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Economic Efficiency of Sorghum Production for Smallholder Farmers in Eastern Ethiopia: The Case of Habro District

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Abstract
This study aimed at estimating the technical, allocative, and economic efficiencies of smallholder sorghum farmers and identifying factors that determine them in Habro district. Cobb-Douglas production function was fitted using stochastic production frontier approach to estimate technical, allocative and economic efficiency levels, whereas Tobit model was also used to identify factors affecting efficiency levels of the sample farmers. The mean technical, allocative and economic efficiencies of sorghum farmers were 74, 44 and 32 percents, respectively. Results of the Tobit model revealed that age, sex and farm size affect technical efficiency positively and significantly, while experience and land fragmentation affect technical efficiency negatively. The result also indicated that experience and education have positive and significant effect on allocative efficiency while age and sex were found to have significant negative effect. The result of the study also shows that farm size has a positive and significant effect on economic efficiency whereas land fragmentation and extension contact affect economic efficiency negatively and significantly.
Keywords: sorghum, production, efficiency, stochastic frontier, tobit

1. Introduction

Ethiopia is mainly an agrarian country. The agricultural sector accounts for roughly 43 percent of GDP, and 90 percent of exports. Nevertheless, food security remains a critical issue for many households, and for the country as a whole. Moreover, expansion of the cropped area to more marginal lands has led to severe land degradation in some areas. With a total area of about 1.13 million km^2 and about 51.3 million hectares of arable land, Ethiopia has tremendous potential for agricultural development. Only about 11.7 million hectares of land, however, are currently being cultivated; just around 20 percent of the total arable area. Nearly 55 percent of all smallholder farmers operate on one hectare or less (MoARD, 2010).

Sorghum (*Sorghum bicolor* (L.) Moench) is the fourth most important cereal crop following wheat, rice and maize. It is a food staple for more than 500 million people in the semi-arid tropics of Africa and Asia and more than 80% of the world area of production is confined to these two continents. In sub-Saharan Africa, over 100 million people depend on sorghum as staple (Serna-Saldivar and Rooney, 1995; Smith and Frederiksen, 2000). It is primarily a crop of resource-poor small-scale farmers and is grown predominantly in low-rainfall, arid to semi-arid environments. The crop is typically produced under adverse conditions such as low input use and marginal lands. It is well adapted to a wide range of precipitation and temperature levels and is produced from sea level to above 2000 m.a.s.l. Due to its drought tolerance and adaptation attributes, this crop is grown in eastern Africa where agricultural and environmental conditions are unfavorable for the production of other crops. All lines of evidence point to the north-east quadrant of Africa, mainly Ethiopia, as the centre of domestication of sorghum. Therefore, the greatest genetic diversity for both cultivated and wild forms of sorghum is found in Ethiopia and the surrounding eastern African countries. It is the second most important staple cereal crop after maize in the region, making a huge contribution to the domestic food supply chain and rural household incomes with a total acreage of 8,199,741 ha. For instance, in Ethiopia, it is the 2nd staple cereal after tef, *Eragrostis tef,* and ranks 3rd after maize, and tef in total national production.

Sorghum is one of the major traditional food crops of Ethiopia that ranks third in area coverage following tef and maize. It is grown on 1.2 million ha with a total production of 1.6 million t comprising about 13% of the total cereal production in the country (CACC, 2003). The grain is used for human food, whereas the crop residue is used for livestock feed. It is one of the most important cereal crops of the tropics grown extensively over wider areas with elevation range from 1400 to 2100 meters above sea level (m.a.s.l). Its ability to adapt to adverse environmental conditions has made sorghum a popular crop worldwide. It is the major source of energy and protein for millions of people living in semi-arid tropical Africa and Asia. According to CSA (2013), sorghum ranks third after maize and tef in total production, after maize in yield per hectare and after tef and maize in area harvested.

Although in Ethiopia significant land area is allocated for growing sorghum and there is high demand for sorghum grain for food, multiple uses for its residue and, is suitable for drought-prone areas, the mean national yield is less than 1.5 t/ ha, which is far below the yield potential of the crop (CACC, 2003).

In Habro district sorghum is the first cereal crop produced as a food crop followed by teff and maize. However, the minimum output of sorghum was 2 quintals per hectare while the maximum output is 32 quintals per hectare as observed from the study. This indicates that there is a big productivity gaps among farmers in the study area. Therefore, it was important to know the efficiency level of the farmers in sorghum production and identify the determinants which cause efficiency differentials among farmers in the study area.

Crops production and area coverage

In the study area both annual crops and perennial crops are produced simultaneously. The major annual crops grown in the area include sorghum, maize, teff, haricot bean, barely, chickpea and finger millet. Mostly these crops are used for food consumption and rarely for market purpose. The major perennial crops produced in the area include chat, coffee and mango. These perennial crops are often used for market sale. As a result they are known as cash crops. On average, chat covers about 30.44% of land out of the total cultivated land followed by coffee and mango which were 16.86% and 4.15% respectively.

Table 1. Area coverage and yield per hectare of major annual crops.

		Area coverage(ha)		
Crop type	N	Mean	Percent	Average yield (Qt/ha)
Sorghum	130	0.46	55.42	14.22
Maize	82	0.18	21.68	20.58
Teff	53	0.20	24.09	8.20
Haricot bean	96	0.14	16.86	13.03
Chickpea	74	0.10	12.04	4.12
Finger millet	47	0.12	14.45	12.69
Barley	18	0.08	9.63	13.79

Source: Own computation

2. Methodology

2.1. Data and Sample selection

The study was based on both primary and secondary data. Both formal and informal methods of data collection were undertaken to collect data from sample households, key informants, development agents (DAs), concerned agricultural professionals and administration offices at all levels. A multi-stage sampling technique was employed to analyze economic efficiency of small holder sorghum producers. Firstly, Habro district was purposively selected due to its large extent of sorghum production. Then, out of several sorghum producing kebeles found in the district, 3 kebeles were selected randomly. Finally, by taking into account the probability proportional to size a total of 130 sample households were selected among 3397 sorghum producer farmers using random sampling technique.

Table 2. Total number of sample household heads

Kebeles	Total sorghum producing household heads	Sample
Kufa-kas	1282	50
Lugo	1148	43
Oda-aneni	967	37
Total	3397	130

2.2. Specification of the econometric models

A stochastic frontier approach was utilized to estimate the level of efficiencies. In addition, tobit model was also applied to analyze factors that affect the efficiency level of the farmers.

2.2.1. Stochastic frontier model

The stochastic frontier model was independently proposed by Aigner et al. (1977) and Meeusen and van Den Broeck (1977). The model can be expressed as:

$$Y_i = F(X_i ; \beta) + \varepsilon_i \qquad i= 1, 2, 3\ldots n \qquad (1)$$

$$\varepsilon_i = v_i - u_i$$

Where Y_i is the output of the ith firm, Xi is vector of input variables for the ith firm, F() is the appropriate functional form and β is vector of unknown parameters to be estimated. ε_i, is the composed error term. The random factor (V) is a symmetric error, which accounts for random variations in output due to external factors beyond the control of the farmer, e.g., weather and disease outbreak, and it is assumed to be independently and identically distributed (IID) with N (0, σv^2), while the technical inefficiency effects (U), is often assumed to have a half normal distribution |N (0,σu^2)|. U reflects deviation resulting from factors under the firm's control, such as technical inefficiency.

A stochastic frontier method requires a prior specification of the functional form. Among the possible algebraic forms, Cobb-Douglas functional form was selected for this study. According to Coelli (1995), the Cobb-Douglas functional form has most attractive feature which is its simplicity. A logarithmic transformation provides a model which is linear in the logs of the inputs and hence easily lends itself to econometric estimation.

The linear functional form of Cobb-Douglas production function used for this study is given by Equation (2).

$$\ln(\text{output}) = \beta_o + \beta_1\ln(\text{land}) + \beta_2\ln(\text{oxen}) + \beta_3\ln(\text{labour}) + \beta_4\ln(\text{seed}) + v_i - u_i \qquad (2)$$

For driving the dual cost frontier, the following minimization problem given in Equation (3) is essential.

$$\underset{x}{Min}\,C = \sum_n \omega_n x_n \qquad (3)$$

subject to

$$Y_k^{i*} = \hat{A}\prod_n x_n^{\hat{\beta}_n}$$

where $\hat{A} = \exp(\hat{\beta}_0)$ $\hat{A} = \exp(\hat{B}_0)$

ω_n = input prices

$\hat{\beta}$ = parameter estimates of the stochastic production function and

Y_k^{i*} = input oriented adjusted output level from Equation 14.

The following dual cost function given in Equation (4) will be found by substituting the cost minimizing input quantities into Equation (2).

$$C(Y_k^{i*}, w) = HY_k^{i*\mu}\prod_n \omega_n^{\alpha_n} \qquad \textbf{(4)}$$

where $\alpha_n = \mu\hat{\beta}_n$, $\mu = (\sum_n \hat{\beta}_n)^{-1}$ and $H = \frac{1}{\mu}(\hat{A}\prod_n \hat{\beta}_n^{\hat{\beta}_n})^{-\mu}$

Sharma *et al.* (1999) suggests that the corresponding dual cost frontier of the Cobb Douglas production functional form in equation (16) can be rewritten as:

$$Ci = C(\omega_i, Y^*; \alpha) \qquad (5)$$

Where Ci: is the minimum cost of i[th] farm associated with output Y_i^*.

ω_i: is the vector of input prices for the i[th] firm and

α: is the vector of parameters to be estimated

The economically efficient input vector of the i^{th} firm X_i^e is drived by applying Shepards' lemma (Jema, 2008; Kehinde and Awoyemi, 2009) and substituting the firms input prices and adjusted output level, a system of minimum cost input demand equation can be expressed as:

$$\partial Ci / \partial\omega_n = X_i^e(\omega_i, Y^*; \theta) \qquad (6)$$

Where θ is the vector of parameters and n = 1, 2, 3... N inputs.

The observed, technically and economically efficient costs of production of the i^{th} firm are then equal to $\omega_i^{'}X_i$, $\omega_i^{'}X_i^t$ and $\omega_i X_i^e$; respectively.

According to Sharma *et al.* (1999), the above cost measures are used to estimate the technical, allocative and economic efficiencies respectively.

$$TE_i = \omega_i^{'}X_i^t / \omega_i^{'}X_i \qquad \textbf{(7)}$$

$$EE_i = \omega_i X_i^e / \omega_i^{'}X_i \qquad (8)$$

Following Farrell (1957), allocative efficiency index of the i[th] farmer can be derived from Equations 7 and 8 as follows;

$$AE = EE_i / TE_i = \omega_i X_i^e / \omega_i^{'} X_i^t \quad (9)$$

2.2.2. Tobit model

Following Gujarati (2004) the tobit model used was:

$$E = E^* = \beta_0 + \beta_1 Z_1 + \beta_2 Z_2 + \beta_3 Z_3 + \beta_4 Z_4 + \ldots\ldots\ldots + \beta_{13} Z_{13} + v \quad (10)$$

$$E = E^* \text{ if } E^* > 0, \quad E = 0 \text{ if } E^* < 0.$$

Where:

E is the efficiency measures representing technical, allocative and economic efficiency

E* is the latent variable

β's are unknown parameters to be estimated

v is a disturbance term.

Z_1 = Age of the household head in years

Z_2 = Education level of the household head

Z_3 = Experience in sorghum production in years

Z_4 = Farm size in hectares

Z_5 = Number of sorghum plots

Z_6 = Frequency of extension contact

Z_7 = Dummy variable showing male household heads=1, female headed household=0

Z_8 =Dummy variable showing participation in off/nonfarm occupation=1, otherwise zero

Z_9 =Livestock size

Z_{10} =Dummy variable showing access to credit=1, otherwise zero

Z_{11} =Dummy variable showing access to training=1, otherwise zero

Z_{12} =Family size

Z_{13} =Proximity of sorghum farm

3. Results and Discussion

3.1. Econometric Model Results

Before running the econometric model, the data was tested against econometric problems. The value of variance Inflation Factor (VIF) for all variables entered into the model were low and below 10, which indicate the absence of severe multicollinearity problem among the explanatory variables. Gujarati (2004) have suggested that multicollinearity is not necessarily a problem unless it is very high. In addition, Breusch-Pagan test was also used to detect the presence of hetroskedasticity and the test result indicated that there was no problem of hetroskedasticity in the models.

3.1.1. Estimation of production functions

The dependent variable of the estimated production function was physical output of sorghum measured in quintal and the input variables used in the analysis were area of land allocated to sorghum (ha), oxen (oxen-days), human labor (man-days), and quantity of seed (kg).

The result of the model showed that two of the input variables in the production function: i.e., land and labour, had a positive and significant effect on the level of sorghum production. Hence, the increase in these inputs would increase output of sorghum significantly.

Table 3. Estimates of the Cobb Douglas frontier production function

Variables	Coefficients	Std. Err.
Constant	1.698**	0.548
Land	0.554***	0.147
Seed	0.025	0.034
Oxen	0.216	0.158
Labour	0.336***	0.092
Lambda (λ)	1.974***	0.072
Sigma squared (σ^2)	0.125***	0.026
Gamma (γ)	0.796	

NB: *** Significant at the 0.01 level.

** Significant at the 0.05 level.

Source: model output

The ratio of the standard error of u (σu) to the standard error of v (σv), known as lambda (λ), was 1.974. Based on λ, gamma (γ) which measures the effect of technical inefficiency in the variation of observed output can be derived (i.e. $\gamma = \lambda^2 / [1+\lambda^2]$). The estimated value of gamma was 0.796 which indicated that 79.60% of total variation in sorghum farm output was due to technical inefficiency. The diagnostic statistics of inefficiency component reveals that sigma squared (δ^2) was statistically significant at 1 percent as indicated in the above table.

This indicates goodness of fit, and the correctness of the distributional form assumed for the composite error term.

3.1.2. Technical, allocative and economic efficiency scores

The result of efficiency scores indicated that farmers in the study area were relatively good in TE than in AE or EE of production. Generally, there is a considerable amount of efficiency variation among sorghum producer farmers.

Table 4. Summary statistics of efficiency scores

Type of efficiency	Min	Max	Mean	Std. Dev.
TE	0.31	0.93	0.74	0.11
AE	0.30	0.84	0.44	0.08
EE	0.26	0.35	0.32	0.02

Source: Own computation

The mean technical efficiency level of 74% indicated that sorghum producing farmers have a chance to efficiently utilize resources and hence they could increase the current sorghum output by 26% using the existing technology. The TE among farmers varies from 31 to 93%, with standard deviation of 0.11. This shows that there is a wide disparity among sorghum producer farmers in their level of technical efficiency.

The mean allocative efficiency of farmers in the study area was 44% indicating that on average, sorghum producer farmers can save 56% of their current cost of inputs if resources are efficiently utilized. In other words, sorghum producer farmers increased their cost of production by 56% because of allocative inefficiency. This implies that there is a great opportunity to increase the efficiency of sorghum producers by reallocation of resources in cost minimizing way.

As designated in the above table, mean economic efficiency level of sample households was 32% with minimum and maximum efficiency scores of 26% and 35% respectively. This shows that there is a need to improve their level of economic efficiency. The result implies that if the farmer with an average level of economic efficiency were to reach the level of the most economically efficient household, then he/she could experience a cost saving of 8.6% derived from [1-(0.32/0.35)]*100. Similarly, the most economically inefficient farmer would save cost of 26% derived from [1-(0.26/0.35)]*100 to attain the level of the most efficient farmer.

3.1.3. Factors affecting efficiency of smallholder farmers

Table 5. Factors affecting efficiency of smallholder farmers in sorghum production

Variables	TE		AE		EE	
	ME	Std. Err.	ME	Std. Err.	ME	Std. Err
Constant	0.5268***	0.0437	0.5692***	0.0325	0.3074***	0.0087
Age	0.0040***	0.0009	-0.0026***	0.0006	-0.0000	0.0002
Education	-0.0151	0.0221	0.0126*	0.0077	-0.0010	0.0020
Experience	-0.0027***	0.0009	0.0018**	0.0007	0.0001	0.0002
FAMSIZE	0.0002	0.0038	-0.0007	0.0028	-0.0008	0.0008
Fragmentation	-0.0398*	0.0216	-0.0167	0.0160	-0.0096**	0.0043
EXTNCON	-0.0108	0.0187	-0.0034	0.0138	-0.0082**	0.0037
Sex	0.0782***	0.0197	-0.0612***	0.0146	0.0004	0.0039
OFNFA	0.0050	0.0176	-0.0104	0.0131	-0.0016	0.0035
Livestock	-0.0000	0.0014	-0.0000	0.0010	-0.0002	0.0002
Credit	0.0221	0.0221	-0.0060	0.0164	0.0031	0.0044
TRNNG	0.0078	0.0170	-0.0098	0.0126	-0.0012	0.0034
Farm size	0.0358*	0.0195	-0.0110	0.0145	0.0108***	0.0039
DISPLOT	-0.0007	0.0054	0.0013	0.0040	0.0002	0.0011

Note: *** -Significant at the 0.01 level
** -Significant at the 0.05 level
* -Significant at the 0.1 level

Source: Model output

Some of the significant variables are discussed as follows:

The finding of the study shows that age affected technical efficiency of the smallholder farmers positively and significantly at 1% significance level. This implies that older farmers were more efficient than younger ones and this is consistent with findings of Ali and Abdel-Karim (2012) and Dhungana *et al*. (2004). This was probably because of growing stock of experience in farming. In addition, older farmers had more resources at their disposal, which included capital in form of livestock, agricultural implements and assets. However, the estimated coefficient of age was negative and significant for allocative efficiency at 1% significance level. The reason for this is probably that the age variable picks up the effects of physical strength as well as farming experience of the household head. Although farmers become more skillful and knowledgeable as their age increases, the learning by doing effect is attenuated after certain age level, when their physical strength starts to decline. Liu and Zhung (2000), Awudu and Huffman (2000), Kibaara (2005), and Tahir *et al*. (2008) made similar conclusions.

The estimated coefficient of education was found to have positive and significant impact on allocative efficiency at 10% significance level. The result of this study indicated that education is important factor in increasing the efficiency in sorghum production. Also, a study by Seyoum *et al*. (2001) concluded that educated farmers respond more readily to new cost effective technology and produces closer to the frontier output. The result indicates that, AE requires better knowledge and managerial skill. In other words, educated farmers have relatively better capacity for optimal allocation of inputs in the study area. This is in line with the previous findings of Jema and Andersson (2006), Musa (2013) and Kifle (2014).

Experience significantly affected technical efficiency and allocative efficiency of the sampled households at 1% and at 5% level of significance, respectively. But, the sign of the coefficient for technical efficiency is negative which is contradictory to our expectation. Farmers with many years of production experience have high capital accumulation than those farmers who have little experience. Therefore, ones the farmer accumulated capital the desire for farming might be weak and he will shift to other business activities instead. Additionally, high number of years spent on sorghum production may be an indication of old age. The activeness of the farmer reduces as he/she grows old, meaning that labour productivity reduces as age increases at a point of diminishing returns. So, this might lead to decreasing efficiency of smallholder farmers in sorghum production. This study agrees with the earlier outcome of Kibirige (2008). The sign of the estimated coefficient for allocative efficiency is positive which is in line with the hypothesis made. Having more experience and knowledge on agricultural production methods, post-harvest handling of agricultural products, agronomic practices and management of natural resources would increase efficiency of smallholder farmers in agriculture. As one gets skillful in the methods of production, he/she would be better in optimal allocation of resources. In the study area, where land scarcity is a major problem, farmers' experience in sorghum production plays a great role in an efficient allocation of resources in order to increase production. This result is in line with the earlier research finding of Musemwa *et al.* (2013) in their study on factors affecting efficiency of field crop production among resettled farmers in Zimbabwe.

The result of the study also shows land fragmentation is one among the explanatory variables which affected both technical and economic efficiencies negatively and it is significant at 10% and 5% level, respectively. The increasing number of plots leads to increased inefficiency or decreased efficiency by creating shortage of family labour, wastage of time and other resources that should have been available at the same time. Additionally, having large number of plots may lead to wastage of time resource and cost inefficiency than having less number of plots. The result agreed with the previous research works of Fekadu (2004).

It was hypothesized that extension contact would improve the efficiency of smallholder farmers. But unfortunately, it was found to have a negative and significant relationship with economic efficiency of farmers. This might be due to the fact that as a farmer contacted the extension worker frequently he/she would not have enough time to potentially and appropriately allocate resources. In addition to this, during data collection farmers in the area said that most of the time extension workers did not raised issues specific to agricultural production mechanisms (agronomic practices, post-harvest handling, crop disease control methods, etc.) rather they spend more time in involving on the activities which are not related to their profession. For instance, health related issues (construction of toilet, initiating farmers to vaccinate their children, etc.), collection of loans and awareness creation on political issues. So, there is no new knowledge they got from extension workers regarding agricultural production in order to improve their skills. Generally, these factors would make the efficiency of the farmers to decline. This result is in line with the previous finding of Aghdasi and Zhou (2013).

The result also shows that farm size have a significant and positive impact on TE and EE, at 10% and 1% level of significance, respectively. This positive relationship was also observed in several other studies (Kumbhakar *et al.,*1991; Bravo-Ureta and Rieger, 1991; Ngwenya *et al,* 1997; Handri and Whittaker, 1999; Hazarika and Alwang, 2003). This could probably be because of farmers with larger area of cultivated land have the capacity to use compatible technologies that could increase the efficiency of the farmer. On the other hand, the smaller-sized farms are populated heavily by young and inexperienced people and therefore, they are expected to have lower average efficiency levels than large and more experienced farmers. Moreover, farmers who have large farm size would have an opportunity to use and allocate the maximum available resources efficiently because they do not have land size limitation. Additionally, farmers with large farm size may also have an easier access to new improved agricultural technologies introduced in to the area. Generally, large farm size owners are more efficient as compared to small land size owners.

5. Summary and Conclusion

The stochastic production frontier model output showed that among input variables land and labour were significant variables that positively affect the production of sorghum. This indicates that increased use of these inputs will increase the production level to a greater extent. Technical efficiency scores range from 31 percent to 93 percent while allocative and economic efficiency scores range from 30 percent to 84 percent and from 26 percent to 35 percent respectively. This shows that there is efficiency variation among sample farmers in the study area. Average technical efficiency stands at 74 percent while the average allocative and economic efficiency stands at 44 percent and 32 percent, respectively. This suggests that there is room for further increase in output without increasing the level and cost of inputs. Output of sorghum can be increased by 26 percent without altering the level of input usage. The current input cost can also be reduced by 56 percent without changing the level of production.

Tobit model results showed that land fragmentation, farm size, and experience in sorghum production, age and sex of the household head are significant determinants of technical efficiency. Furthermore, the results revealed that age, education level, experience in sorghum production and sex of the household head significantly influence allocative efficiency of smallholder farmers in the study area. The result also showed that extension contact, land fragmentation and farm size are important factors that significantly affect economic efficiency of the smallholder farmers in the area. Such farm and farmer characteristic should be encouraged to enhance efficiency among smallholder sorghum producing farmers.

The study recommended that policies and strategies to be designed and implemented to increase the efficiency of smallholder farmers in sorghum production in the study area should focus on the above mentioned factors.

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