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Estimation of technical efficiency of dairy farms in central zone of Tigray National Regional State

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Abstract

This paper was conducted to estimate technical efficiency in milk production of dairy farmers in central zone of Tigray National Regional State using stochastic frontier production function approach. Cross-sectional data collected from 163 dairy farmer households was used in the analysis. The result shows that the average technical efficiency of sampled dairy farmer households is about 63.7%. It also shows that labor input by households and average amount of daily cost of crop residue/byproduct do not influence amount of milk produced when stochastic frontier and inefficiency effects are estimated in combination. The estimates of coefficients of other explanatory variables of stochastic frontier production function (i.e. number of lactating cows, average daily cost of purchased supplements, average daily health/veterinary expenditure and average amount of water consumed daily) are found to influence amount of milk produced positively. From the explanatory variables incorporated in inefficiency model sex of household head, extension contact and households off farm income do not influence inefficiency of dairy farmer households while age of household head, years of education of the household head and cattle size are found to influence inefficiency of dairy farmer households negatively. Age squared of household head and household sizes influence inefficiency of dairy farmer households positively. Thus, it can be concluded that by improving

dairy farmers' access to education, family planning program and improving bureaucratic environment in providing extension services it is possible to increase amount of milk produced.

Keyword: Economics

1. Introduction

As of [Central Statistical Agency \(2015a,b\)](#) Ethiopia has the largest livestock population in Africa. This livestock sector has been providing significant contribution to the development and growth of the economy of the country. The livestock products and by-products which includes meat, milk, honey, eggs, cheese, and butter could provide the required animal proteins which can improve nutritional status of the people. being source of foreign currency livestock sector can also contribute to export sector and thus improve the trade balance of a country. Besides, livestock provide a certain degree of security in times of crop failure. The manure we get from livestock can be used for improving soil fertility and as source of energy. In addition, the dairy sector contributes to economic growth in such a way that it can increase income and employment opportunity. For instance, in 2010 it creates 588,000 full time on-farm jobs. As of [Zelalem et al.](#), Ethiopia's foreign exchange earnings from dairy products increased from \$73, 000 in 2005 to \$123,000 in 2009. As of [CSA \(2015a,b\)](#), however, most of dairy products are used for home consumption.

Ethiopia's livestock population is estimated to 188,929,303 from which total cattle estimated to be about 56,706,389, out of which female cattle constitute about 55.45 % ([CSA, 2015a,b](#)) and 10.5 million dairy cattle ([USAID, 2010](#)). Ethiopia has great potential for dairy sector development because it has favorable climate for improved, high yielding dairy cattle breeds and regions with less animal disease.

As of [Zelalem et al. \(2011\)](#) even though Ethiopia has large number of dairy cows and significant number of dairy farmer participate in the dairy sector, the sector is not well developed and is not contributing the expected impact on economic growth of the country. The average milk produced per a day (Liters/caw) is decreasing from 1.69 in 2010 to 1.349 in 2014. As of [CSA \(2015a,b\)](#) the average daily milk production (i.e. 1.327 liters) in Tigray National Regional State is slightly less than the national average. It is also found that the average dailymilk production (i.e. 0.936 liter/cow) in Central Zone of Tigray national regional state is lower than the regional average. Though it is the least performing Zone in Tigray National Regional State, as to the knowledge of researchers it is not researched yet. Thus, the current study estimates Milk Production Efficiency and its determinants in this Zone by using stochastic frontier model.

The general objective of this study is to estimate technical efficiency of dairy farm in Central Zone of Tigray National Regional State. The Specific Objectives are to investigate the input output relationship in dairy farm production, and to identify the demographic and socio-economic factors affecting technical efficiency of dairy farms.

2. Background

Production is a process of transforming inputs (e.g. labor, capital, and raw materials) to output (which can be in the form of intermediate goods, final goods or services). This transformation of inputs to outputs can be represented in production function. It shows the maximum level of output that can be produced from a given production technology and level of input (Aigner et al., 1977; Kumbhakar et al., 2015).

2.1. Defining efficiency

Efficiency is defined as the maximum level of output produced with the inputs which is actually employed or whether that output is produced at minimum cost. Efficiency is categorized to technical efficiency and allocative efficiency which together gives overall efficiency. Technical efficiency relates observed level of output and ideal or potential level of output. In the other word, it measures the maximum attainable level of output that can be resulted from best practice and optimal combinations of inputs. In principle technical efficiency implies maximizing level of output produced with given the level of cost production. Allocative efficiency on the other hand shows producer's success in choosing optimal set of inputs consistent with relative factor prices. In principle it implies minimizing cost of production from given the level output produced (M. J. Farrell, 1957 and Greene, 2008).

To make Farrell approach to efficiency measurement clear consider Fig. 2. Suppose, for simplicity, a firm is using two inputs to produce single output under constant return to scale. We can represent all relevant information by Isoquant since we assumed constant return to scale. In Fig. 2, point P indicates inputs of two factors of production that the firm is observed to use in production of a unit of output.

Point Q indicates efficient firm using two factors of production in similar ratio as point P by using only OQ / OP as much of each factor of production. We can also understand that from the same level of inputs, OP / OQ times as much output can be produced. Thus, OQ / OP is defined as technical efficiency of the firm P. This ratio takes the values which is equal to one or 100% for perfectly efficient firm, and indefinitely small if the amounts of input per unit output is indefinitely large. In addition, increasing level of input per a unit of output imply lower technical efficiency other things being constant.

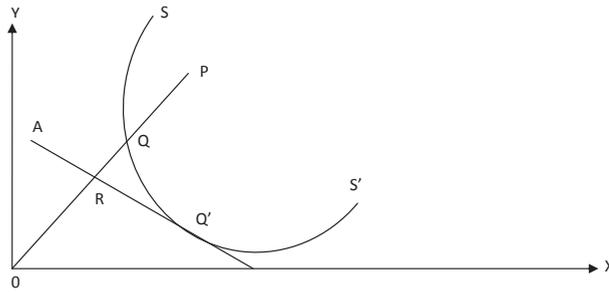


Fig. 1. Farrell approach to technical Efficiency measurement.

Fig. 1 also shows if the slope of line AA' is equal to ratio of two factors' prices Q' and not Q is the optimal method of production; for though both points indicates 100% technical efficiency, the costs of production at Q' will only be OR / OQ of those at Q . This ratio can be defined as price efficiency of Q (Farrell, 1957).

Kumbhakar et al. (2015) classified technical inefficiency as input-oriented and output-oriented technical inefficiency. If observed level of output is produced using fewer level of inputs it implies input-oriented technical inefficiency and if higher level of output is achieved for a given level of inputs it implies output-oriented technical inefficiency.

Kumbhakar et al. (2015) shows graphically that the inefficient production plans are located below the production frontier. In the Fig. 2, $F(X)$ represents production possibility frontier. Point A represents inefficient production point since it is found below production possibility frontier. It can be seen in two ways why it is inefficient point. Firstly, at present level of input X , larger level of output can be produced (that is at point B). Thus, line segment \overline{AB} indicates the lost output as a result of technical inefficiency. This measures *output-oriented* (OO) technical inefficiency. Secondly, at point A equal level of output can be produced using fewer amount of inputs (that is at point C). Thus, line segment \overline{AC} indicates the level of inputs that can be decreased level of output being constant. This measures *input-oriented* (IO) technical inefficiency.

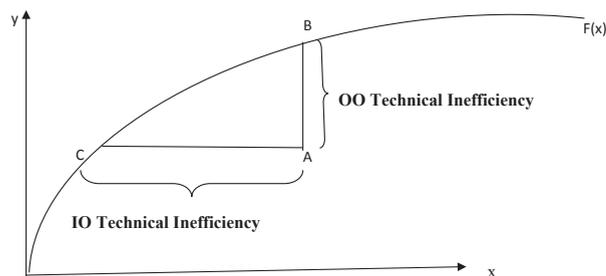


Fig. 2. Input-output and output-output Technical inefficiency for the one-input, one output.

In this study output- oriented technical efficiency is employed. It is preferred because it is widely used in single equation stochastic production frontier.

2.2. Approach for measuring efficiency

There are two most prominent and widely applied methods used for measuring efficiency. These are Stochastic Frontier Analysis (SFA) and the Data Envelopment Approach (DEA). The SFA was developed by (Aigner et al., 1977) and (Meeusen and van der Broeck, 1977) while DEA was developed by Charnes et al. (1978). Various researchers have been applied the two methods to analyze efficiency in various countries and sectors by comparing the two methods based on their strengths and weaknesses.

SFA is a parametric approach while DEA is non-parametric approach. The function in SFA model involves a composite error term which accounts both for the statistical noise in the data as well as the inefficiency in production which is one of its strength while DEA uses linear programming function which does not decompose stochastic disturbance from inefficiency effect in production. In DEA method the deviation from efficient frontier is accounted for only inefficiency, but not statistical noise. This is one of the weakness of DEA approach.

As of Coelli (1995) imposing restrictive assumptions to both production function and the distribution of stochastic errors terms is one weakness of SFA method. DEA, however, does not impose restrictive assumptions to production function and distributions of disturbance terms. This one strength of DEA which makes it suitable to accommodate problems that may arise from such restrictions (Erkoc, 2012).

The other weakness of DEA is that it is vulnerable to measurement errors and outliers. Thus, it has been argued that DEA is less convenient for applications particularly in developing country agricultural setting where data quality is doubtful and such measurement errors are much pronounced (Erkoc, 2012; Coelli, 1995).

In this study SFA is used because of its advantage in decomposing the error term into inefficiency and noise (stochastic) term.

The study of efficiency in production has been subject of many researchers in the past. The largest number of researchers have been studying efficiency in production related to agriculture sector specifically crop production. The study of efficiency in livestock production is almost neglected sector specifically in Ethiopia though it has the largest livestock population in Africa. As of Aleme and Lemma (2015) the contribution of livestock to the economic growth of the country is low. Thus, to enhance the contribution of livestock specifically dairy sector to economic growth

factors influencing technical efficiency of dairy farmers and level of their technical inefficiency should be estimated so that policy recommendation provide in this study might be used by policy makers.

The existing literatures show that various factors influence the output of dairy production and technical efficiency of dairy farm households.

According to [Ali Al-Sharafat \(2013\)](#) Number of cows, feed intake and labor man days affect level of output of milk production positively while value of veterinary services, fixed inputs and depreciation costs have no significant impact on level of output of milk production. Education, herd size (cows) and experience affects efficiency in milk production positively while contact with extension service does not affect efficiency in milk production. The mean technical efficiency computed in this study from 100 dairy farms in Jordan was found to be 39.5%.

As of [Bardhan and Sharma \(2013\)](#) depreciation, veterinary expenditure and green fodder index does not affect the amount of milk produced while miscellaneous expenditure and dry fodder index positively affects the amount of milk produced in plain areas. Concentrate index and family labor, on the other hand, affect amount of milk produced negatively. It also shows that efficiency of dairy farmers is positively affected by proportion of output used, but negatively affected by, age of households in hill areas and herd size in plain areas. Nonfarm income, education of households, land holding size, price received and access to information, however, do not influence level of efficiency in milk production in both plain and hill areas. The mean technical efficiency of 60 household dairy farmers of Kumaon division of Indian on which this study was conducted was found to be 89.27%.

[Adane et al. \(2015\)](#) found that total number of lactating cows, total number of labor, total cost of purchased supplement and agro ecology influence milk production positively while total grazing land available, amount of crop residue, total cost of purchased forage, total health expenditure and cow breed do not influence level of milk output. Sex of household, age of household, age square and walking distance to development agency do not influence efficiency level of dairy farmers while education and total wealth of house hold were found to influence inefficiency of dairy farmers negatively. Only Walking distance to district *woreda* town is found to influence inefficiency level of dairy farmers positively. This research was conducted on 1227 dairy farmers in Ethiopia and found 55.5% mean technical efficiency.

The finding of [Nega and Simeon \(2006\)](#) shows that local breed cows, family labor and hired labor do not affect level of milk output while cross breed cows, concentrate, forage and veterinary cost affect milk output positively. It also shows that age, sex, location and credit do not affect inefficiency level while literacy and

livestock training influence inefficiency level of dairy farmers negatively. This study was conducted on 74 dairy farmers of central high lands of Ethiopia and found 79% mean technical efficiency.

Although reviewed literatures indicate that there are various factors affecting output level of milk and technical efficiency of dairy farmer households some of the results are conflicting. It means that some literatures reported some factors which affect output level and technical efficiency level of dairy farmer households either positively or negatively while others reported the same variables to have no impact on output level and efficiency level of dairy farmer households. For instance, as of [Ali Al-Sharafat \(2013\)](#), [Bardhan and Sharma \(2013\)](#) and [Adane et al., \(2015\)](#) veterinary cost has no impact, but positive impact as of [Nega and Simeon \(2006\)](#) on amount of milk produced. Labor input has positive impact on amount of milk produced as found in [Ali Al-Sharafat \(2013\)](#) and [Adane et al. \(2015\)](#) but, negative impact as found in [Bardhan and Sharma \(2013\)](#) and no impact as found in [Nega and Simeon \(2006\)](#). Education of household head negatively affects technical inefficiency of milk production as found in [Bardhan and Sharma \(2013\)](#), [Nega and Simeon \(2006\)](#) and [Adane et al. \(2015\)](#) but, positively influence it as found in [Ali Al-Sharafat \(2013\)](#).

Besides, some literatures gave great consideration only for smaller number of factors proposed to have impact on output level and technical efficiency level of dairy farmer households. For instance, [Bardhan and Sharma \(2013\)](#) doesn't include number of lactating cows in its production function while number of lactating cow is an essential input determining the amount of milk produced. In addition, all reviewed literatures [i.e. [Ali Al-Sharafat \(2013\)](#); [Bardhan and Sharma \(2013\)](#); [Adane et al. \(2015\)](#); [Nega and Simeon \(2006\)](#)] didn't incorporate amount of water consumed while it is essential determinant for amount of milk produced.

The current study contributes to existing literatures in that it is more comprehensive that is it gives greater attention for greater number of variables which are supposed to influence level of milk output and efficiency of dairy farmer households. Thus, it is possible to better understand the factors that affect level of milk output and technical efficiency of dairy farmer households and thus recommend appropriate policy action.

3. Methodology

For this study firm level data were collected from 163 dairy farmer households in Aksum town, Adwa town and AbieAdi town. These towns were preferred because of relatively rich in livestock resources (dairy farm is relatively well practiced), after the consultation of Agriculture and rural development Officer, small and micro-scale enterprise officers.

3.1. Sampling technique, sample size and data collection technique

To determine sample size Newbold(1995) was followed: n

$$= \left[\frac{(p*q*z^2)}{e^2} + \left(\frac{z^2*p*q}{N*e^2} \right) \right]$$

Where:

n = sample size

p = proportion that the sample will occur

q = proportion that the sample will not occur = (1- p).

z = standardized score.

e = Error term.

N = total number of Population.

The confidence interval used is 95% which means level of significance (error term is 0.05) and corresponding Z value is 1.96. The probability that the sample will occur is 0.50 and will not occur is 0.50. The number of target population of Aksum town, Adwa town and Abie Adi town is 520, 200 and 60 respectively (total 780) in 2015(Small and micro scale enterprises office of respective towns). Thus, substituting all variables in the above equation the sample size was found to be 198. Following [Ali Al-Sharafat \(2013\)](#) for questionnaire testing 32 dairy farmers were added. Therefore, total 230 dairy farmers were proposed to be interviewed. Interview was preferred because there might be illiterate respondents. Accordingly a structured interview question was prepared to collect primary data from dairy farmer household. Samples were allocated for towns by proportionate sampling technique and selected by Systematic Random Sampling technique supplemented by Snowball sampling technique. Data collected from 18 respondents from abie Adi town, 59 respondents from Adwa town and 86 respondents from Aksum town was used in analysis.

3.2. Data analysis technique

Both descriptive (including percentages, means, variances, tables and graphs) and econometric methods of data analysis were used. Under the econometric analysis, stochastic frontier model was used to estimate technical efficiency of farmers and to examine various variables that affect technical efficiency of farmers. STATA software 11 version was used for estimation.

3.3. The empirical model specification

Similar to Dhehibi et al. (2014) this study employed Battese and Coelli (1995) model with some modifications to fit with cross sectional data. Eq. (1) which represents stochastic production function and Eq. (2) which represents technical inefficiency function are presented as follows:

$$\ln y_i = \ln f(x_i; \beta) + v_i - u_i \quad (1)$$

$$u_i = \sigma' z_i + \varepsilon_i \quad (2)$$

Where,

- \ln = natural logarithm
- y_i = output quantity for the i^{th} farm
- x_i = (kxk) matrix of inputs of production of the i^{th} farm
- β = (kx1) vector of parameters to be estimated.
- ε_i = Random variable

Technical Efficiency of production for the i^{th} dairy farmer can be represented as:

$$TE_i = \exp(-u_i) = \exp(-\sigma' z_i - \varepsilon_i) = \exp\left[-E\left(\frac{u_i}{w_i}\right)\right] = 1 - E\left(\frac{u_i}{w_i}\right) \quad (3)$$

From Eq. (3) one can see technical efficiency of a farmer is between 0 & 1. The dairy farmer's specific efficiencies will be estimated using the estimator which is based on conditional expectation of u_i from composed error $w_i = (v_i - u_i)$. As of Jondrow et al. (1982) the dairy farmer's specific estimates of technical inefficiency can be computed using the expectation of the inefficiency term conditional on the estimate of the entire composed error term.

To Predict TE we can apply either the expected value or the mode of this conditional distribution as an estimate of U :

$$E\left[\frac{U}{W}\right] = \sigma^* \left[\left(\frac{f(w\lambda/\sigma)}{1 - F(w\lambda/\sigma)} \right) - \left(\frac{w\lambda}{\sigma} \right) \right] \quad (4)$$

Where,

- f = standard normal density
- F = distribution functions

Which is to be evaluated at $w\lambda/\sigma$, $\sigma_*^2 = \frac{\sigma_v^2 \sigma_u^2}{\sigma^2}$, $\lambda = \sigma_u/\sigma_v$ and $\sigma^2 = \sigma_u^2 + \sigma_v^2$

The mean TE can be defined as:

$$\text{Mean TE} = E \left[\exp \left\{ -E \left(U_i/w_i \right) \right\} \right] = E \left[1 - E \left(U_i/w_i \right) \right] \quad (5)$$

The β and δ coefficients are unknown parameters to be estimated, together with the variance parameters, which are expressed in terms of:

$$\sigma_*^2 = \frac{\sigma_v^2 \sigma_u^2}{\sigma_v^2 + \sigma_u^2} \quad (6)$$

$$\gamma = \frac{\sigma_u^2}{\sigma_v^2 + \sigma_u^2} \quad (7)$$

Where,

- The value of γ is between zero and one.

In this study Cobb Douglas frontier production function is employed being the most commonly used method in the empirical estimation of frontier models and for its simplicity. The translog form is not preferred because it is susceptible to multicollinearity and degrees of freedom problems (T. J. Coelli, 1995).

The model is specified as follows:

$$\begin{aligned} \text{LnATMPD} = & \beta_0 + \beta_1 \text{LnNLC} + \beta_2 \text{LnLI} + \beta_3 \text{LnAACRBP} + \beta_4 \text{LnADCPS} \\ & + \beta_5 \text{LnADHE} + \beta_6 \text{LnAWCD} + v_i - u_i \end{aligned} \quad (8a)$$

Where,

- Ln is natural logarithm.
- ATMPD = average total milk produced per a day by the i^{th} household measured in liters.
- NLC = number of lactating cows owned by i^{th} household. As numbers of lactating cows increase the total milk produced increases. Thus, it has positive impact on total amount of milk produced.
- LI = Labor input (average man-hour per a day) used by i^{th} household for milk production. The longer the time used in production of milk, the better dairy cows are managed and the higher the amount of milk that can be produced, *citrus paribus*.
- AACRBP = average amount of crop residue/crop byproduct used by household per day (in Ethiopian Birr). Crop residue/byproducts (like that of millet, maize, Teff, and the like) not in terms of kilogram but in Ethiopian Birr per day were used. This is because our respondents didn't know the weight but its cost only. As the amount of crop residue/byproduct used increases it was expected that milk production increases.

- ADCPS = Average daily cost of purchased supplements for dairy cows of the i^{th} household (in Ethiopian Birr). It is expected to affect amount of milk produced positively.
- ADHE = average daily health expenditure measured in Ethiopian Birr of the i^{th} household incurred for dairy cows. It may affect amount of milk produced positively or negatively.
- AWCD = Average amount of water consumed daily by dairy cows (in Liter). The more water consumed the more milk could be produced.
- B 's are parameters to be estimated
- v_i = is random error which represents stochastic variations in milk output as a result of factors outside the control of the farmer such as disease, measurement error etc.
- u_i is the non-negative random term representing the technical inefficiency in production of farm i .

3.4. Technical efficiency

To identify factor that affect inefficiency level of dairy farmer the function can be specified as follows, but estimated with combination of production function using Stata software version 11:

$$TE(u_i) = \delta_0 + \delta_1 \text{SexHH} + \delta_2 \text{AHH} + \delta_3 \text{AHHS} + \delta_4 \text{YEDHH} + \delta_5 \text{Cattlesize} + \delta_6 \text{EContact} + \delta_7 \text{HHsize} + \delta_8 \text{HHOI} + \varepsilon_i \quad (8b)$$

Where,

- $TE(u_i)$ = i^{th} farmer's technical inefficiency score
- SexHH = Sex of the i^{th} household head (0 if Male, 1 if Female)
- AHH = Age of the i^{th} household head (in years). It has positive impact on inefficiency.
- AHHS = Age square of the i^{th} household head (in years):- this shows non-linear relationship between efficiency and Age of the household head. There may be the age limit at which efficiency declines. It is expected to affect efficiency level negatively.
- YEDHH = Highest education level of the i^{th} household head (in years). It is expected to affect technical inefficiency negatively since educated farmers can use improved method of production.
- Cattlesize = this includes the number of oxen, none lactating and lactating cows. Farmers with smaller cattle size are more efficient in milk production. Positive impact on inefficiency is expected.

- EContact = Extension contact (No. of visits) of i^{th} household head. The more frequent farmers contact extension workers the more they will be advised to improve their productivity. Thus, negative impact on the inefficiency is expected.
- HHsize = household size. The larger the number of household the more labor force available to feed, milk, keep dairy cows so that their productivity increase. Thus, negative impact on inefficiency is expected.
- HHOI = Dummy variable whether i^{th} household member has off-farm income source. If house hold get higher off farm income it can ease their financial constraint and thus, apply various inputs to their milk production. This can increase the amount of milk produced.
- δ_i = Inefficiency parameters.
- ε = random error

4. Result and discussion

4.1. Descriptive analysis

Under this sub-topic descriptive results like mean, standard deviation, minimum and maximum of continuous and dummy variables used in the study are discussed.

Table 1 show results related to continuous variables. On average, sampled dairy farmer households produced about 11 liters over the study period. This is less than that of Jordan (i.e. 13 liters/day) as founded in study by Ali Al-Sharafat (2013). The minimum and maximum average daily milk produced by dairy farmer households is found to be 0.5 liters and about 41 liters respectively. The minimum

Table 1. Description of statistics of continuous variables used in the model.

Variables	Observation	Mean	Standard Deviation	Minimum	Maximum
ATMPD	163	11.35	9.72	0.5	40.67
NLC	163	1.53	0.71	1	3
LI	163	296.89	187.59	47	810
AACRBP	163	28.48	25.29	1.44	105
ADCPS	163	19.11	23.78	0.4	131
ADHE	163	1.66	2.20	0.001	14
AWCD	163	45.75	30.15	10	120
AHH	163	48	12	22	80
YEDHH	163	6.72	4.70	0	18
Cattlesize	163	2.33	1.35	1	7
HHsize	163	4.93	2.04	1	10
EContact	163	3.72	4.35	0	21

Source: computed from field survey, 2016

number of lactating cows was 1 and the maximum number was 3. It can be understood that even though there is no as such larger difference in number of lactating cow/s owned by dairy farmer households the level of milk produced is greatly differed. This might be because of difference in appropriate use of inputs (efficiency level of dairy farmer households) and difference in other socio-economic factors. There was great difference in the time spent for herding, milking, feeding and managing of dairy cows, the minimum and the maximum being 47 minutes (i.e. about an hour) and 810 minutes (i.e. about thirteen and half hours) respectively. The amount of crop residue/byproducts used for feeding lactating cow/s is found to be with minimum expense of about 1.4 Birr and maximum 105 Birr. The expenses used for purchased supplements which consists of concentrate feeds, traditional beverage byproducts and industrial byproducts used for feeding lactating cow/s is found with minimum and maximum expense of 0.4 Birr and 131 Birr respectively. The average daily health expenditure, which consists of drugs and expenses on veterinary services, for lactating cow/s was found to be with minimum 1 cent and maximum about 14 Birr over the study period. Though this amount might be small note that most health related services are provided by the government freely through extension system or in highly subsidized manner. The average water consumed daily by lactating cow/s of sampled dairy households was found to be with minimum 10 liters and maximum 120 liters. The minimum age of sampled dairy farmer households was 22 years and maximum was 80 years. The minimum year of education of sampled dairy households was 0 years (uneducated at all) and maximum 18 years (second degree). The minimum extension contact by dairy farmer households over previous five months counted from study period was 0 while the maximum was twenty-one days.

Table 2 shows results related to dummy variables. The larger number of sampled dairy farm households were male headed accounting for about 80% of total respondents. Only about 20 % of respondents were female headed households. About 57 % of sampled dairy farm households responded that at least one of their household members generated their income from off farm activities while about 43% of sampled dairy farm households responded none of their members generated their income from off farm activities. From this it can be said that there might be gap to

Table 2. Description of statistics of dummy variables used in the model.

Variable	description	Frequency	Percentage
SexHH	Male	131	80.37
	Female	32	19.63
	Total	163	100.00
HHOFI	No	70	42.94
	Yes	93	57.06
	Total	163	100.00

Source: own computation from survey data, 2016

Table 3. Description of statistics of dependent variable across dummy variables.

Dummy variables		Observation	Dependent variable: ATMPD			
			Mean	Standard Deviation	Minimum	Maximum
SexHH	Male	131	11.56	10.04	.5	40.67
	Female	32	10.52	8.37	1.67	37.32
	Total	163				
HHOFI	Yes	93	12.02	10.15	.88	40.67
	No	70	10.47	9.10	.5	37.33
	Total	163				

Source: own computation from survey data, 2016

improve efficiency by diversifying their economic activities and increase their income to cover cost of cattle feeds by easing financial constraint. The lower average daily cost of purchased supplement paid for dairy cows can be increased by this way which may increase milk productivity.

Table 3 shows summary of statistics for average amount of milk per dairy farmer household across sex of household head and household's off farm income. The average amount of milk produced daily slightly differs across sex of the household head of respondents. On average male headed dairy farmer households produced 11.56 liters while female headed dairy farmer households produced 10.5 liters daily (i.e. difference is about 1 liter). The minimum and maximum average amount of milk produced daily by male headed dairy farmer households are 0.5 liters and 40.67 liters respectively. The minimum and maximum average amount of milk produced daily by female headed dairy farmer households are 1.67 liters and 37.32 liters respectively.

Besides, Table 3 indicates that on average dairy farmer households whose at least one member earns off farm income produced larger average amount of milk daily (about 12 liters) than dairy farmer households whose none of its member doesn't earn off farm income (about 10.5 liters) (i.e. greater by about 1.5 liters). The minimum and maximum amount of average daily milk produced by household whose at least one member earn off farm income is 0.88 liters and 40.67 liters respectively. The minimum and maximum amount of average daily milk produced by household whose none of member earn off farm income is 0.5 liters and 37.33 liters respectively.

4.2. Empirical analysis

4.2.1. Maximum likelihood estimators

Before we analyze technical inefficiency and factors affecting it we must test the existence of inefficiency in the production function for the sampled dairy farmer households. Table 4 shows that all three distributions support the acceptance of the

Table 4. Maximum Likelihood estimates of the Cobb Douglas stochastic production frontier function with various distribution of inefficiency term.

Half Normal distribution			Exponential distribution		Truncated normal distribution		
Variables			Coefficient	Standard Error	Variables		
LnATMPD	Coefficient	Standard Error			LnATMPD	Coefficient	Standard Error
LnNLC	.87	.14***	.86	.14***	LnNLC	.86	.14***
LnLI	.21	.08**	.19	.09**	LnLI	.20	.08**
LnAACRBP	-.14	.05**	-.14	.06**	LnAACRBP	-.13	.05**
LnADCPS	.11	.04**	.12	.05**	LnADCPS	.11	.04**
LnADHE	.09	.02***	.09	.02***	LnADHE	.09	.02***
LnAWCD	.38	.09***	.39	.10***	LnAWCD	.38	.09***
_cons	.09	.55	-.08	.58	_cons	.05	.56
/lnsig2v	-2.06	.38***	-1.75	.30***	/mu	-.77	2.19
/lnsig2u	-.43	.28	-1.592	.42***	/lnsigma2	.12	.92
sigma_v	.36	.07	.4175	.06	/ilgtgamma	1.96	1.0*
sigma_u	.80	.11	.4512	.09	sigma2	1.13	1.05
sigma2	.77	.15	.38	.06	Gamma	.88	.11
lambda	2.26	.17	1.08	.15	sigma_u2	.99	1.03
					sigma_v2	.1394	.06
Number of obs = 163			Number of obs = 163		Number of obs = 163		
Wald chi2(6) = 208.35			Wald chi2(6) = 221.38		Wald chi2(6) = 209.34		
Log likelihood = -44.85			Log likelihood = -145.22		Log likelihood = -144.71		
Prob > chi2 = 0.00			Prob > chi2 = 0.00		Prob > chi2 = 0.00		
Likelihood-ratio test of sigma_u = 0:			Likelihood-ratio test of sigma_u = 0		H0: No inefficiency component: z = -1.1		
chibar2(01) = 6.27			: chibar2(01) = 5.55 Prob>=chibar2 = 0.009		Prob<=z = 0.023		
Prob>=chibar2 = 0.006							

*, ** and *** = significant at 10%, 5% and 1% level of significance respectively.

alternative hypothesis (i.e. there is inefficiency in our model). The value of lamda (λ) also indicates that inefficiency is significant in all three distributions since it is greater than 1 in all three distributions. Besides, the value of gamma (γ) shows that there is 87.69% variation in output of dairy farmer households due to technical inefficiency. These tests show that technical inefficiency is likely to have an important effect in explaining output among sampled farmers in the study area. Thus, OLS estimates do not provide appropriate results. To get appropriate results Maximum Likelihood estimation must be employed.

In all three models in [Table 4](#) the generalized likelihood ratio test shows that variables incorporated in production function are all together highly significant. It means that the null hypothesis that the coefficient estimates for the explanatory variables $\eta_1 = \eta_2 = \eta_3 = \eta_4 = \eta_5 = \eta_6 = 0$, is rejected at 1% level of significance. The z-values/p-values also show that all explanatory variables are independently highly significant.

Only average daily cost of crop residue/byproduct (LNAACRBP) is found opposite to its expected sign and significant at 5% significance level. On average as average daily cost of crop residue/byproduct increases by 1% the amount of milk produced per day by each dairy farm household decreases by about 0.14 %, *citrus paribus*. This indicates that there is no efficiency gap to increase milk production by increasing average daily cost of crop residue/byproduct. This result is similar to the finding of [Adane et al. \(2015\)](#).

The rest of explanatory variables are found with their expected sign and three of them (i.e. number of lactating cows, average daily health expenditure and average water consumed daily) are significant at 1% significance level, and two of them (i.e. labor input, and average daily cost of purchased supplements) are significant at 5% significance level. On average, as number of lactating cows, Labor input to dairy cow farm, average daily cost of purchased supplements, average daily health expenditure and average amount of water consumed daily by dairy cows increases by 1% the amount of milk produced per day per household increases by about 0.87%, 0.21%, 0.11%, 0.11% and 0.38% respectively, *citrus paribus*. The positive impact of number of lactating cows and labor man days on average amount of milk produced daily is similar to the finding by [Ali Al-sharafat \(2013\)](#) in Jordan.

The results from half normal and exponential distribution are almost similar. This was approved by [Jondrow et al. \(1982\)](#).

[Table 5](#) shows the result from combined estimation of stochastic production function and technical inefficiency effects in all three distributions of error term. The generalized log likelihood test shows that all variables are jointly significant. Putting it shortly the null hypothesis: ($\eta_1 = \eta_2 = \eta_3 = \eta_4 = \eta_5 = \eta_6 = 0$ in the case of

effects are estimated in combination. It means that dairy farmer household, on average, cannot increase milk production by increasing the amount of minutes used for herding, milking, feeding and managing lactating cows and daily cost of crop residue/byproduct. This result of labor input is similar to that of [Nega and Simeon \(2006\)](#). The estimates of coefficients of other explanatory variables of stochastic frontier (i.e. LnNLC, LnADCPS, LnADHE and LnAWCD) are found to have similar effect in direction as before (i.e. when stochastic production frontier is estimated separately, see [Table 4](#)). On average if the number of lactating cows, average daily cost of purchased supplements, average daily cost of health services and average water consumed daily by lactating cows increases by 1%, the average daily amount of milk produced by each household increase by about 0.7%, 0.12%, 0.08% and 0.29% respectively and these variables are significant at less than 5% significance level.

From the explanatory variables incorporated in inefficiency model four (i.e. AHH, YEDHH, AHHS and HHsize) are found statistically significant and four are found to be statistically insignificant in truncated normal distribution. However, 5 explanatory variables are significant in half normal and exponential distribution. These are AHH, AHHS, YEDHH, Cattlesize and HHsize. It means that cattle size is not significant in truncated normal distribution. The significance of both age of dairy farmer household head and age squared shows that the relationship between inefficiency and age of the dairy farmer household head is nonlinear. Other things being constant, age of the dairy farmer household increases efficiency only until 50 years and beyond 50 years it decreases efficiency. This result is similar to that of [Bardhan and Sharma \(2013\)](#).

Furthermore, [Table 5](#) shows that each 1% increase in years of education decreases inefficiency level of dairy farmer household by 0.1%. This is because the better the dairy farmer household is educated, the better he/she performs and utilizes modern production practices. Extension contact is found to be insignificant to technical efficiency of sampled dairy farmer households; this might be attributed to the complex bureaucratic systems and inappropriate design in extension programs. As the cattle size increases by 1% technical inefficiency decreases by about 0.73%. This could be because of economies of scale which implies that as the cattle size increases the less costs per production unit is obtained and better distribution of resources is gained. The sign of household size is not as expected. As house hold size increases by 1% percent, inefficiency in milk production increases by about 0.39%, 0.57% and 0.22 % as half normal, exponential and truncated models indicates, *ceteris paribus*. This might be because of increase in dependency ratio and cost of life.

[Table 6](#) shows the estimate of average (mean) efficiency of sampled dairy farmers is 63.7% which indicates that farmers are not getting the maximum output to be gained

Table 6. Estimate of technical efficiency.

Mean technical efficiency	Observation	Mean	Standard Error	Minimum	maximum	[95% Conf. Interval]
	163	0.637	0.017	0.099	0.924	0.603 0.671

from their input with current technology. There is large gap (i.e. equal to 36.3%) to increase their output without increasing their input.

One can see from [Table 7](#) that only two sampled farmer households scored greater than 90% efficiency score and one sampled farmer household scored less than 10% of efficiency score. The minimum efficiency score was 9.9% and the maximum efficiency score was 92.4%. This shows that there is greater variation in efficiency scores of sampled dairy farmers. 48 sampled dairy farmer household (i.e. 29.43%) achieved less than half of efficiency score while 115 sampled farmer households (70.57%) achieved greater than half of efficiency score.

4.3. Frontier post-estimation

a) Kernel density estimation for the half normal distributional assumption

In order to confirm the assumed assumption, a kernel density function is plotted in the STATA-11 as follows in the [Fig. 3](#) and it proves the assumption that inefficiency effect error term u_i is non-negatively distributed with half normal distribution.

b) Linktest

The link test shows that the model has no misspecification problem since \hat{u}_i is significant at 1% level of significance and \hat{u}_i^2 is insignificant (see [Table 8](#)).

Table 7. Frequency distribution of technical efficiency for individual farms.

Efficiency interval	Frequency	Cumulative frequency	Percentage	Cumulative percentage
TE < 0.1	1	1	0.61	0.61
0.1 < TE < 0.2	6	7	3.68	4.29
0.2 < TE < 0.3	15	22	9.20	13.49
0.3 < TE < 0.4	9	31	5.52	19.01
0.4 < TE < 0.5	17	48	10.42	29.43
0.5 < TE < 0.637	19	67	11.66	41.09
0.623 < TE < 0.7	19	86	11.66	52.75
0.7 < TE < 0.8	35	121	21.47	74.22
0.8 < TE < 0.9	40	161	24.54	98.76
0.9 < TE < 1	2	163	1.24	100.0

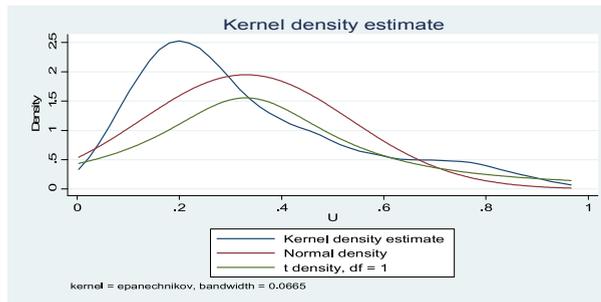


Fig. 3. Kernel density estimation of error term, u_i under half normal distribution.

Table 8. Linktest.

Iteration 0: log likelihood = -132.03099					
Iteration 1: log likelihood = -131.81914					
Iteration 2: log likelihood = -131.81903					
Iteration 3: log likelihood = -131.81903					
Stoc. frontier normal/half-normal model					
					Number of obs = 163
					Wald chi2(2) = 304.64
Log likelihood = -131.81903					Prob > chi2 = 0.0000
LnATMPD	Coefficient	Standard Error	Z	P> z	[95% Conf. Interval]
_hat	1.48	.42	3.54	0.000	.66 2.30
_hatsq	-.06	.90	-0.66	0.510	-.23 .11
_cons	-.70	.50	-1.42	0.156	-1.67 .27
/lnsig2v	-1.82	.33	-5.48	0.000	-2.47–1.17
/lnsig2u	-.97	.44	-2.22	0.026	-1.83–.11
sigma_v	.40	.07			.29 .56
sigma_u	.62	.13			.40 .94
sigma2	.54	.13			.23 .79
Lambda	1.53	.19			1.15 1.91
Likelihood-ratio test of sigma_u = 0: chibar2(01) = 2.53 Prob>=chibar2 = 0.056					

c) Likelihood ratio test (lrtest)

Our model passed this test at 1% level of significance (see Table 9). It means that we can reject the null hypothesis of fewer parameters at 1% level of significance.

d) Heteroskedasticity

The usual tests for heteroskedasticity like White’s test & Breusch-Pagan test are not valid in stochastic frontier analysis because of composite error term, but we can fit

Table 9. Lrtest.

Likelihood-ratio test	LR chi2(2) = 37.93
(Assumption: model1 nested in.)	Prob > chi2 = 0.0000

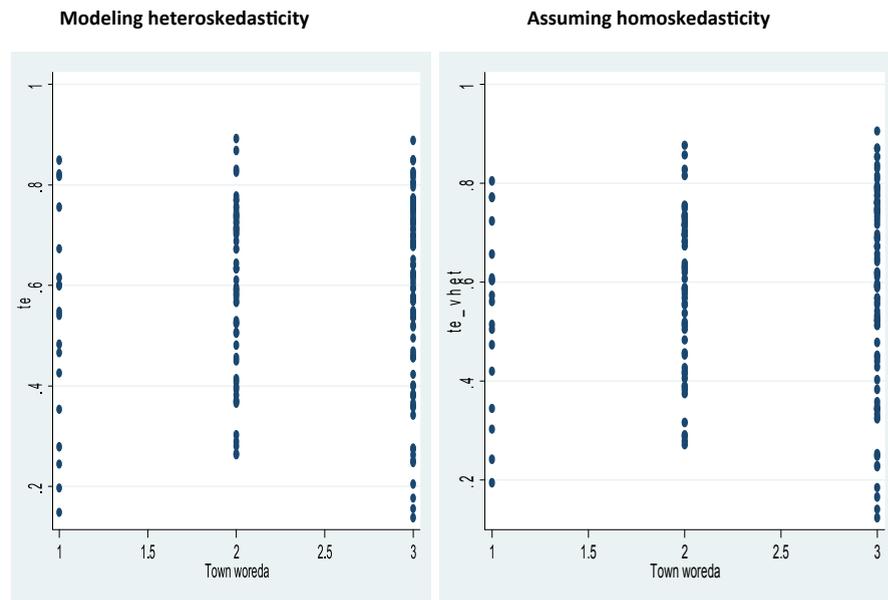


Fig. 4. Heteroskedasticity.

error terms predicted without and with heteroskedasticity and compare their distribution (see Fig. 4).

5. Conclusion

Though Ethiopia has the largest livestock population in Africa and thus larger number of dairy cows, it is a net importer of dairy products with import values significantly exceeding export values. The average daily milk production (**1.327** liters) in Tigray National Regional State is slightly less than the national average (**1.349** liters). The average daily milk production (**0.936** liters) in Central Zone of Tigray is much lower than the regional average. This motivates the researchers to estimate the technical efficiency of dairy farmer households and identify factors that affect technical efficiency of dairy farmer households in this zone by using stochastic production frontier on cross sectional data collected from 163 dairy farmer households.

Stochastic production function and technical efficiency function are estimated in combination after the existence of inefficiency is confirmed. The result shows that average daily amount of milk produced by sampled dairy farmers is significantly and positively affected by number of lactating cows, average daily cost of purchased supplements, average daily health expenditure and average amount of water consumed daily; significantly and negatively affected by average amount of crop residue/byproduct's cost. The inefficiency score of sampled dairy farmers is significantly and positively affected by age squared of household head and size of household. On the other hand, the inefficiency score of dairy farmers is significantly

and negatively affected by age of household head, years of education of household head and size of cattle while sex of household head, extension contact and off farm income of household member doesn't affect inefficiency score. The estimated mean efficiency of 63.7% implies that considerable increment in milk output (i.e. by 36.3%) is possible without changing the current amount of resources and technology used by sampled dairy farmer households.

5.1. Recommendations

- ✔ Farmers should be given informal as well as formal education so that their skill and entrepreneur ability will be improved.
- ✔ Intensive training on importance and use of family planning should be provided for dairy farmers so that dairy farmers should be user of family planning program.
- ✔ Extension program should be redesigned appropriately and reached the dairy farmers to attain its objective so that farmer's technical efficiency will be increased. Dairy farmers should be trained regarding proper feeding, calving, milking, cleaning of cows, milk storage, milk marketing and other management skills so that they could get larger output from the present amount of their inputs. Furthermore, improved marketing system, cattle feed production and supply, and milk processing facilities should be established. Since these are potential for investment, investors should be promoted and given a chance to establish milk processing factory. Dairy production place with necessary infrastructure like water, electricity power, road and the like should be presented for dairy farmers.
- ✔ Further research should be done by Veterinary professionals by controlled experimental research on the impact of crop residue/byproduct on milk output

Declarations

Author contribution statement

Haile Girma: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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