Two estimation approaches are conventionally used to estimate the inefficiency effects of farmers: the two stage estimation procedure and the one stage estimation technique. In one-stage estimation, inefficiency effects are defined as an explicit function of certain factors specific to the firm, and all the parameters are estimated in one-step using the maximum likelihood procedure. The second approach is the two-stage estimation procedure in which first the stochastic production function is estimated, from which efficiency scores are derived, then in the second stage the derived efficiency scores are regressed on explanatory variables using ordinary least square (OLS) method or Tobit regression. Tobit model is best suited for such analysis because of the nature of the dependent variable (efficiency scores), which takes values between 0 and 1 and yield the consistent estimates for unknown parameter vector (Maddala, 1999). However, unfortunately there were no 0 and 1 efficiency scores in the model output. Therefore for this study, the estimation takes the form of two stage estimation wherein the production function is estimated separately and the inefficiency effects is analyzed using OLS estimation method.

The farm-specific technical efficiency (TE) is defined in terms of observed output (Y_i) to the corresponding frontier output (Y_i) using the available technology is obtained as:

$$\mathrm{TE}_i = \frac{Y_i}{Y_i^*} = \frac{Actual\ yield}{Potential\ yield} = \frac{\exp(x_i\beta - \mu_i)}{exp(x_i\beta)} = \exp(-\mu i) \tag{6}$$

Technical efficiency takes value on interval (0, 1), where 1 indicates a fully efficient farm. In this study, the yield gap (YG_i) of i^{th} producer in teff production is the difference between potential yield (PYi) and actual yield (AYi) and estimated in Equation (7) as follows:

$$\mathrm{YG}_i = \mathrm{PG}_i - \mathrm{AY}_i \tag{7}$$

The farm specific economic efficiency (EE) is defined as the ratio of minimum observed total production cost (C*) to actual total production cost (C) is calculated as:

$$\mathrm{EE}_i = \frac{C_i}{C_i^{\ *}} \tag{8}$$

According to Farrell (1957), the allocative efficiency (AE) index can be derived from Equations (7) and (8) as follows:

$$\mathrm{AE}_i = \frac{\mathrm{EE}_i}{\mathrm{TE}_i} \tag{9}$$

Following the quantification of the technical, allocative, and economic efficiency measures, a second stage analysis involves a regression of these measures on several hypothesized socio-economic and institutional factors affecting inefficiency of farmers. The linear regression model has thus been a common approach to the analysis of the effects of farm-specific factors on productive inefficiency is specified as follow:

$$Ln\left(\frac{\mathrm{E}_i}{1-\mathrm{E}_i}\right) = u_i = \delta X_i + \varepsilon_i \tag{10}$$

where Ln denotes the natural logarithm (base, e); E_i or ui is the inefficiency of the i^{th} firm and is assumed to be a function of farm specific socio-economic and institutional factors; X_i is a vector of explanatory variables; δ is a vector of parameters to be estimated, and ε_i are identically and independently distributed random errors N(0, σ^2).

According to Green (2003), in SPF hypothesis tests can be made using ML ratio test that are not possible in non-parametric models. A number of tests were made in this study using the Likelihood Ratio (LR) test given by Equation (11).

$$LR = \lambda = -2\ ln\ [L(H0)\ /\ L(H1)] \tag{11}$$

where λ is the likelihood ratio (LR); $L(H_0)$ is the log likelihood value of the null-hypothesis; $L(H_1)$ is the log likelihood value of the alternative hypothesis; and ln is the natural logarithms.

The maximum likelihood estimates for the parameters of the stochastic frontier are obtained using the FRONTIER 4.1 (Coelli 1996) computer program and Stata 13 version, in which the variance parameters are expressed in terms of the parameterization as:

$$\sigma^2 = \delta_v^2 + \delta_u^2 \tag{12}$$

$$\gamma = \frac{\sigma_u^2}{(\sigma_v^2 + \sigma_u^2\ )} \tag{13}$$

where σ^2 is the total variance of the model and the term represents the ratio of the variance of inefficiency's error term to the total variance of the two error terms defined above. The value of variance parameter ranges between 0 and 1.

2.5 Empirical model specification

2.5.1 Stochastic production frontier model

The model of Cobb-Douglas production functional form used is specified as:

$$Ln(Output) = \beta_0 + \beta_1\, ln(Seed) + \beta_2\, ln(Fertilizer)\ + \beta_3\, ln(Area) \\ + \beta_4\, ln(Labor) + \beta_5 ln(Oxen)\ + v_i\ - ui \tag{14}$$

where output is the total output of teff produced in kg/ha, seed is the total quantity of teff seed used in kg/ha, fertilizer is the total amount of Nitrogen, Phosphorous and Sulphur (NPS) and/or urea in kg/ha, area is the total area covered by teff in hectares, labor is family and hired labor measured in man-days, oxen is the amount of draught power used in oxen day, β are unknown production function parameters, v_i is the disturbance error term, independently and identically distributed as $N(0, \sigma_v^2)$ intended to capture events beyond the control of farmers; and μ_i - is a non-negative random variable, independently and identically distributed as $N(\mu, \sigma_\mu^2)$ intended to capture technical inefficiency effects in the production of teff measured as the ratio of observed output to maximum feasible output of the i^{th} household.

2.5.2 Stochastic cost frontier model

The cost frontier model is formulated as:

$$Ln(Cost) = \alpha_0 + \alpha_1\, ln(Seed) + \alpha_2\, ln(Fertilizer) + \alpha_3\, ln(Area) + \alpha_4\, ln(Labor) + \alpha_5 ln(Oxen) + v_i - ui \quad (15)$$

where cost is the total cost inputs incurred to produce teff measured in Ethiopian currency Birr per hectare (ETB/ha), seed is the cost of teff seed measured in ETB/ha, fertilizer is the total cost of NPS and/or urea measured in ETB/ha, area is the rental value land measured in Birr, labor is total cost of labor and measured in ETB/ha, oxen is the cost of oxen power measured in ETB/ha, α are unknown cost function parameters and v_i, u_i are as defined earlier.

2.5.3 Determinants of inefficiency

Ordinary Least Squares (OLS) was used to determine the socioeconomic and institutional factors that influenced technical, economic, and allocative inefficiency of teff producers in the study area. The inefficiency function can be written as:

$$\mu_i = \delta_0 + \delta_1 Sex + \delta_2 Edu + \delta_3 Age + \delta_4 Fert + \delta_5 \text{offam} + \delta_6 Lives + \delta_7 Fams + \delta_8 Farm + \delta_9 Prox + \delta_{10} Credit + \delta_{11} Exten + \varepsilon_i \quad (16)$$

where the subscript i, indicates the i^{th} household in the sample; μ_i is the technical, economic and allocative inefficiency score; δ_i is a vector of parameter to be estimated; $\boldsymbol{\varepsilon_i}$ is error term. Sex is the sex of households which takes a value of 1 if the household head is male and zero, otherwise; Edu represents the education level of the household farmer measured in continuous years of formal schooling; Age represents the age of the household head in number of years; Fert represents the fertility status of the teff plot, which would take a value 1 if the land is perceived fertile and 0, otherwise; Offam is participation of sampled households in off/non-farm activities which takes a value of 1 if the household head is involved in off/non-farm activities and 0 otherwise; Lives is the total number of livestock in terms of Tropical Livestock Unit (TLU); Fams represents the number of household size; Farm represents the total land size operated by the farmer during the production year including his owned land, sharecropped lands and rented lands; Prox is the distance of the farm from the house of the household in walking minutes; Credit represents access to credit for teff production 1 if the household received credit, 0 otherwise; Exten represents frequency of extension contact, measured by the number of extension visits by extension agents in production season.

3 Results and discussion

3.1 Demographic and socioeconomic characteristics of households

The average age of farmers was 46.31 years implying that most of the household heads were within their productive age and education level of 2.95 years of schooling in average. Similarly, majority (about 95.3%) of the respondents were male headed. The average family size was 5.66, indicating large family size that coupled with small land size and backward production system create difficulty for the farmer to sustain their family. The result also revealed that 54.27 percent of sample households were participated in various off/non-farm activities and 61.56 percent of them got credit from formal and informal sources. In the study area, livestock has considerable role for household income and food security. On average, the livestock holding of the sampled farmers was 7.16 TLU. According to the descriptive result, the average land holding of the sample households in the study area was 1.72 hectare. A farmer on average has 1.89 plots with average distance between the plot under teff crop and the farmer's home were 13.67 minutes and the average frequency of extension contacts during the production season in relation with teff production was about 3.66 times. Regarding to farmers' perception on soil fertility the result of the survey showed that 55.91 percent of respondents perceived their teff farm is fertile (Table 1).

Table 1 Demographic and socioeconomic characteristics of the sample households

Continuous variables	Mean	St. Deviation
Age (years)	46.31	14.53
Education (years of schooling)	2.95	2.68
Farm size (ha)	1.72	0.68
Proximity (Minute)	13.67	4.97
Livestock (TLU)	7.16	2.64
Family size (number)	5.66	1.58
Extension (frequency)	5.8	22.66
Dummy variables	**Responses**	**Percentage**
Sex	Male(1)	95.3
	Female(0)	4.7
Fertility perception	Fertile(1)	55.91
	Otherwise(0)	44.09
Off/non-farm	Yes(1)	54.27
	No(0)	45.73
Credit	Used(1)	61.56
	Not used(0)	38.44

Source: Authors computation (2020)

As indicated below Table 2 the average teff yield was 1030 kg/ha. This implies that there is low level of yield and potential resource use inefficiency in the study areas. The average land allocated for teff was 0.79 ha with seed rate of 21.5 kg/ha in average. Regarding fertilizer type, the most commonly and intensively used chemical fertilizer for the production of teff crop are NPS and Urea. The survey results revealed that the sample farmers on average used 66.5 kg/ha of chemical fertilizer. On average, the sample farmers used 28.68 man days per hectare of human labor and 15.24 oxen days per hectare for teff production activities.

Table 2 Descriptive statistics of both inputs and output variables

Variable description	Mean	St. Deviation
Output (Kg/ha)	10.3	5.86
Seed (Kg/ha)	21.5	13.56
Fertilizer (Kg/ha)	66.5	29.90
Area(ha)	0.79	0.52
Human labor(MDs/ha)	28.68	11.82
Oxen(OXDs/ha)	15.24	8.29
Cost of production (ETB/ha)	5568.68	1678.4
Cost seed (ETB/ha)	976.5	898.67
Cost fertilizer (ETB/ha)	2118.45	1954.5
Cost of land (ETB)	2856.44	1958.44
Cost human labor (ETB/ha)	995.78	823.15
Cost oxen (ETB/ha)	850.45	775.21

Source: Authors computation (2020)

Similar to the production function, cost function are summarized and presented in Table 2. Among other inputs, cost of oxen took the smallest share and cost fertilizers took highest share, out of the total cost of teff production.

3.2 Estimation of production function and hypothesis tests

The stochastic production frontier was applied using the maximum likelihood estimation procedure using Frontier 4.1 computer program. Prior to model estimation, all the hypotheses (assumption of stochastic frontier) were tested using generalized likelihood ratio (LR) given in Equation 11. Accordingly, the following hypotheses were tested, namely to select the correct functional form for the given data set, for the existence of inefficiency and finally for variables that explain the difference in efficiency.

The test was carried out by estimating the stochastic frontier production function and conducting a likelihood ratio test assuming the null hypothesis of no technical inefficiency (Ho: $\gamma = 0$). The generalized likelihood ratio statistics, λ= 22.44, presented in Table 3 is found to be greater than the critical value of 6.63. Hence, we reject null hypothesis (Ho) at 1 percent level of significance showing that the average response function is not an adequate representation of the data. Consequently, the null hypothesis that teff farmers in the area are fully efficient is rejected.

Likewise, the LR statistical test was estimated for the selection of the appropriate functional form (Cobb–Douglas versus Translog production function). The test result show that the calculated value of $\lambda = 13.64$ is less than the critical value of 30.58, thus the null hypothesis is not rejected at 1 percent level of significance implying that Cobb-Douglas functional form best fit the data set. Similarly, the next hypothesis is that the null hypothesis that the explanatory variables associated with technical inefficiency effects model are all zero, (H_0: $U_i=\delta_0 = \delta_1 = \delta_2$ - - - $\delta_{11} = 0$). To test this hypothesis likewise, λ was calculated using the value of the log likelihood function under the stochastic frontier model (a model without explanatory variables of inefficiency effects, H_0) and the full frontier model (a model with variables that are presumed to determine inefficiency of each farmer, H_1). The calculated value of $\lambda = 61.64$ is greater than the critical value of 24.72, thus the null hypothesis that variables in the inefficiency effects model are simultaneously equal to zero is rejected at 1 percent level of significance. Hence, these variables explain the difference in inefficiency among farmers.

Table 3 Generalized likelihood ratio tests of hypothesis for the parameters of the SPF

Null hypothesis	DF	LH_o	LH_1	Calculated χ^2 (LR) value	Critical value (χ^2,0.01)	Decision
Ho: $\gamma = 0$	1	-3.07	45.16	22.44	6.63	Reject
Ho: $\beta_6 = \beta_7$ - - - = β_{20}=0	15	13.17	97.87	13.64	30.58	Not reject
H_0: $u_i = \delta_1 = \delta_2 = \ldots = \delta_{11} = 0$	11	-45.23	67.14	61.64	24.72	Reject

Source: Authors computation (2020)

The maximum likelihood (ML) estimates of the parameters of the SPF were obtained using the program FRONTIER version 4.1. The results of the MLE are shown in Table 4 shows that the estimated coefficient of seed was found to be negatively and significantly affect on teff productivity at 5 percent level of significance. This indicates that 1 percent increase in seed usage will reduce the teff yield by 0.11 percent. The main reason for this negative sign is that farmers use much higher seed rate than the recommended rate. Similarly, the application of chemical fertilizers (NPS and Urea) had highly significant and positive influence on teff productivity at one percent level of significance. This depicts that farmers who apply higher rates of chemical fertilizer receive higher teff yields. Therefore, increasing the current level of fertilizer use would significantly increase teff productivity. The use of human labor had a significant and positive effect on teff productivity at 1 percent level of significance. This suggests that increasing labor utilization in teff production in operations such as land preparation, planting, fertilizer application and weeding would significantly increase teff productivity because of the current underutilization of human labor.

The diagnostic statistics of inefficiency component reveals that sigma squared (σ^2) was statistically significant which indicates goodness of fit, and the correctness of the distributional form assumed for the composite error term. The estimated value of Gamma (γ) is 0.58 which indicates that 58 percent of total variation in teff output among sample farmers is due to technical inefficiency.

Table 4 Maximum-likelihood estimates of the Cobb-Douglas SPF model

Variables	Coefficient	Standard-error	t-ratio
Constant	2.59***	0.81	3.19
lnSeed	-0.11**	0.05	-2.20
lnFertilizer	0.22***	0.07	3.14
lnLabor	0.38***	0.09	4.22
lnOxen	0.23	0.19	1.21
lnArea	0.18	0.14	1.28
Sigma-squared (σ^2)	0.43***	0.09	4.77
Gamma (γ)	0.58**	0.25	2.32
Log likelihood Function	-48.67		

Source: Authors computation (2020); Note: ** and *** significant at 5% and 1% significance level, respectively.

The dual frontier cost function, derived analytically from the stochastic production frontier shown in Table 6, is as follows:

$$\begin{aligned} \mathrm{LnC_i} = 2.11 + 0.03\mathrm{lnw_{seed}} + 0.19\ln \mathrm{w_{fertilizer}} + 0.28\mathrm{lnw_{labor}} \\ + 0.11\mathrm{lnw_{oxen}} + 0.0.8\mathrm{lnw_{area}} + 0.79\mathrm{lnY_i^*} \end{aligned} \qquad (17)$$

where C_i is per-farm costs of producing teff; Y_i^* is total teff output adjusted for any statistical noise and scale effects and *w* stands for input costs.

3.3 Efficiency scores and their distribution

The results of efficiency analysis indicate that the mean values of technical, allocative and economic efficiencies of the sample households were about 69, 60 and 56 percent, respectively. This shows that sample households were relatively good in technical efficiencies than allocative and economic efficiencies. The mean level of technical efficiency further tells us that the level of teff yield of the sample respondents can be increased on average by about 31 percent if appropriate measures are taken to improve the level of efficiency of teff growing farmers. Similarly, the average allocative efficiency of the sample farmers was about 60 percent that shows that farmers are not allocatively efficient in producing teff and hence, a farmer with average level of allocative efficiency would enjoy a cost saving of about 40 percent to attain the level of the most efficient farmer. Likewise, the mean economic efficiency of the sample farmers was 56 percent implying that there was a significant level of inefficiency in the production process. This low average level of economic efficiency was the total effect of both technical and allocative inefficiencies. That is the producer with an average economic efficiency level could reduce current average cost of production by 44 percent to achieve the potential minimum cost level without reducing output levels.

The frequencies of occurrences of the predicted technical, allocative and economic efficiencies in range indicate that the highest number of household have technical, allocative and economic efficiencies score between 60 and 80 percent. There were also some households whose allocative and economic efficiencies score levels were less than 20 percent, but there was no technical efficiency score in this range. This also indicates the existence of substantial allocative and economic inefficiencies than technical inefficiency in the production of teff during the study period in the study area (Figure 1).

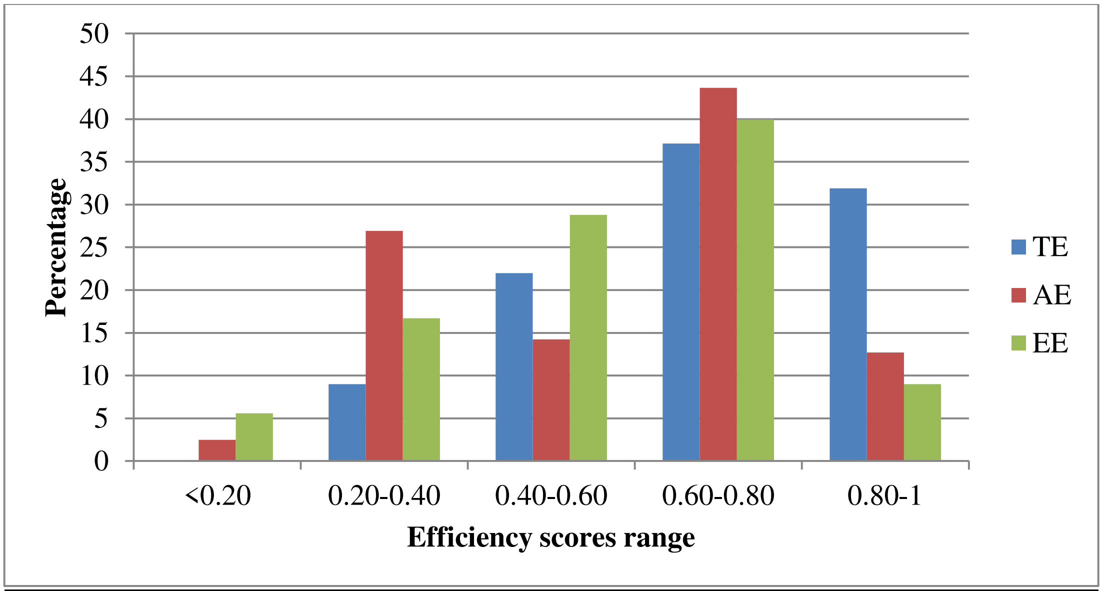

Figure 1 Frequency distribution of technical, allocative and economic efficiencies scores

3.4 Determinants of teff inefficiency

Assessing determinants of agricultural production efficiencies is more important than merely presenting a set of efficiencies indices for designing agricultural policy to improve smallholders' agricultural productivity and efficiencies and hence reduce resource waste and improve farmers' livelihoods (Tenaye, 2020). Table 5 illustrates the socio-economic, demographic, farm characteristics and institutional factors that affect inefficiency in teff production. The ordinary least squares (OLS) regression was used to identify factors that affect inefficiency levels among the sampled farmers.

Education status of household head that can be a proxy variable for managerial ability of the farmer, had a negative and significant effect on technical and economic inefficiencies at 1 percent and allocative inefficiency of teff production at 5 percent level of significance implying that less educated farmers are not technically, allocativelly and economically efficient than those that are relatively better educated. Hence, educated farmers more often have better access to agricultural information and higher tendency to adopt and utilize improved inputs (like fertilizers and crop varieties) more optimally and efficiently. This result is in line with the findings of (Asfaw et.al. 2019 and Ayele et al. 2019).

Age of household head (which is a proxy variable for farming experience) had statistically significant and negative relationship with technical inefficiency of teff production at 5 percent of level of significance. This suggested that older farmers were more efficient than their young counterparts. The reason for this was probably because the farmers become more skill full as they grow older due to cumulative farming experiences. The result is in conformity with the results of (Wassihun et.al. 2019; Dessie et al. 2019; Abate et.al. 2019).

In Table 5 the model result also indicated that soil fertility was negatively and significantly affected technical, allocative and economic inefficiencies at 1 percent level of significance. This implies that farmers who have allocated fertile land for teff production were more technically, allocativelly and economically efficient than their counterparts. This may be associated with those fertile lands require less commercial fertilizer application which leads to reduction in cost and leads to reduction in the inefficiency of farmers. This result is similar with the studies by (Mamo et al. 2017 and Asfaw et al. 2019).

Frequency of extension contact had statistically significant and negative relationship with technical and allocative inefficiencies of teff production at 1 and 5 percent level of significance, implying that farmers who contact more with the development agent have lower inefficiency. Extension services are assumed to help in dissemination and adoption of new technologies. In addition, this extension services offer guidance to the farmers related to the use of various resources such as fertilizer and provide consultancy services in managing their scarce resources more efficiently. This result is also consistent with research done by (Edosa et al. 2019; Ayele et.al. 2019) and in contradiction with the study by (Abate et al. 2019).

In this study the coefficient of participation in off/non-farm activities has negative sign and statistically significant at 10 and 1 percent level of significance effect with respect to allocative and economic inefficiencies, respectively. The reason is the income obtained from such activities could be used for the purchase of agricultural inputs and supplement financing of household expenditures which they cannot provide from the farm income hence increases their efficiency. Therefore, it enables farmers in maximizing their output at efficient cost of production. This finding is consistent with the results reported by several authors in the literature, such as (
Kifle et.al (2017) and Tenaye (2020).

Table 5 OLS regression results for determinants of inefficiency of teff producers

Variables	TE		AE		EE	
	Coefficient	SE	Coefficient	SE	Coefficient	SE
Constant	1.07***	0.15	0.83**	0.42	2.44***	0.38
Sex	-0.06	0.04	-0.07	0.11	-0.07	0.02
Education	-0.80***	0.12	-0.35**	0.17	-0.07***	0.01
Age	-0.45**	0.20	-0.07	0.04	-0.05	0.03
Off/non-farm	-0.18	0.5	-0.13*	0.07	-0.09***	0.02
Livestock	-0.11	0.09	-0.09	0.12	-0.05	0.04
Family size	-0.14	0.72	-0.14	0.10	-0.14	0.09
Farm size	0.03	0.05	0.02	0.08	-0.04	0.03
Proximity	0.02	0.13	0.01	0.02	0.06	0.08
Fertility	-0.21***	0.02	-0.17***	0.06	-0.10***	0.02
Credit	-0.05	0.33	-0.15	0.12	-0.04	0.05
Extension contact	-0.17***	0.04	-0.09**	0.04	-0.09	0.06
R^2	87.23		92.72		83.17	
Adj. R^2	85.64		89.09		79.90	

Source: Model output (2020); Note: *, ** and *** significant at 10%, 5% and 1% significance level, respectively

4 Conclusion and policy suggestions

Agriculture continues to be the main engine driving the development of Ethiopian economies with increasing productivity and efficiency in production having the potential to alleviate poverty and increase food and nutrition security. However, farmers are discouraged to produce more because of inefficient agricultural systems and differences in efficiency of production. Thus it is possible raise productivity through improving efficiency by using existing resource base and available technology. The main objective of this study was to analysis productivity and efficiency of teff production in Jimma zone of Oromia region, southwest Ethiopia. Data was collected from 323 teff farmers through a structured questionnaire.

From the stochastic frontier analysis, results of this study confirmed that there is considerable room to enhance production and productivity of teff production by improving management practices using existing inputs and technologies. The estimated stochastic production frontier model indicated that seed, fertilizer and labor were significant and positive determinants of productivity level of teff in the study area. Hence, the increase in these inputs would increase productivity of teff. Similarly, OLS regression result indicated that technical inefficiency negatively and significantly affected by age of the household head, education, extension contact, and soil fertility. In addition, soil fertility, education, extension contacts and participation in off/non-farm activity negatively and significantly affected allocative inefficiency. Moreover, economic inefficiency negatively and significantly affected by education, participation in off/non-farm activity and soil fertility.

Therefore, providing formal and informal type of farmers' education by using the available human and infrastructural facilities like extension agents and farmers training centers. The local government should arrange field days, cross-visits, creating forum for experience sharing elder households and provision of short-term training programs so as to share the knowledge of elder households to young farmers. Development programs need to strengthen improved land management practices to improve and maintain the fertility of farm land to increase efficiency of farmers. Besides to this, future endeavors may need to look into mechanisms by which farmers can get access to better ways of farming through extension services and improve market information. There is also need for the government organizations to train farmers on off/non-farm entrepreneurship, so that they can earn profits from off/non-farm income generating activities through which they will acquire the needed farming capital thus helps to increase efficiency in teff production.

Abbreviations

AE: Allocative efficiency; CSA: Central statics agency; EE: Economic efficiency; FAO: Food and agriculture organization; GDP: Gross domestic product; Ha: Hectare; Kg: Kilogram; LH_0: Log likelihood ratio of null hypothesis; LH_1: Log likelihood ratio of alternative hypothesis; LR: Log likelihood ratio; NPS: Nitrogen, phosphorous and sulphur; SPF: Stochastic production function; TE: Technical efficiency; SNNP: Southern nations, nationalities and peoples; WFP: World food program

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Authors' contributions

The first author generated the idea and design of the study, performed the statistical analysis and write-up. All authors carried out the data collection and provided comments on the draft manuscript, read and approved the final manuscript.

Competing interests

The authors declare no competing interests.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The data that support the findings of this study can be obtained from the corresponding author on reasonable request.

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Notes

1. *Kebele* is the smallest administrative hierarchy in Ethiopia.

References

Abate TM, Dessie AB, Mekie TM (2019) Technical efficiency of smallholder farmers in red pepper production in North Gondar zone Amhara regional state, Ethiopia. *Journal of Economic Structures,* 8(1), 18

Abdul-Salam Y, Phimister E (2015) Efficiency effects of access to information on small scale agriculture: *Empirical Evidence from Uganda* (No. 357-2016-18284)

Abraha MT, Shimelis H, Laing M, Assefa K (2017) Achievements and gaps in teff productivity improvement practices in the marginal areas of Northern Ethiopia: implications for future research directions. *International Journal of Agricultural Sustainability*, 15(1), 42-53

Aigner, D.J, Lovell, A.K and Schmidt, P. 1977. Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics* 6:21-37.

Asfaw M, Geta E, Mitiku F (2019) Economic efficiency of smallholder farmers in wheat production: The case of Abuna Gindeberet district, Oromia National Regional State, Ethiopia. *Open Access Journal of Agriculture Research,* 1-12

ATA (Agricultural Transformation Agency) (2016) Transforming agriculture in Ethiopia. Annual report 2015/2016

Ayele A, Haji J, Tegegne B (2019). Technical efficiency of wheat production by smallholder farmers in Soro district of Hadiya zone, southern Ethiopia. *East African Journal of Sciences,* 13(2):113-120

Ayele G, Bekele M, Zekeria S (2006) Productivity and efficiency of agricultural extension package in Ethiopia. *Ethiopian Development Research Institute*

Bekele A, Chanyalew S, Damte T, Husien N, Genet Y, Assefa K, Tadele,Z (2019) Cost-benefit analysis of new tef (Eragrostis tef) varieties under lead farmers' production management in the Central Ethiopia. *Ethiopian journal of agricultural sciences*, 29(1), 109-123

Birrara E (2017) Teff production and marketing in Ethiopia. *A Journal of Radix International Educational and Research Consortium*, 6(4), 2250–3994

Charnes A, Cooper WW, Rhodes E (1978) Measuring the efficiency of decision making units. *European Journal of Operational Research*, 2: 429-444

Cheng A, Mayes S, Dalle G, Demissew S, Massawe F (2017) Diversifying crops for food and nutrition security - A case of teff. *Biol Rev Camb Philos Soc*, 92(1): 188-98

CIA (Central Intelligence Agency) (2018) The work of a nation, Ethiopian economy profile. CIA World Fact Book, January 20, 2018

Cochran, WG (1977) Sampling techniques, 3rd edn. Wiley, New York

Coelli TJ (1996) A guide to FRONTIER version 4.1: A computer program for stochastic frontier production and cost function estimation. *CEPA Working papers*, 7:1-33

Coelli TJ, Battese, GE (1996) Identification of factors which influence the technical inefficiency of Indian farmers. *Australian Journal of Agricultural Economics* 40(2):103-128

Coelli T, Rao D, O'Donnell C, Battese G (2005) An introduction to efficiency and productivity analysis 2nd edition. New York: Springer

Crymes AR (2015) The international footprint of teff: Resurgence of an ancient Ethiopian grain

CSA (Central Statistical Agency) (2007) Population and housing census of Ethiopia 2007: *Statistical Report*

CSA (2017) Agricultural sample survey 2016/2017 (2009 E.C).Volume I report on area and production of major crops (private peasant holdings, meher season), Addis Ababa

CSA (2018) Agricultural sample survey 2017/2018; Report on area and production of major crops, Vol. I, CSA, Addis Ababa

CSA (2019) Agricultural sample survey 2018/2019 (2011 E.C).Volume I report on area and production of major crops (private peasant holdings, meher season), Addis Ababa

Debebe ., Haji J, Goshu D, Edriss AK (2015) Technical, allocative, and economic efficiency among smallholder maize farmers in Southwestern Ethiopia: Parametric approach. *Journal of development and Agricultural Economics*, 7(8), 282-291

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

Edosa TT, Kebede T, Shumeta Z (2019) Analysis of Price efficiency of smallholder farmers in maize production in Gudeya Bila district, Oromia National Regional State, Ethiopia: *Stochastic, Dual Cost approach*

FAO and WFP (2012) Crop and food security assessment mission to Ethiopia. Special report of Food and Agriculture Organization and World Food Programme.

FAO (2015) Analysis of price incentives for teff in Ethiopia. *Technical notes series*, MAFAP, by Assefa B. Demeke M., Lanos B, Rome

Farrell MJ (1957) The measurement of productive efficiency, J. R. Stat. Soc. Ser. A 120 (3) (1957) 253

Farrell MJ (1957) The measurement of productive efficiency. *Journal of the Royal Statistical Society: Series A (General),* 120(3), 253-281

Fikadu A, Wedu TD, Derseh E (2019) Review on economics of teff in Ethiopia. *Open Access Biostatistics & Bioinformatics*, 2, 1-8

Food and Agriculture Organization (2016) Database of agricultural production. FAO Statistical Databases (FAOSTAT). http://faostat.fao.org/default.aspx

Gela Adugna, Jema Haji, Megistu Ketema, Hebtemariam Abate (2019). Technical, allocative and economic efficiencies of small-scale sesame farmers: The case of West Gondar Zone, Ethiopia. *Review of Agricultural and Applied Economics (RAAE),* 22: 10–17

Greene WH (2003) Econometric analysis fifth edition. *New Yersey: Prentice Hall*

Ibrahim WH, Mekdim DR, Guush B, Bart M, Alemayehu ST (2018) Teff and its role in the agricultural and food economy: The economics of teff: Exploring ethiopia's biggest cash crop. *International Food Policy Research Institute Washington*, DC. Chapter 2

Jandrow J Lovell AK, Materov I, Schmidt P (1982) On the estimation of inefficiency in the stochastic production function model. *Journal of Econometrics,* 19, 233-238

Kifle M, Gebremicael TG, Girmay A, Gebremedihin T (2017) Effect of surge flow and alternate irrigation on the irrigation efficiency and water productivity of onion in the semi-arid areas of North Ethiopia. *Agricultural water management*, 187, 69-76

Kopp R, Smith V (1980) Frontier production function estimates for steam electric generation. *Southern Economic Journal,* 47: 1049–1059

Maddala GS (1999) Limited dependent variable in econometrics. Cambridge University Press, New York

Mamo T, Getahun W, Chebil A, Tesfaye A, Debele T, Assefa S, Solomon T (2017) Technical efficiency and yield gap of smallholder wheat producers in Ethiopia: A stochastic frontier analysis. *African Journal of Agricultural Research*, 13(28):1407-1418

Meeusen W, Broeck JVD (1977) Efficiency estimation from Cobb–Douglas production functions with composed error. *International Economic Review* 18:435-444

Mihiretu A, Abebaw L (2020) Scale-wide evaluation and promotion of improved teff technologies under dryland scenario: Economic profitability, farmers' preference and constraints in Northeast Amhara, Ethiopia. *Cogent Food & Agriculture,* 6(1), 1746228

Minten B, Tamru S, Engida E, Kuma T (2013) Ethiopia's value chain on the move: the case of teff. *ESSP Working Paper series,* 52, 1-26

Murillo-Zamorano, LR (2004) Economic efficiency and frontier techniques. *Journal of Economic surveys,* 18(1), 33-77

Palanisami K, Paramasivam P, Ranganathan (2002) Agricultural production economics: Analytical method and application. New Delhi (Associated publishing company)

Setotaw F (2011) Technological change and economic viability in teff production. *Proceeding of the Second International Workshop* (pp 266–284), November 7-9, 2011. Debre Zeit, Ethiopia

Tabe-Ojong JMP, Molua EL (2017) Technical efficiency of smallholder tomato production in semi-urban farms in Cameroon: A stochastic frontier production approach. *J. Mgmt. & Sustainability*, 7, 27

Teklu Y, Tefera H (2005) Genetic improvement in grain yield potential and associated agronomic traits of teff (Eragrostis Tef). *Euphytica*, 141(3), 247–254

Tenaye A (2020) Technical efficiency of smallholder agriculture in developing countries: The case of Ethiopia. *Economies*, 8(2), 34

Thiam A, Bravo-Ureta BE, Rivas TE (2001) Technical efficiency in developing country agriculture: A meta-analysis. *Journal of Agricultural Economics*, 25: 235 – 243

Toma P, Miglietta PP, Zurlini G, Valente D, Petrosillo I (2017) A non-parametric bootstrap-data envelopment analysis approach for environmental policy planning and management of agricultural efficiency in EU countries. *Ecological Indicators*, 83, 132-143

Wassie SB (2014) Technical efficiency of major crops in Ethiopia: Stochastic frontier model (Master's thesis)

Wassihun AN, Koye TD, Koye AD (2019) Analysis of technical efficiency of potato (Solanum tuberosum L.) Production in Chilga District, Amhara national regional state, Ethiopia. *Journal of economic structures*, 8(1), 34

Figures

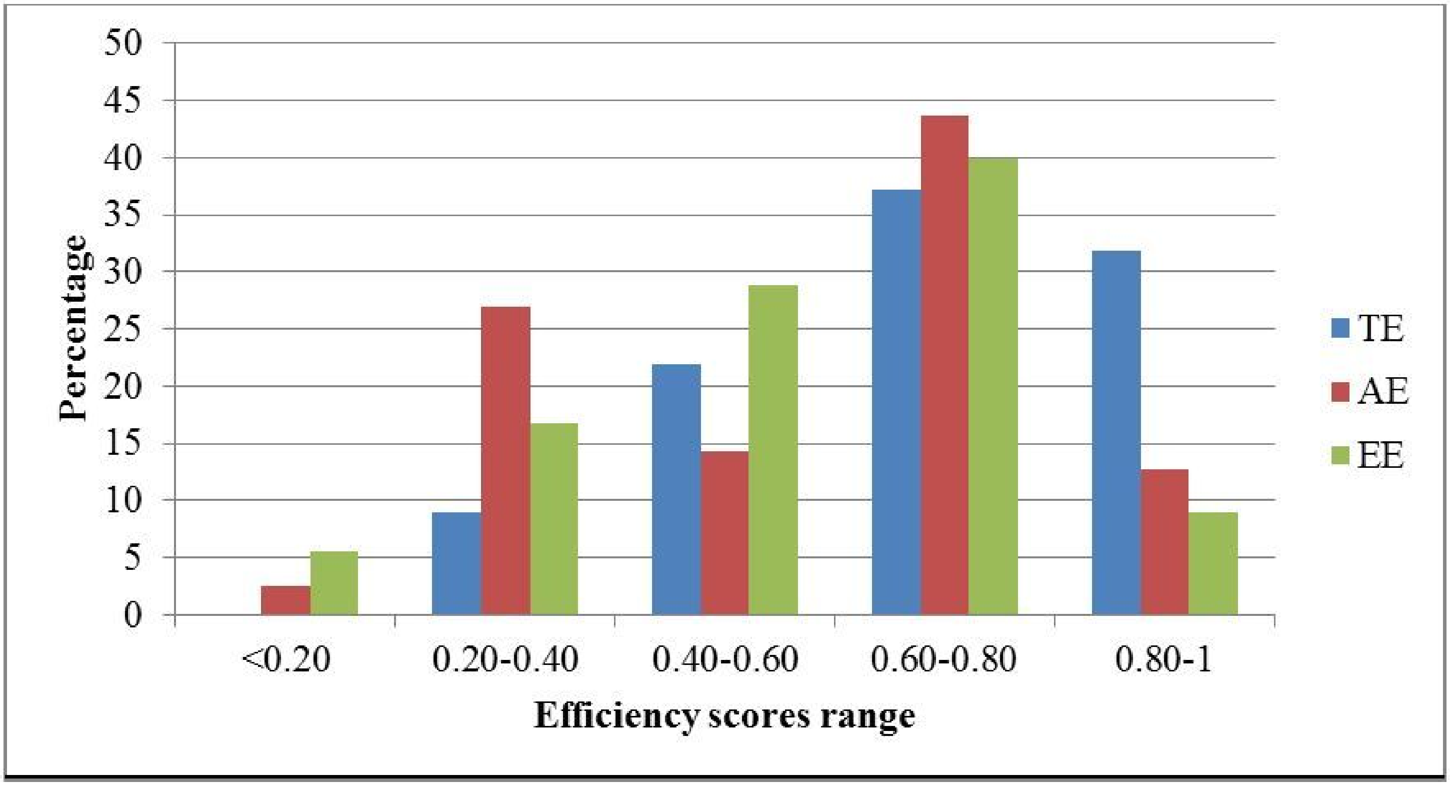

Figure 1

Frequency distribution of technical, allocative and economic efficiencies scores