FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

Technical, allocative and economic efficiency of malt barley producers in Arsi zone, Ethiopia

Sime Shiferaw¹*, Jema Haji¹, Mengistu Ketema² and Million Sileshi¹

Abstract: With the available resources and existing production technology, to minimize the gap between demand and supply of malt barley grain, improving productivity by enhancing production efficiency is the best option available as the vast majority of Ethiopian farmers are poor and lack the required capital to adopt new technologies and to reallocate the resources. This research estimated the technical, allocative, and economic efficiencies using the stochastic production frontier and identified their determinants by employing the two-limit Tobit regression for randomly selected malt barley farmers in Arsi zone, Ethiopia. The mean technical, allocative, and economic efficiency levels were found to be 87.1%, 80.6% and 70.6%, respectively. The Tobit model results show that education, credit access, livestock size, distance from market, proximity to homestead, and soil fertility status were significant factors affecting all efficiency estimates. Family size and landholding had a significant effect on allocative and economic efficiencies, whereas

ABOUT THE AUTHOR
Sime Shiferaw is a PhD student of Agricultural Economics at School of Agricultural Economics and Agribusiness, Haramaya University, Ethiopia. Sime obtained a diploma in Animal health from Addis Ababa University, BA degree in Economics from Haramaya University, and MSc degree in Agricultural and Applied Economics from Egerton University (Kenya). He has experience in teaching and socioeconomic research. Sime’s research interests are topics related to agricultural and applied economics including adoption, productivity, food insecurity and poverty, and impact assessment studies.

PUBLIC INTEREST STATEMENT
The malt barley production sub-sector in Ethiopia is generally characterized by high demand but limited supply of the grain. Following the establishment of new breweries in the country and the expansion of the existing ones, and due to the shift in the behavior of consumers toward high beer consumption, the demand for malt barley is rising rapidly. However, domestic production of MB accounts for only about one-fourth of the total demand. As a result, a significant amount of hard currency is being spent on imports of malt barley. A major cause for the inadequate supply of malt barley is low productivity. Theoretically, this can be improved by adopting new technologies, reallocating the available resources, and increasing production efficiency. In developing countries like Ethiopia, where the majority of farmers are so poor and encounter capital shortages, the first two options may not be viable. Therefore, with the existing level of technology and agricultural resources, the plausible choice left to the farmers is to increase productivity through improving production efficiency. Moreover, knowledge of the factors that determine production efficiency differentials among farmers is pivotal. This can assist policymakers in developing appropriate policies to boost malt barley productivity by enhancing its production efficiency.
cooperative membership, extension contact, and off/non-farm income were the major determinants of technical efficiency. The results, in general, demonstrated that the production efficiency of malt barley farmers could be improved with the existing farm resources and level of technology. Based on the findings, the production efficiency *malt barley producers in Arsi zone* can be enhanced by expanding formal and informal education, creating ways of experience sharing amongst farmers, improving input distribution systems, and providing quality extension, financial, market and transportation services.

**Subjects:** Agriculture & Environmental Sciences; Development Studies; Sustainable Development; Rural Development; Economics and Development; Economics

**Keywords:** malt barley; efficiency; stochastic frontier; Tobit; Ethiopia

1. Introduction

Although there is a continuing structural transformation in the Ethiopian economy, mainly from agriculture to services, agriculture remains the country's most important sector as it accounts for about 35% of total output, generates 80% of foreign exchange earnings, and employs 66% of the total population (NBE (National Bank of Ethiopia), 2018; WB (World Bank), 2018). The government of Ethiopia regards smallholder agriculture as the most significant sector and sees improving smallholder farmers' productivity as an important step to achieving food security and poverty reduction (EATA (Ethiopian Agricultural Transformation Agency), 2010). During the past years, various development interventions have been undertaken including the successive growth and transformation plans (GTP I and II; ATA (Agricultural Transformation Agency), 2017) to enhance agricultural productivity and transform the structure of the economy from an agricultural to industry and service-driven economy and make Ethiopia a middle-income country by 2025.

The malt barley (MB) production sub-sector in Ethiopia has recently become a highly emerging one due to the interest shown by multinational beer companies to fulfill their demand for malt by sourcing from domestic production (Bezabeh et al., 2020). However, according to ICARDA (International Center for Agricultural Research in the Dry Areas; 2019), only about 25% of the total raw MB grain demand of breweries in Ethiopia is being covered by the domestic supply. Thus, breweries in the country are importing most of their malt requirements, and their import bill valued at 66 million USD (United States Dollar) in 2015, is expected to reach 420 million USD by 2025 (Alemu, 2016; Rashid et al., 2015).

The low malt barley supply from local production is because of the low productivity of barley in Ethiopia in general and malt barley in particular (Rashid et al., 2015). The average barley yield of 2.1 metric tons per hectare (mT/ha) in Ethiopia is less than the barley yield in the highest performing African countries like Zimbabwe (5.5 mT/ha) and Kenya (3.9 mT/ha), and is much below the yield in the best-performing European countries with average yields of over 7.5 mT/ha CSA (Central Statistical Agency), 2019; FAO (Food and Agriculture Organization), 2019). One major factor responsible for the low level of production and productivity is the inefficiency prevailing in farmers’ production process (Teferra et al., 2018; Wollie et al., 2018).

Previous studies on production efficiency in Ethiopia have mostly focused on the estimation of efficiency for staple crops such as sorghum, food barley, maize, and wheat (Alelu & Haji, 2016; Bezu et al., 2021; Tesema et al., 2019; Wollie et al., 2018), while those carried out on malt barley crop have primarily concentrated on measuring only the technical efficiency of production (Bekele & Regasa, 2019; Lema et al., 2022; Shate et al., 2021). However, considerable production gains could be attained by increasing the economic efficiency (EE) of crop production rather than considering only the technical efficiency (TE) of crop production (Haji, 2006; Wai & Hong, 2020). Understanding the technical, allocative, and economic efficiency levels and their drivers helps in
identifying MB production constraints at the farm level. Particularly, empirical data on these may assist policymakers in developing proper policies to boost production and productivity of the agricultural sector by increasing farm-level and malt barley-specific production efficiency. This shall, in turn, improve the livelihood of the farmers through increasing their income, and consequently, reducing food insecurity and alleviating poverty (Fahad & Wang, 2018, 2020; Su et al., 2021; Teferra et al., 2018). Hence, this study is conducted with the objectives of estimating the technical, allocative, and economic efficiencies of malt barley farmers, as well as identifying the underlying factors that determine the level of efficiencies in Arsi zone, central Ethiopia.

2. Methodology

2.1. Description of the study area
Arsi zone is located between 7°8’58’’-8°49’00’’ North latitudes and 38°41’55’’-40°43’56’’ East longitudes. The zone has an altitude range of 805–4195 meters above sea level and is mainly characterized by moderately cool (40%) followed by cool (34%) agro-climatic zones. Crop production along with livestock rearing is the main economic stay of farmers inhabiting in Arsi zone. Cereals constitute the majority of crop production followed by pulses, vegetables, oilseeds, fruit crops, and spices. The major cereal crops cultivated in Arsi zone are wheat, barley, maize, teff, and sorghum.

Although barley is known to grow in areas between 1,800 and 3,000 m above sea level, it is mostly found growing between 2,000 and 3,500 m above sea level (Mulatu & Grando, 2011). This makes the highlands of the Arsi zone favorable areas for the production of barley. CSA (Central Statistical Agency), 2016 annual report shows that the Arsi zone produced about one-fourth of the total barley production in the Oromiya region, which is about 13% of the total barley output in Ethiopia. Presently, MB in the Arsi zone is considered an important commercial crop apart from its considerable utilization for food. The Asella malt factory, established in 1984 near the capital of Arsi zone (Asella), is the largest malt barley buying and processing plant in Ethiopia. This can be a big opportunity for MB producers in the area, as smallholders in developing countries often suffer from lack of a large and consistent market channel to encourage increased production.

2.2. Sources of data and sampling techniques
This paper is based on cross-sectional data from 385 malt barley producers in Arsi zone, Ethiopia. A multistage sampling technique was followed to select the study districts, kebeles (peasant associations), and sample farmers. First, the Arsi zone was selected purposely because of its capacity for MB production. Next, districts in the zone were classified as MB-producing and non-producing districts. Then, from the districts producing MB, Digalu-Tijo and Lemu-Bibilo districts were selected randomly. Subsequently, based on the total number of MB producing peasant associations (PAs) in each district, two PAs from Digalu-Tijo district and five PAs from Lemu-Bibilo district were selected randomly. Afterwards, a list of households who produced MB during the 2020/2021 cropping season was obtained from agricultural offices in each PA. Lastly, based on the total number of malt barley producers in each PA, a simple random sampling procedure was employed to proportionally choose the appropriate number of respondents (Table 1).

The study was based on primary data collected from malt barley producers. Trained interviewers used a pre-tested semi-structured questionnaire to collect the data. Also, focus group discussions were held to complement on the data collected through questionnaire.

2.3. Data analysis methods

2.3.1. Technical, allocative and economic efficiency estimations
Since the seminal work of Farrelli (1957), there are two commonly used approaches of measuring production efficiency, namely: the Data Envelopment Analysis (DEA) and the Stochastic Production Frontier (SPF). Both techniques analyze data using distinct approaches, taking into consideration
random noise and flexibility in the structure of technology of production. Due to these variations, choosing between the parametric SPF and the non-parametric DEA methods has been an issue of debate. Nevertheless, studies carried out on efficiency measurement indicate that a researcher can use any of these methodologies because the estimated results are not significantly different (Coelli et al., 2002; Haji & Andersson, 2006).

Table 1. Selected farm households distribution by district and PAs

| District           | Selected PAs  | Total households | No. of interviewed farmers |
|--------------------|---------------|------------------|----------------------------|
| Digalu-Tijo        | Kubsa Bora    | 897              | 58                         |
|                    | Digalu Bora   | 1033             | 66                         |
| Lemu-Bibilo        | Koma Karra    | 732              | 47                         |
|                    | Dawra Bursa   | 835              | 53                         |
|                    | Koma Katara   | 810              | 52                         |
|                    | Sirbo         | 1006             | 64                         |
|                    | Bekoji Negessa| 701              | 45                         |
| Total              |               | 6014             | 385                        |

Table 2. The hypothesized variables of MB production efficiency and their expected signs

| Variable               | Measurement | Expected sign | Related empirical studies                                        |
|------------------------|-------------|---------------|-----------------------------------------------------------------|
| Sex                    | Dummy       | +             | Asfaw et al. (2019), Bezu et al. (2021)                          |
| Farming experience     | Years       | +             | Gebretsadik (2017), Dessale (2019)                              |
| Family size            | Adult equivalent | ±  | Debebe et al. (2015), Wona and Sori (2018), Okello et al. (2019) |
| Education              | Years       | +             | Gela et al. (2019), Tenaye (2020)                               |
| Credit                 | Dummy       | +             | Tesema et al. (2019), Tafesse et al. (2021)                     |
| Extension contact      | No. of contacts | + | Ahmed et al. (2014), Wona and Sori (2018)                        |
| Distance to market     | Walking minutes | -  | Teferra et al. (2018), Wollie et al. (2018)                     |
| Off/non-farm income    | Birr per year | ±  | Asfaw et al. (2019), Gela et al. (2019), Wai and Hong (2020)    |
| Landholding size       | Hectares    | +             | Elema et al. (2017), Tesema et al. (2019)                       |
| Livestock holding      | TLU          | +             | Bezu et al. (2021), Tafesse et al. (2021)                       |
| Cooperativ membership  | Dummy       | +             | Gebretsadik (2017), Gela et al. (2019)                          |
| Proximity to homestead | Walking minutes | -  | Wollie et al. (2018), Tesema et al. (2019)                     |
| Fertility of soil      | Categorical | +             | Tenaye (2020), Bezu et al. (2021)                               |

The SPF model, simultaneously developed by Meeusen and van den Broeck (1977) and Aigner et al. (1977), was used to estimate technical, allocative, and economic efficiency scores. The stochastic frontier
technique presumes that deviances from the frontier are attributable to random errors and firm-specific inefficiency (Coelli et al., 2005). Despite its weaknesses in assuming an explicit functional form for the production technology and the distribution of inefficiency terms, the parametric SPF model is the most widely used technique of efficiency analysis (Coelli et al., 2005; Hjalmarsson et al., 1996). The stochastic frontier technique offers the advantage of dealing with stochastic noise and allows statistical tests of hypotheses about the structure of production technology, the degree of inefficiencies, and the performance of the model.

The SPF fits to a production or cost function using one of several functional forms, including linear, translog, Cobb–Douglas, logarithmic, or quadratic (Coelli et al., 1998). Most empirical studies in stochastic frontier and econometric inefficiency estimation have used the Cobb–Douglas and translog models (Bezu et al., 2021; Okello et al., 2019; Tenaye, 2020; Wai & Hong, 2020; Wollie et al., 2018). The results of the generalized likelihood ratio (LR) test performed in this study favored the Cobb–Douglas production function over the translog specification. Thus, the Cobb–Douglas production function specification is used to measure malt barley production efficiency.

The Cobb–Douglas production function used in this study is stated as

$$\ln Y_i = \beta_0 + \beta_1 \ln \text{land} + \beta_2 \ln \text{labor} + \beta_3 \ln \text{fertilizer} + \beta_4 \ln \text{seed} + \beta_5 \ln \text{oxen} + \beta_6 \ln \text{chemicals} + \epsilon_i$$

(1)

where $\ln$ represents natural logarithm, $Y_i$ refers to total malt barley output of the $i^{th}$ farmer; land (hectares), labor (man-days), fertilizer (kg), seed (kg), oxen (oxen-days) and chemicals (liters) are the inputs used in MB production (Table A in Appendix); $\beta_0$ is the constant term; $\beta_1, \ldots, \beta_6$ are coefficients of input variables, and $\epsilon_i$ is the error term defined as $(v_i - u_i)$; $v_i$, independent of $u_i$, is a random disturbance term, normally distributed and intended to capture the effects of the stochastic noise. $u_i$, a non-negative random variable representing the technical inefficiency of production, is independently and identically distributed as half-normal,$\alpha_1\mathcal{N}(0, \sigma^2_1)$.

A dual cost frontier of the Cobb–Douglas production function in (1) is specified as

$$\ln C_i = a_0 + a_1 \ln W_L + a_2 \ln W_F + a_3 \ln W_L + a_4 \ln W_C + a_5 \ln W_O + a_6 \ln W_S + \alpha Y_i + (v_i + u_i)$$

(2)

where $C_i$ is minimum cost of MB production for the $i^{th}$ household; $Y_i^*$ is total MB output adjusted for noise; $W_L$ up to $W_S$ respectively represent prices of land, labor, fertilizer, seed, oxen and chemicals; and, as are the parameters to be estimated.

Following the works of Kopp and Diewet (1982), and Bravo-Ureta and Rieger (1991), for a given output level produced by the $i^{th}$ farmer, $Y_i^*$, the technically efficient input vector, $X_{i\alpha}$, is obtained by simultaneously solving equation (2) and the observed input ratios $X_i / X_i = m_i (i > 1)$. If the production function in equation (1) is self-dual, its associated dual cost frontier parameters can be obtained algebraically and stated as

$$\ln C_i = C(W_i, Y_i^*; \alpha)$$

(3)

where $C_i$ is minimum cost of producing output $Y_i^*$ by the $i^{th}$ household, $W_i$ is a vector of input prices, and $\alpha$ represents vector of parameters. Then, by applying Shephard’s Lemma and substituting the households’ input prices and adjusted output level into the resulting system of input demand equations, the economically efficient input vector of household $i$, $X_{i\alpha}$, can be obtained as

$$\frac{\partial C_i}{\partial W_{\alpha}} = X_i^*(W_i, Y_i^*; \alpha)$$

(4)

where $n$ represents the total number of inputs used.

Then, the observed, technically efficient and economically efficient production costs for the $i^{th}$ household are respectively given as $W_iX_n$, $W_iX_{\alpha}$ and $W_iX_{i\alpha}$. Using these cost measures, the TE and overall economic efficiency (EE) indices can be computed as
There are two ways of estimating efficiencies using stochastic production functions, namely: one-stage estimation and two-stage estimation. In the one-stage approach, parameters of the frontier production function are estimated simultaneously with those of an inefficiency model, in which the technical inefficiency effects are specified as a function of other variables (Battese & Coelli, 1995). This method is best suited to estimating only the determinants of technical efficiency, and, for this reason, it has been criticized for its inability to estimate the determinants of allocative and economic inefficiencies (Bravo-Ureta & Rieger, 1991).

Hence, the present study adopted the second method which involves two-stage estimation procedures. First, the stochastic production function from which the efficiency scores are derived is estimated; and, in the second stage, the derived efficiency scores are regressed on explanatory variables using the two-limit Tobit regression. This approach is chosen because it allows the estimation of allocative and economic efficiencies in addition to the technical efficiency of malt barley production (Aye & Mungatana, 2011; Beshir et al., 2012; Bravo-Ureta & Rieger, 1991; Debebe et al., 2015; Wana & Sori, 2018).

2.3.2. Determinants of technical, allocative and economic efficiencies

After estimating the technical, allocative, and economic efficiency levels and assessing the efficiency disparities amongst the sample households, the next very important step in this study was to identify factors determining efficiency and triggering efficiency differentials between the households. For this purpose, the most commonly applied econometric models are the ordinary least squares (OLS) and the two-limit Tobit regression models. The dependent variable in efficiency estimation takes values between 0 and 1 with some values censored at both limits. Ordinary least squares (OLS) regression cannot be used to analyze data that has been truncated or censored. Cameron and Trivedi (2009) noted that estimating a linear regression in the presence of censoring involves various computational complications. That is, since the censored sample is not representative of the population, OLS regression will not produce consistent parameter estimates. According to Maddala (1999), the Tobit model, which is based on the concept of maximum likelihood, becomes a preferred choice for estimating regression coefficients of such dependent variables. Thus, in this study, using the Tobit model, the dependent variable (i.e., efficiency score) is regressed against various independent variables which were anticipated to affect malt barley production efficiency (Table 2).

Following Maddala (1999), the two-limit Tobit model is formulated as

\[ Y_i^* = X_i \beta + \mu_i \]  

(8)

Through representing the censored observed dependent variable as \( Y_i \), the Tobit model can be stated as

\[ Y_i = \begin{cases} 
1 & \text{if } Y_i^* \geq 1 \\
Y_i^* & \text{if } 0 < Y_i^* < 1 \\
0 & \text{if } Y_i^* \leq 0 
\end{cases} \]  

(9)
where \( Y^* \) is a latent variable that represents efficiency score of household \( i \), \( X_i \) are vectors of independent variables affecting production efficiency for household \( i \), \( \beta \) refer to vectors of unknown parameters, and \( \mu_i \) is a normally distributed error term independent of \( X_i \).

The expression of the likelihood function of the Tobit model is given by

\[
L(\beta, \sigma^2, \mu, X_{L1}, L_{2j}) = \prod_{y=1}^{L_{1j}} \left( \frac{L_{yj} - \mu_j X_j}{\sigma} \right) \prod_{y=L_{2j}}^{L_{yj}} \frac{1}{\sqrt{2\pi} \sigma} \phi \left( \frac{y_j - \mu_j X_j}{\sigma} \right) \prod_{y=L_{2j}}^{L_{yj}} 1 - \left( \frac{L_{yj} - \mu_j X_j}{\sigma} \right)
\]

(10)

where \( L_{1j} \) is lower limit and \( L_{2j} \) is the upper limit, \( \phi(.) \) and \( \phi(.) \) are standard and normal density functions, respectively.

According to McDonald and Moffitt (1980) and Gould et al. (1989), the total marginal effect of the Tobit model from the likelihood function in equation (10) is divided into the following three marginal effects.

(i) The unconditional expected value of the dependent variable

\[
\frac{\partial E(y^*)}{\partial X_j} = (Z_U) - (Z_L) \frac{\partial E(y^*)}{\partial X_j} + \frac{\partial (E(y^*) - (Z_L))}{\partial X_j} + \frac{\partial (1 - (Z_U))}{\partial X_j}
\]

(11)

(ii) The expected value of the dependent variable conditional upon being between the limits

\[
\frac{\partial E(y^*)}{\partial X_j} = \beta_m \left[ 1 + \frac{Z_L Z_U - Z_U (Z_U)}{(Z_U) - (Z_L)} \right] - \frac{\left[ \phi(Z_U) - \phi(Z_U) \right]^2}{(Z_U) - (Z_L)}
\]

(12)

(iii) The probability of being between the limits

\[
\frac{\partial (E(y^*) - (Z_L))}{\partial X_j} = \beta_m \frac{\phi(Z_U) - \phi(Z_U)}{\sigma}
\]

(13)

where \( \phi(.) \) refers to the normal density function, \( (.) \) is the cumulative normal distribution, \( Z_L = \frac{X_j - \mu_j}{\sigma} \) and \( Z_U = \frac{X_j - \mu_j}{\sigma} \) are standardized variables derived from the likelihood function given the limits of \( Y^* \), and \( \sigma \) refers to the standard deviation of the model.

3. Results and discussion

3.1. Simple descriptive statistics results

The mean age of malt barley producers in the study area was 44.10 years with an average household size of 4.66 persons measured in adult equivalents. About 89.6% of the respondents were male household heads with an average educational level of 4.61 years. The farmers, on average, cultivated malt barley on 0.82 hectares of land, utilized 40.66 man-days of labor, 131.83 kg of fertilizer, and 0.64 L of agrochemicals, and realized an output of 18.17 quintals of malt barley. Table 3 shows the summary statistics of technical inputs and some institutional and socioeconomic variables of MB farmers in the study area.

3.2. Results from econometric models

3.2.1. The production function estimates

Table 4 compares the maximum likelihood (ML) parameter estimates of the Cobb–Douglas stochastic production frontier function with the traditional OLS estimates of the average production function. The dependent variable in the model was malt barley output (kg) harvested during the 2020/21 production season, using the production inputs such as area under MB (ha), oxen (oxen-days), labor (man-days in man-equivalent), seed (kg), chemicals (herbicides and pesticides in liters), and fertilizers (sum of NPS (nitrogen, phosphorus, and sulfur) and urea fertilizers applied
in kg. The results of the stochastic production frontier analysis show that, except chemicals, all other inputs had a significant and positive effect on MB production. This indicates that malt barley production was responsive to input utilization. The coefficients of the production function represent the elasticities. Thus, *ceteris paribus*, the increase in land, labor, oxen, seed, and fertilizer inputs by 1% would cause malt barley production to grow by 0.45, 0.32, 0.15, 0.08, and 0.05%, respectively. The sum of the six input elasticities gives a value of 1.05, indicating that scale elasticity is greater than one, and so the MB production function exhibits IRS (increasing returns to scale).

Using the Cobb–Douglas production function parameter estimates in Table 4, the corresponding dual cost frontier function parameters are given as

### Table 3. Descriptive statistics of input and explanatory variables

| Variables           | Unit   | Mean   | Std. Deviation |
|---------------------|--------|--------|----------------|
| Output              | Kilograms | 1816.85 | 1214.68        |
| Malt barley farm size | Hectares | 0.82 | 0.54          |
| Labor               | Man-days | 40.66 | 24.22          |
| Seed                | Kilograms | 77.65 | 49.85          |
| Oxen                | Oxen-days | 17.75 | 12.07          |
| Chemical            | Liters | 0.64 | 0.61          |
| Fertilizer          | Kilograms | 131.83 | 84.54         |
| Age                 | Years | 44.10 | 10.90         |
| Family size         | Adult equivalent | 4.66 | 1.58         |
| Education           | Years | 4.61 | 3.41         |
| Total landholding   | Hectares | 2.40 | 1.17         |
| Livestock           | TLU | 8.53 | 3.65         |
| Sex                 | Dummy (1 = male) | 0.90 | 0.31         |
| Cooperative membership | Dummy (1 = yes) | 0.41 | 0.49         |
| Credit access       | Dummy (1 = yes) | 0.22 | 0.41         |

Source: Results from sample survey data (2021).

### Table 4. Maximum likelihood and OLS estimates of production function

| Variables   | ML estimates | OLS estimates |
|-------------|--------------|---------------|
|             | Coeff.       | Std. Error    | Coeff.       | Std. Error    |
| Constant    | 5.5374**     | 0.2008        | 5.3053**     | 0.1965        |
| ln (Land)   | 0.4547***    | 0.0421        | 0.4445***    | 0.0428        |
| ln (Labor)  | 0.3152***    | 0.0455        | 0.3383***    | 0.0448        |
| ln (Seed)   | 0.0800**     | 0.0380        | 0.0813**     | 0.0405        |
| ln (Oxen)   | 0.1457***    | 0.0420        | 0.1354***    | 0.0430        |
| ln (Chemical) | 0.0029     | 0.0129        | 0.0027       | 0.0134        |
| ln (Fertilizer) | 0.0532*** | 0.0176        | 0.0586***    | 0.0182        |
| Wald χ² statistic | 5985.27*** |               |               |               |
| Sigma2      | .0422465     | .0068202      |               |               |
| Lambda      | 1.774589     | .0380359      |               |               |
| Lag likelihood | 194.36     |               |               |               |

Source: Results from sample survey data (2021).
Notes: ** and ***indicate significance at 5% and 1% levels, respectively.
\[ \ln C_i = -0.794 + 0.125 \ln W_{\text{land}} + 0.128 \ln W_{\text{labor}} - 0.081 \ln W_{\text{seed}} + 0.282 \ln W_{\text{oxen}} + 0.264 \ln W_{\text{chemicals}} + 0.019 \ln W_{\text{fertilizers}} + 0.742 \ln Y^*_i \]

where \( C_i \) refers to the minimum production cost for \( i \)th farmer, \( W_i \)'s are the respective input prices, and \( Y^*_i \) represents the index of malt barley output adjusted for statistical noise and scale effects.

### 3.2.2. Production efficiency scores and distributions

**Table 5** shows the summary statistics and frequency distribution of the technical, allocative, and economic efficiency scores. The average TE of the sample households was found to be about 87.1% with a minimum of 66.3% and a maximum of 96.6%. This implies, in the short run, if farmers can get the important managerial and technical skills, they will on average be able to increase their production by 12.9%. This result also implies that if the average MB producer were to attain the same level of TE as its most efficient counterpart, she or he could realize 9.83% reduction of inputs used to produce the output of the most efficient counterpart.

The average allocative efficiency of the malt barley farmers was 80.6%, meaning that if these farmers operated at full allocative efficiency, they could lower their production costs by 19.4% while producing the same amount of output. The average economic efficiency level is 70.6%, with minimum and maximum efficiency scores of 36.5% and 91.3%, respectively. That means, a farmer with an average level of economic efficiency may cut the current average production costs by 29.4% to reach the minimum cost level while maintaining the same output level. This also indicates that, a MB producer with a mean level of economic efficiency would save production cost by 22.67% \((1-(0.706/0.913))*100\) to reach the level of most economically efficient producer.

According to the summary statistics results in **Table 5**, about 41%, 41% and 44% of the efficiency estimates of the sample households in the study area lie below the mean level of technical, allocative and economic efficiency scores, respectively. It also reveals that only 15.32% and 0.52% of the farmers were respectively operating above 90% of allocative and economic efficiency levels as compared to 43.38% of them lying in this range for technical efficiency.

| Efficiencies range | TE Frequency | AE Frequency | EE Frequency | Percentage |
|--------------------|-------------|--------------|--------------|------------|
| 0.31–0.40          | -           | -            | 3            | -          |
| 0.41–0.50          | -           | -            | 21           | - 0.26    |
| 0.51–0.60          | -           | -            | 55           | - 3.64    |
| 0.61–0.70          | 5           | 40           | 84           | 1.30 10.39|
| 0.71–0.80          | 61          | 99           | 131          | 15.84 25.71|
| 0.81–0.90          | 152         | 172          | 89           | 39.48 44.68|
| 0.91–1.00          | 167         | 59           | 2            | 43.38 15.32|
| Total              | 385         | 385          | 385          | 100 100 100|
| Operating below mean | 158        | 158          | 171          | 41.04 41.04|
| Operating above mean | 227        | 227          | 214          | 58.96 58.96|
| Mean               | 0.871       | 0.806        | 0.706        |            |
| Std. Dev.          | 0.066       | 0.096        | 0.119        |            |
| Min.               | 0.683       | 0.487        | 0.365        |            |
| Max.               | 0.966       | 0.954        | 0.913        |            |

Source: Results from sample survey data (2021).
| Variable                  | Technical Efficiency | Allocative Efficiency | Economic Efficiency |
|---------------------------|----------------------|-----------------------|---------------------|
|                           | Coefficient (Std. Error) | Marginal Effects | Coefficient (Std. Error) | Marginal Effects | Coefficient (Std. Error) | Marginal Effects |
| Education                 | 0.00358*** (0.0010)   | 0.00348               | 0.0040*** (0.0015)   | 0.0039            | 0.00648*** (0.00178)   | 0.00640 |
| Family size               | 0.00123 (0.0019)      | 0.00120               | 0.00107             | 0.00159           | -0.000669* (0.00357)   | 0.00661 |
| Credit                    | 0.01461** (0.0064)    | 0.01411               | 0.01245             | 0.02213           | 0.03581*** (0.01192)   | 0.03520 |
| Extension contact         | 0.00200* (0.0011)     | 0.00195               | 0.00174             | 0.00257           | -0.000043 (0.00211)    | -0.00043 |
| Off/non-farm income       | 0.00079** (0.0003)    | 0.00077               | 0.00069             | 0.00257           | -0.000003 (0.00061)    | -0.00003 |
| Distance from market      | -0.00053*** (0.0001)  | -0.00052              | -0.00066            | -0.00068          | -0.00118*** (0.00021)  | -0.00117 |
| Landholding               | -0.00316 (0.0028)     | -0.00307              | -0.00275            | -0.00406          | -0.02468*** (0.00530)  | -0.02437 |
| Livestock size            | 0.00296*** (0.0009)   | 0.00287               | 0.00257             | 0.00380           | 0.00669*** (0.00166)   | 0.00660 |
| Cooperative membership    | 0.01244** (0.0056)    | 0.01207               | 0.01076             | 0.01679           | 0.00434 (0.01045)      | 0.00428 |
| Proximity to homestead    | -0.00134*** (0.0002)  | -0.00130              | -0.00117            | -0.00172          | -0.00167*** (0.00040)  | -0.00165 |

(Continued)
### Table 6. (Continued)

|                      |       |       |       |       |       |
|----------------------|-------|-------|-------|-------|-------|
|                      | 0.02838*** (0.0051) | 0.02760 (0.0051) | 0.0390*** (0.0051) | 0.0378 (0.0051) | 0.05520*** (0.0051) |
| Fertility of soil    | 0.02469 | 0.02469 | 0.03424 | 0.03424 | 0.03424 |
|                      | 0.03646 | 0.03646 | 0.0357 | 0.0357 | 0.0357 |
|                      | 0.03646 | 0.03646 | 0.0357 | 0.0357 | 0.0357 |
| Constant             | 0.7562*** (0.0336) | 0.7562*** (0.0336) | 0.7562*** (0.0336) | 0.7562*** (0.0336) | 0.7562*** (0.0336) |
| Log likelihood       | 610.91 | 426.30 | 371.72 | 371.72 | 371.72 |

Notes: ***, ** and * indicate significance at 1%, 5% and 10% levels, respectively.
The table presents only values of significant variables. The marginal effects in cells represent total change \( \frac{\partial y}{\partial x} \), expected change \( \frac{\partial E(y)}{\partial x} \), and probability change \( \frac{\partial f(z)}{\partial x} \).
Source: Results from sample survey data (2021).
3.2.3. Determinants of production efficiency

As indicated in Section 2.3.2, the Tobit model was employed to identify the determinants of technical, allocative, and economic efficiencies. The diagnostic tests conducted for non-normality and heteroscedasticity showed that there were no severe econometric problems in the dataset. Table 6 presents Tobit regression results and the marginal effect estimates for the significant variables in the analysis. The results show that credit access, education, livestock size, and soil fertility significantly and positively affect technical, allocative, and economic efficiencies, whereas distance from the market and proximity to the homestead have significant negative effects on all efficiency estimates. Both allocative and economic efficiency were positively affected by family size, whereas farm size had a significant negative impact on both. Extension contact, cooperative membership, and off/non-farm income are found to significantly and positively affect TE of MB production.

Education allows producers to have better access to information, understand farming instructions easily, make good farm planning, adopt improved production technologies, and correlate the best matches of production inputs with lower cost. This was observed in this study as the education variable had a positive and significant effect on TE, AE, and EE at a 1% probability level. The marginal effect of education shows that a 1-year increase in the education of the household head would increase the probability of a household falling into the TE, AE, and EE categories by 0.46%, 0.37%, and 0.22%, respectively, and the expected value of TE, AE, and EE increases by about 0.31%, 0.34%, and 0.60%, with an overall increase in the probability and level of these efficiencies by 0.35%, 0.39% and 0.64%. The result is in conformity with the findings of Gela et al. (2019), Tenaye (2020), and Wai and Hong (2020).

The availability of different sources of financing solves liquidity constraints farmers may face especially during the peak seasons of production and enables them to make timely acquisition and utilization of inputs, thereby allowing them to implement farm management decisions timely. A change in the credit access variable from 0 to 1 would increase the probability of the malt barley producers being technically, allocatively, and economically efficient almost by 2.21%, 3.13%, and 1.62%, respectively, and change the expected value of technical, allocative and economic efficiencies by 1.23%, 2.35% and 3.25%, resulting in an overall increase in the probability and level of these efficiency estimates by 1.41%, 2.71% and 3.52%. Similar results had been found by Teferra et al. (2018), Tesema et al. (2019), and Tafesse et al. (2021). Conversely, Gela et al. (2019) and Tenaye (2020) found a negative influence of credit on efficiency.

The variable representing the size of livestock possessed by the households as measured by tropical livestock units (TLU) was positive and statistically significant in affecting production efficiency estimates at a 1% probability level. That is, households with a large number of livestock are more technically, allocatively, and economically efficient than households with a small number of livestock. This might be because livestock provides draft power, and manure, and serves as a source of revenue that may be utilized to purchase essential production inputs. The current result is in line with the findings of Elemo et al. (2017), Tafesse et al. (2021), and Bezu et al. (2021).

Contrary to the initial hypothesis of the study (Table 2), the landholding size of the households has a statistically significant negative association with AE and EE. This supports the idea that households with small farms have a better level of efficiency than those with large landholdings (Bezu et al., 2021; Tafesse et al., 2021; Wai & Hong, 2020). This might be because, given the level of technology and the limited access to resources, farmers may not be able to adequately execute the essential crop husbandry practices that should be completed on time when farm sizes are large; and this leads to a reduction in their efficiency. In addition, large landholding might reduce production efficiency by causing scarcity of family labor as well as other production inputs that could have been utilized at the same time in the production of malt barley but on different crops like wheat, food barley, linseed, etc. in the study area. Elemo et al. (2017) and Tesema et al. (2019) found different results.

Family size of a household had a significant positive influence on both allocative and economic efficiencies. This result is in agreement with the findings of Debebe et al. (2015), Wana and Sori
(2018), and Tesema et al. (2019) who in their respective studies found that households with large size of family are more efficient than farmers with smaller household size. One possible explanation is that a bigger family size ensures the availability of family labor for agricultural activities to be performed in time and reduces the cost incurred in hiring labor. Nevertheless, Okello et al. (2019) and Wai and Hong (2020) found opposite results.

The distance between farmer’s residence and the nearest market center was significant in influencing all efficiency estimates at a 1% level of probability. Farmers located far from market centers were found to be less efficient as compared to their close residing counterparts. This might be because a farther distance from the market center implies having limited access to both input and output markets, as well as incurring significant transaction costs to access market information and transport inputs/outputs. Furthermore, a greater distance from the market may deter farmers from engaging in market-oriented production. Ahmed et al. (2015), Teferra et al. (2018), and Wollie et al. (2018) found similar results.

A boost in the income level of farmers is highly correlated with their efficiency level. This is witnessed in this study by the fact that income from off-farm activities has a significant and positive effect on technical efficiency of MB production. Off/non-farm income can be used as additional cash to buy farm inputs, and also serve as a supplement for home consumption and thus positively influencing TE of MB production. The marginal effect of off/non-farm income in Table 6 shows that, for a one thousand birr increase in the earnings generated from off/non-farm activities, the TE of farmers would increase by about 0.08%. This might be because most of the off/ non-farm activities (selling trees, handicrafts, and selling local drinks) performed by the sample households in the study area do not compete with the time allocated for farm activities. The result is consistent with Wana and Sori (2018), Gela et al. (2019), and Asfaw et al. (2019), but contradicts with the results of Wai and Hong (2020).

Agricultural cooperatives are expected to offer malt barley producers with viable information about production technologies, give training, deliver improved inputs, and arrange ways of easy access to credit services to encourage farmers. Thus, this study considered membership in cooperatives as a determinant of production efficiency and found a significant negative relationship between cooperative membership and TE among sampled households at a 5% probability level. Abate et al. (2014), Debebe et al. (2015), and Gela et al. (2019) also found similar results.

Proximity to the homestead is significantly and negatively related to technical, allocative, and economic efficiencies. This might be because, the lesser distance between farmers’ residences and MB plots allows the farmers to sufficiently spend their working time on the farm, increases their frequency of supervision and management of the farm, and lets them apply various crop husbandry procedures and organic fertilizers (especially the bulky animal dung). In addition, households that reside at a nearer distance to their MB farms have cost advantages as the transaction cost involved in delivering inputs and transportation of the product is minimized. The study result is consistent with Teferra et al. (2018), Wollie et al. (2018), and Tesema et al. (2019).

The result in Table 6 indicates that the soil fertility status variable is positive and significant at the 1% level of probability, showing that soil fertility is an important factor in determining malt barley production efficiency. In other words, farmers who allocated relatively fertile farms were more efficient than those who allocated less fertile farms. This might be because farmers with farms with good fertility conditions do not incur a lot of costs for management as these farms do not require frequent plowing, weeding, and application of various chemicals (herbicides and pesticides) as compared to farms with low soil fertility conditions. This is in line with Asfaw et al. (2019), Tenaye (2020), and Bezru et al. (2021).
4. Conclusion and recommendations

This study employed the SPF method to estimate the level of technical, allocative, and economic efficiencies of malt barley production, and the two-limit Tobit model was used to identify their determinants. The mean scores of technical, allocative, and economic efficiency were found to be 87.1%, 80.6%, and 70.6%, respectively. The results of the Tobit regression indicate that education, household size, access to credit, extension contact, livestock holding, distance from market, cooperative membership, off/non-farm income, proximity to homestead, farm size, and soil fertility status are all important determinants of malt barley production efficiency. In general, the findings of this study indicate that with the existing level of technology and resource base, MB producers in Arsi zone are operating below the maximum TE, AE, and EE levels. Thus, to improve the efficiency of malt barley production in Arsi zone, development approaches and efforts aimed at factors that contribute to efficiency differentials among farm households might help in the formulation of better intervention policies. This would help in enhancing productivity and thus alleviating the food insecurity problem in the country. In this regard, the study suggests strategies aimed at improving education, credit access, livestock production, road and market infrastructure, cooperatives, and soil fertility, as well as encouraging farmers to participate in off-farm activities and motivating and mobilizing the rural people, especially the youth, in farming activities.

Acknowledgements

We greatly acknowledge the farmers for their unreserved cooperation in sharing their insights. Enumerators and agricultural experts are much appreciated for their support during the survey.

Funding

This work was supported by a funding from Haramaya University, Office of Vice President for Research Affairs.

Author details

Sime Shiferaw1
E-mail: simeroko@gmail.com
Jema Haji2
Mengistu Ketema2
Million Sileshi1

1 School of Agricultural Economics and Agribusiness, Haramaya University, Dire Dawa, Ethiopia.
2 Ethiopian Economics Association, Addis Ababa, Ethiopia.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Citation information

Cite this article as: Technical, allocative and economic efficiency of malt barley producers in Arsi zone, Ethiopia, Sime Shiferaw, Jema Haji, Mengistu Ketema & Million Sileshi, Cogent Food & Agriculture (2022), 8: 2115669.

References

Abate, G. T., Francesconi, G. N., & Getnet, K. (2014). Impact of agricultural cooperatives on smallholders’ technical efficiency: Empirical evidence from Ethiopia. Annals of Public and Cooperative Economics, 85(2), 257–286. https://doi.org/10.2139/ssrn.2225791
Ahmed, M. H., Lemma, Z., & Endrias, G. (2014). Technical efficiency of maize producing farmers in Arsi Negelle, central rift valley of Ethiopia: Stochastic frontier approach. Agriculture & Forestry, 60(1), 157–167. http://dx.doi.org/10.1007/s10423-013-9561-9
Ahmed, M. H., Lemma, Z., & Endrias, G. (2015). Measuring technical, economic and allocative efficiency of maize production in subsistence farming: Evidence from the central rift valley of Ethiopia. Applied Studies in Agribusiness and Commerce, 9(3), 63–74. https://doi.org/10.19041/APSTRACT/2015/3/9
Aigner, D. J., Lovell, C. K., & Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. Journal of Econometrics, 6(1), 21–37. https://doi.org/10.1016/0304-4076(77)90052-5
Alemu, M. A. (2016). Partial substitution of malted barley by raw barley in brewing technology [MSc Thesis]. Addis Ababa University.
Alemu, G., & Haji, H. (2016). Economic efficiency of sorghum production for smallholder farmers in eastern Ethiopia: The case of Habro district. Journal of Economics and Sustainable Development, 7(15), 44–51. https://issuu.com/Journals/index.jsp?EDS/article/view/32623/33515
Asfaw, M., Getu, E., & Mitiku, F. (2019). Economic efficiency of smallholder farmers in wheat production: The case of Abuna Gindeberet district, Oromia National Regional State, Ethiopia. International Journal of Environmental Sciences & Natural Resources, 16(2), 41–51. https://doi.org/10.19080/IJESNR.2019.16.555932
ATA (Agricultural Transformation Agency). (2017). Agricultural transformation agenda: Annual report 2016-17, November 2017.
Aye, G. C., & Mungatana, E. D. (2011). Technological innovation and efficiency in the Nigerian maize sector: Parametric stochastic and non-parametric distance function approaches. Agreron: Agricultural Economics Research, Policy and Practice in Southern Africa, 50(4), 1–24. https://doi.org/10.303185.2011.617870
Battese, G. E., & Coelli, T. J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. Empirical Economics, 20(2), 325–332. https://doi.org/10.1007/BF01205462
Bekele, Y., & Regasa, G. (2019). Technical efficiency of smallholder malt barley producers in Tyro district (Ethiopia). RUDN Journal of Economics, 27(3), 525–535. https://doi.org/10.22363/2313-3239-2019-27-3-525-535
Beshir, H., Emana, B., Kassou, B., & Haji, J. (2012). Economic efficiency of mixed crop-livestock production system in the north eastern highlands of Ethiopia: The stochastic frontier approach. Journal of Agricultural Economics and Development, 11(1), 10–20.
Bezabeh, A., Feyene, F., Haji, J., & Lemma, T. (2020). Impact of contract farming on income of smallholder farmers in Ethiopia. Cogent Food & Agriculture, 6(1). https://doi.org/10.1080/23311932.2020.2115669
malt barley farmers in Arsi and West Arsi zones of Oromia region, Ethiopia. Cogent Food & Agriculture, 6 (1), 1834662. https://doi.org/10.1080/23311932.2020.1834662

Bezu, K. H., Chala, B. W., & Wakjira, M. (2021). Economic efficiency of wheat producers: The case of Debos Libanos district, Oromia, Ethiopia. Turkish Journal of Agriculture - Food Science and Technology, 9(6), 953–960. https://doi.org/10.24295/turjaf.v9i6.953-960.4244

Bravo-Ureta, B. E., & Rieger, L. (1991). Dairy farm efficiency measurement using stochastic frontiers and neoclassical duality. American Journal of Agricultural Economics, 73(2), 421–428. https://doi.org/10.2307/1242726

Cameron, A. C., & Trivedi, P. V. K. (2009). Microeconometrics Using Stata. A. Sta Press Publication, StataCorp LP.

Coelli, T. J., Rao, D. S. P., & Battese, G. E. (1998). An introduction to efficiency and productivity analysis. Kluwer Academic Publishers.

Coelli, T. J., Rao, D. S. P., O'Donnell, C. J., & Battese, G. E. (2005). An introduction to efficiency and productivity analysis (2nd ed.). Springer Media, Inc.

Coelli, T. J., Sandura, R., & Colin, T. (2002). Technical, allocative, and cost scale efficiencies in Bangladesh rice cultivation: A non-parametric approach. Journal of Agricultural Economics, 53(3), 607–626. https://doi.org/10.1111/1477-9552.2002.tb00040.x

CSA (Central Statistical Agency). (2016). Agricultural sample survey: Area and production of major crops, meher season. CSA, Vol. I.

CSA (Central Statistical Agency). (2019). Agricultural sample survey: Area and production of major crops, meher season. CSA, Vol. I.

Debebe, S., Haji, J., Goshu, D., & Edris, A. K. (2018). Technical, allocative, and economic efficiency among smallholder maize farmers in Southwestern Ethiopia: Parametric approach. Journal of Development and Agricultural Economics, 7(8), 282–291. https://doi.org/10.5897/JDAE2015.0652

Dessale, M. (2019). Analysis of technical efficiency of small holder wheat-growing farmers of Jamma district, Ethiopia. Agriculture and Food Security, 8(1), 1–8. https://doi.org/10.1186/s40066-018-0250-9

EATA (Ethiopian Agricultural Transformation Agency). (2010). Accelerating Ethiopian agriculture development for growth, food security and equity. Addis Ababa.

Elmo, M., Tsegay, R., & Mohammed, T. (2011). A study of economic efficiency of mixed crop-livestock production system in the north eastern highlands of Ethiopia. African Journal of Soil Science, 5(2), 256–366. https://storage.internationalsscholarjsournals.org/pdf/257634158463917257.pdf?psop=1

Fahad, S., & Wang, J. (2016). Farmers’ risk perception, vulnerability, and adaptation to climate change in rural Pakistan. Land Use Policy, 79, 301–309. https://doi.org/10.1016/j.landusepol.2018.08.018

Fahad, S., & Wang, J. (2020). Climate change vulnerability, and its impacts in rural Pakistan: A review. Environmental Science and Pollution Research, 27(1), 1334–1338. https://doi.org/10.1007/s11356-019-06878-1

FAO (Food and Agriculture Organization). (2019). FAOSTAT statistical database. Food and Agriculture Organization of the United Nations, Rome, Italy. https://www.fao.org/faostat/en/
data

Gebretsadik, D. (2017). Technical, allocative and economic efficiencies and sources of inefficiencies among large-scale sesame producers in Kaffa Humera District, western zone of Tigray, Ethiopia: Non-parametric approach. International Journal of Scientific and Engineering Research, 8(6), 2041–2061.

Gela, A., Haji, J., Ketema, M., & Abate, H. (2019). Technical, allocative and economic efficiencies of small-scale sesame farmers: The case of west Gondar zone, Ethiopia. Review of Agricultural and Applied Economics, 22(2), 10–17. https://doi.org/10.15414/raoe.2019.22.02.10-17

Gould, B., Soup, W., & Klemme, R. (1985). Conservation tillage. The role of farm and operator characteristics and the perception of soil erosion. Land Economics, 65(2), 167–182. https://doi.org/10.2307/3146791

Haji, J. (2006). Production efficiency of smallholders’ vegetable-dominated mixed farming system in eastern Ethiopia: A non-parametric approach. Journal of African Economics, 16(1), 1–27. https://doi.org/10.1093/jpejl/044

Haji, J., & Andersson, H. (2006). Determinants of efficiency of vegetable production in smallholder farms: The case of Ethiopia. Acta Agriculturae Scand Section C, 3 (3–4), 125–137. https://doi.org/10.1080/165074061127714

Hjalmarsson, L., Kumbhakar, S., & Heshmati, A. (1996). DEA, DFA and SFA: A comparison. Journal of Productivity Analysis, 7(2(3)), 303–327. https://doi.org/10.1007/BF00157046

ICARDA (International Center for Agricultural Research in the Dry Areas). (2019). Seed Info: Official newsletter of West Asia and North Africa (WANA) seed network. Issue No. 56, Seed Section, ICARDA, P.O. Box 114/0555.

Kopp, R. J., & Diewert, W. E. (1982). The decomposition of frontier cost functions deviations into measures of technical and allocative efficiency. Journal of Econometrics, 19(2–3), 51–65. https://doi.org/10.1016/0304-4076(82)90008-2

Lema, T. Z., Moresha, S. E., Neway, M. M., & Demeke, E. M. (2022). Analysis of the technical efficiency of barley production in north Shewa zone of Amhara regional state, Ethiopia. Cogent Economics & Finance, 10(1), 2043509. https://doi.org/10.1080/23323093.2022.2043509

Maddala, G. S. (1999). Limited dependent variable in econometrics. Cambridge University Press.

McDonald, J. F., & Moffitt, R. A. (1980). The use of Tobit analysis. Review of Economics and Statistics, 62(2), 318–321. https://doi.org/10.2307/1924766

Meeussen, W., & van den Broeck, J. (1977). Efficiency estimation from Cobb-Douglas production functions with composed error. International Economic Review, 18 (2), 435–444. https://doi.org/10.2307/2525757

Mulatu, B., & Grando, S. (2011). barley research and development in Ethiopia. Proceedings of the 2nd national barley research and development review workshop. 28–30 November 2006, HARC, Holetta, Ethiopia. ICARDA, P.O.Box 5466, Aleppo, Syria.

NBE (National Bank of Ethiopia). (2019). Annual report 2017/18, National Bank of Ethiopia, Addis Ababa.

Okello, D. M., Bonabana-Wabbi, J., & Mugonola, B. (2019). Farm level allocative efficiency of rice production in Gulu and Amuru districts, northern Uganda. Agricultural and Food Economics, 7(1), 1–19. https://doi.org/10.1186/s40066-018-0140-0

Rashid, S., Abate, G. T., Lemma, S., Warner, J., Kasa, L., & Minot, N. (2015). The barley value chain in Ethiopia. International Food Policy Research Institute (IFPRI).

Shate, A. E., Tefera, T., & Gidey, G. (2021). Technical efficiency of malt barley production in Malga district of southern Ethiopia. Innovative Systems Design and Engineering, 12 (1), 18–21. https://doi.org/10.17161/ISDE12.1-03

Su, F., Song, N., Ma, N., Sultanmalek, A., Ma, J., Xue, B., & Fahad, S. (2021). An assessment of poverty
Appendix

| Variable                                      | Measurement         |
|-----------------------------------------------|---------------------|
| In(Total malt barley output)                  | Kilograms           |
| In(Total land covered with malt barley)       | Hectares            |
| In(Total labor used)                          | Man-days            |
| In(Quantity of fertilizer used)               | Kilograms           |
| In(Quantity of malt barley seed used)         | Kilograms           |
| In(Oxen-power used)                           | Oxen-days           |
| In(Amount of agro-chemicals used)             | Liters              |
| In(Total cost of MB production)               | Birr                |
| In(Price of land used)                        | Birr per hectare    |
| In(Price of total labor used)                 | Birr per man-equivalent |
| In(Price of fertilizer used)                  | Birr per kilogram   |
| In(Price of seed used)                        | Birr per kilogram   |
| In(Price of oxen-power used)                  | Birr per oxen-day   |
| In(Price of agro-chemicals used)              | Birr per liter      |
