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Sources of technical inefficiency of smallholder farmers in milk production in Ethiopia

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This paper estimates technical inefficiency in milk production of smallholder dairy farmers in the highlands of Ethiopia and identified factors associated with the observed inefficiency using a stochastic frontier production function approach. The analysis utilizes a cross-section data collected from 1,277 farm households. The result indicates a mean technical efficiency of 55%, suggesting a sizeable technical inefficiency in milk production. The result further shows that household wealth, education level and access to markets as well as institutions are the main drivers of technical efficiency in dairy production. Evidently, by improving smallholder access to market and institutions as well as investing on adult education can bring considerable gain in milk production.

Key words: Stochastic frontier production function, technical inefficiency, smallholders, milk production, Ethiopia.

INTRODUCTION

It has been well documented that rural poverty reduction is associated with growth in agricultural productivity (De Janvry and Sadoulet, 2010; Byerlee et al., 2005; World Bank, 2007). One way to increase productivity is by improving efficiency (Ferrell, 1957). The efficiency gains thus obtained could lead to resource savings that can be put into alternative uses (Bravo-Ureta and Rieger, 1991). The implication is that to bring about desirable changes in agriculture, it is important to consider the efficiency aspect.

Dairy plays an important role in the Ethiopian agricultural sector and the national economy (Tegegne et al., 2013). The sector is a source of livelihoods for a vast majority of the rural population in terms of consumption, income and employment. Recent estimates by the nation's Central Statistical Agency (CSA) indicate that there are about 55 million cattle, of which 44.6% are male and 55.4% are female (CSA 2014). The CSA survey further indicates that 2.8 billion liters of milk was produced in 2012/2013, out of which 42.3% was used for household consumption. This shows that dairy production is an important agricultural activity in the country and provides livelihood for significant proportion of smallholders.

According to FAO (2014), over the period 1993 to 2012, total annual milk production has been growing, but

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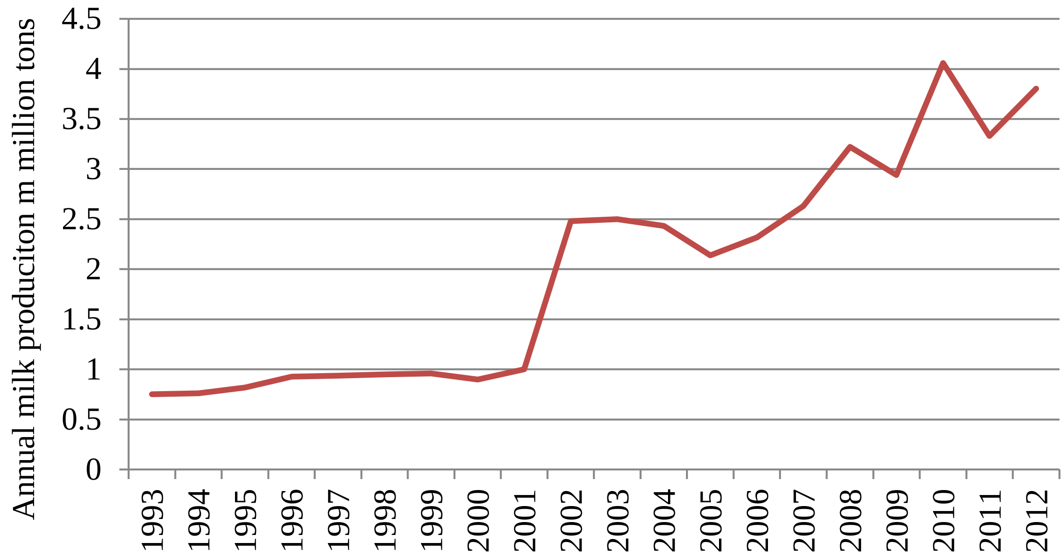

Figure 1. Trend in milk production in Ethiopia between 1993 and 2012. Source: FAOSTAT, 2014.

at a moderately slow rate (Figure 1). Mohamed et al. (2004) attributed the growth mainly to technological interventions and policy reforms. However, Nathaniel et al. (2014) argued that since dairy inputs and services provisions are still at infant stage and the expansion of improved dairy cows is limited in the country, the increase in milk production came mainly from increased number of cows rather than increased productivity. In fact, the national estimate shows that average milk yield per cow per day for indigenous breed is low, at about 1.37 L.

This calls for understanding of the efficiency level of the dairy sector and identifying factors associated with inefficiency. The result of such analysis is expected to better inform research, development and policy decisions and also help to prioritize interventions in the sector. Although, there exist several studies on efficiency analysis of Ethiopian agriculture (Alene and Hassan, 2006; Haji, 2006; Makombe et al., 2011; Nisrane et al., 2011), to the best of the author's knowledge, there exists no such study on milk production. This study, therefore, tried to contribute to the existing gap in knowledge on efficiency factors in dairy production in Ethiopia.

Approaches for measuring efficiency

There are at least three different types of efficiency measures in economic theory. These are technical efficiency, allocative efficiency and economic efficiency. Technical efficiency measures the success of a firm in applying the best practice so as to produce the maximum attainable output level from a given input set at a given level of technology while allocative efficiency measures a firm's success in choosing optimal set of inputs consistent with relative factor prices (Farrell, 1957). On the other hand, a firm's economic efficiency measures the overall efficiency which is defined as the product of technical and allocative efficiency (Bravo-Ureta and Rieger, 1991). This paper exclusively focuses on measuring technical efficiency in milk production in Ethiopia.

Much effort has been exerted to develop the best methodology for measuring efficiency. Following Farrell's (1957) seminal paper on efficiency measurement, a number of approaches have been proposed. The two most prominent and widely applied methods are the Stochastic Frontier Analysis (SFA) and the Data Envelopment Approach (DEA). The SFA has been independently developed by Aigner et al. (1977) and Meeusen and van den Broeck (1977). Charnes et al. (1978) then proposed the DEA as the main alternative to SFA. These methods have been compared for their strengths and weaknesses and were applied for investigating efficiency under different assumptions in various countries and sectors.

SFA is a parametric approach in the sense that it follows a defined production or cost function. The function in the model involves a composite error term that accounts both for the statistical noise in the data as well as the inefficiency in production (Erkoc, 2012). Therefore, any deviation from the efficient frontier (ideal output from a given input set) is attributed to both the stochastic disturbances such as errors in measurement, topography, weather and effects of unobserved and uncontrollable variables and to the individual-specific factors that affect the inefficiency (Coelli, 1995).

Once the individual inefficiency levels are estimated, the major factors causing the inefficiency can easily be identified from the inefficiency model. One of the drawbacks of this method is the imposition of restrictive assumptions on the functional form of the production function and the distribution of random errors. Nonetheless, SFA has been widely applied for analyzing agricultural efficiency both in developed and developing countries. Greene (2008) provided a detailed and comprehensive discussion on different variants of SFA models.

DEA on the other hand tackles the same question with a non-parametric and non-stochastic method. DEA employs linear programming methodology to construct the efficient frontier based on available information on the firms' inputs and outputs in the data. Thus, it is free from functional form restriction and distributional assumptions which are rather important in SFA. The lack of assumptions on the underlying production technology makes DEA suitable to accommodate problems that may arise from such restrictions (Erkoc, 2012).

However, the use of linear programming in DEA which does not allow decomposing the stochastic noise from the inefficiency effect is one major deficiency of the approach. Those who are not on the efficient frontier are considered to be inefficient; and such deviations are attributed only to inefficiency. Furthermore, the fact that this method is non-parametric makes it vulnerable to measurement errors and outliers. As a result, 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). A book length discussion on DEA can be found in Coelli et al. (2005).

MATERIALS AND METHODS

Model specification

There is always a trade-off as to whether to choose the stochastic frontier approach which is prone to misspecification bias or the DEA which suffers from measurement errors (Erkoc, 2012). However, a bulk of the literature suggests that as long as there is no severe misspecification problem, stochastic production frontier method is more suitable for efficiency analysis in a developing country agriculture setting where there are serious issues with data quality and accuracy (Coelli, 1995). Therefore, based on the dominant discourse in the efficiency debate, this study applies the stochastic frontier approach to assess the efficiency level and identify factors that lead to inefficiency of smallholder dairy producers.

The stochastic production frontier analysis begins with specifying a log-linear production function both in input and output as follows:

$$Y_i = \alpha + x_i^{'}\beta + \varepsilon_i \tag{1}$$

$$\varepsilon_i = v_i - u_i \tag{2}$$

Where Y_i represents the natural logarithm of observed output of the i^{th} household, x_i is a vector of the natural logarithms of N inputs for the i^{th} household and β is the vector of unknown technology parameters. The error term ε_i is composed of two components u_i and v_i. The first component u_i is a non-negative random variable measuring the inefficiency. The second error component, v_i, on the other hand, is a stochastic disturbance term assumed to be independently and identically distributed as $N(0, \sigma_v^2)$ over the observations. To form the density of Y_i in Equation 1, the joint density of ε_i needs to be computed. Following Greene (2008), this is given by:

$$f_{\varepsilon,u}(\varepsilon_i, u_i) = f_u(u_i) f_v(\varepsilon_i + u_i) \tag{3}$$

Integrating Equation 3 with respect to u_i then gives the marginal density of ε_i. This measures the contribution of observation i to the log-likelihood (ibid):

$$lnL_i(\alpha, \beta, \sigma_v^2, \sigma_u^2 | Y_i, X_i) = ln\, f_\varepsilon(Y_i - \alpha - \beta X_i\, \alpha, \beta |\, \sigma_v^2, \sigma_u^2) \tag{4}$$

In the literature, the inefficiency term u_i may take exponential (Meeusen and van den Broeck, 1977), half-normal (Aigner et al., 1977), truncated-normal (Stevenson 1980) as well as gamma (Greene 2003) distributions. Though half normal is the most commonly used specification in cross-section studies (Coelli, 1995; Bravo-Ureta and Pinheiro, 1993; Bauer, 1990) the assumption of zero mean for u_i is unnecessary restriction (Stevenson (1980). Thus, u_i in Equation 4 is assumed to have truncated-normal distribution of $U_i \sim N(\mu_i, \sigma_u^2)$, $u_i = |U_i|$. Furthermore, the model assumes heterogeneity in u_i and following Kumbhakar et al. (1991) and Huang and Liu (1994), exogenous variables that influence efficiency are introduced as follows:

$$\mu_i = z_i'\eta \tag{5}$$

Where μ_i is variable mode of the truncated normal distribution, z_i is a vector of household specific explanatory variables that affect household level inefficiency and η is unknown vector of coefficients to be estimated. Then, the log-likelihood will have the following form (Greene 2008):

$$\ln L\,(\alpha, \beta, \sigma, \lambda, \eta) = -N\left[\ln\sigma + \frac{1}{2}\ln 2\pi + \ln\Phi\,(\mu_i/\sigma_u)\right] + \sum_{i=1}^{N}\left[-\frac{1}{2}\left(\frac{\varepsilon_i + \mu_i}{\sigma}\right)^2 + \ln\Phi\left(\frac{\mu_i}{\sigma\lambda} - \frac{\varepsilon_i\lambda}{\sigma}\right)\right]' \tag{6}$$

Where $\lambda = \sigma_u/\sigma_v$, $\sigma^2 = \sigma_u^2 + \sigma_v^2$, $\sigma_u = \lambda\sigma/\sqrt{1+\lambda^2}$ and $\varepsilon_i = Y_i - \alpha - x_i'\beta$

The log-likelihood function in Equation 6 can then be estimated using Stata (Belotti et al., 2013). Once the parameters are estimated, the technical efficiency (TE) of individual household is given as $TE_i = \exp(-u_i)$. Since u_i is not directly estimated from Equation 6, the method proposed by Jondrow et al. (1982) will be used to extract the estimate of u_i which is given by Kumbhakar and Lovell (2000) as:

$$E(u_i|\varepsilon_i) = \sigma_*\left[\frac{\tilde{\mu}_i}{\sigma_*} + \frac{\phi(\tilde{\mu}_i/\sigma_*)}{1 - \Phi(-\tilde{\mu}_i/\sigma_*)}\right] \tag{7}$$

Where $\tilde{\mu}_i = (-\varepsilon_i\sigma_u^2 + \mu\sigma_v^2)/\sigma^2$ and $\sigma_* = \sigma_u\sigma_v/\sigma$. Technical efficiency of farms ranges from 1 to 0. The best practice farm gets a value close to 1 and the least efficient farm gets a value close to zero.

Empirical model

The empirical version of the stochastic frontier production model employed in this paper uses semi-log-linear Cobb-Douglas production function as the basis for the analysis.

Table 1. Description of the explanatory variables in the production frontier equation.

Variable	Variable description	Expected sign
$NCOW_i$	Total number of lactating cows of the i^{th} household during the 2012/13 production season	As the number of lactating cow increase evidently more milk can be produced (+).
$LABR_i$	Total number of labour available in the i^{th} household during the 2012/13 production season for herding, milking, feeding, etc., of dairy cows	Labour is a key input in dairy production. If a household has more labour available for herding, milking, feeding, etc., it is expected that the dairy cows can be better managed leading to higher milk production (+)
$GLAND_i$	Total grazing land available to the i^{th} household during the 2012/13 production season in hectares	As the size of grazing land increase it is expected that pasture grasses available will increase which further contribute to higher milk production (+).
$CROPRD_i$	Amount of crop residue of i^{th} household from own production available for livestock during the 2012/13 production season in kilograms	Crop residue from own production is another important input in the rural part of the country. Thus, it is expected that keeping other things constant a household with more crop residue will produce more milk. (+)
$PSUPP_i$	Total cost of purchased supplement for dairy cows of the i^{th} household during the 2012/13 production season in ETB	Supplements like concentrate feeds and industrial by-products are expected to increase milk production as they provide more nutrient to the cow (+)
$PFORAGE_i$	Total cost of purchased forage for dairy cows of the i^{th} household during the 2012/13 production season in ETB	In addition to the crop residue farmers sometimes purchase forage either to avail more feed to cows or to compensate for shortage of crop residue and pasture grasses. Thus, the effect on milk production can be either positive or negative (+/-).
$HELH_i$	Total health expenditure (drugs and expenses on vet services) the i^{th} household incurred for dairy cows during the 2012/13 production season in ETB	In the rural setting farmers visit veterinary clinics or buy vet drugs whenever animals are inflicted with disease. Thus, higher health expenditure could be associated with less milk production (-)
CCOW_i	Dummy variable that takes 1 if the household has crossbred cow and 0 otherwise	The sample households keep both local and crossbred dairy cows. This variable is used to account for yield differential due to genetic factors (+)
AEZ_i	Dummy variable that takes 1 if the agro-ecology zone is highland and 0 otherwise.	In Ethiopia, highlands are more favorable for dairy production than the lowlands partly due to feed, heat and water stresses (+)

$$\ln TOTM_i = \beta_0 + \beta_1 ln\, NCOW_i + \beta_2 lnLABR_i + \beta_3 ln\, GLAND_i + \beta_4 ln\, CROPRD_i + \beta_5 ln[max(PSUPP_i\,, 1-V_1)] + \beta_6 ln[max(PFORAGE_i, 1-V_2)] + \beta_7 ln\,[max(HELH_i\,, 1-V_3)] + \beta_8 \mathrm{CCOW}_i + \beta_9 \mathrm{AEZ}_i + \varepsilon_i \quad (8)$$

Where; $TOTM_i =$ total annual milk production by the i^{th} household during the 2012/13 production season[1] in liters; V_i = one if the respective cost item is positive and zero otherwise; β_i are unknown coefficients to be estimated and ε_i is the compound error term as specified in Equation 2. The explanatory variables in Equation 8 and their expected signs are described in Table 1. The semi-log-linear specification is selected because it improves the normality of the error term and reduces the effect of outliers on the estimation outcomes, while we had to retain the binary explanatory variables as dummy variables (Wooldridge, 2002). To capture the possible effects of the exogenous variables that affect technical inefficiency, the following model is specified.

$$\mu_i = \eta_0 + \eta_1 HSEX_i + \eta_2 HAGE_i + \eta_3 HAGESQ_i + \eta_4 HEDUC_i + \eta_5 DWT_i + \eta_6 DDA_i + \eta_7 HWEAL_i + \omega_i \quad (9)$$

Where; η_i's are unknown coefficients of the inefficiency effect to be estimated corresponding to each exogenous variable described in Table 2 and ω_i is a stochastic error term that captures the effect of unaccounted household specific variables on technical inefficiency. Following Wang and Schmidt (2002), Equations 8 and 9 are estimated simultaneously.

[1] The 2012/13 production season in Ethiopia is the period that extends from 1 June 2012 to 31 May 2013.

Table 2. Description of the explanatory variables in the technical inefficiency model.

Variable name	Variable description	Expected sign
$HSEX_i$	Sex of the household head (1 Male, 0 Female)	The sex of the household head could have either positive or negative effect on the inefficiency (-/+)
$HAGE_i$	Age of the household head (in years)	It is expected that older farmers would have more experience on dairy production which would lead to less inefficiency (-)
$HAGESQ_i$	Age square of the household head	The relationship between inefficiency and age of the household head may not be linear. Age of the household head increase efficiency only until a certain point and beyond that point it decrease efficiency (+)
$HEDUC_i$	Highest education level of the household head. If the household head had no formal education this variable takes zero value	The more educated the household head the more likely that he/she can process information and apply trainings and advises of the extension system more effectively which could lead to low inefficiency (-)
DWT_i	Walking distance to district/woreda town from the household (in minutes)	Remote households with respect to major markets and administrative centers would have less access to market and institutions which could be associated with inefficiency (+)
DDA_i	Walking distance to Development Agent's (DA) office (in minutes)	As the distance to the DA office increase it is more likely that the household would get less extension service which would lead to higher inefficiency (+)
$HWEAL_i$	Total wealth of household i in ETB	We anticipate wealthy households to be less inefficient as they are more likely to adopt new technologies readily than poor households (-)

Data

The study is based mainly on a cross-sectional baseline data collected by the LIVES[2] project for the 2012/13 production year. The data was collected from February to April 2014 from randomly selected rural households in four regions of Ethiopia (Amhara, Oromia, SNNPR and Tigray). These four regions jointly constitute the largest share of the nation's crop and livestock productions and cover the major agro-ecologies of the country. From the randomly selected respondents, a total of 1,277 milk producers in a mixed crop-livestock agro-ecological setting have been considered for this analysis.

RESULTS

Descriptive result

The descriptive result show that out of the sampled households, only 11.1% (142) are female headed (Table 3). In terms of agro-ecology, about 22% of the sample households are located in lowland areas while the remaining 78% lives in the highlands where it is relatively favorable for milk production. About 93% (1,188) of the households own only local breed cows. This is consistent with the national estimate where the overwhelming majority of cow population is of the local breed.

On the other hand, on average, the sample households own less than two cows and produce about 322 L of milk during the target production year (Table 4). On average, a household has 2 household members who could readily be engaged in herding, feeding, milking and managing the dairy cows. In the Ethiopian rural setting, it is not uncommon to observe young people, mainly boys, to be involved in herding cows and the female do the milking. Ethiopian smallholder farmers mainly depend on green pasture measured in this paper in terms of size of grazing land per household and residue from own crop production to feed their animals (Tegegne et al., 2013). The implication is that total grazing land and crop residue from own production are the major inputs for dairy production. In this regard, the data shows that on average a household had about 0.15 hectare of grazing land for his/her dairy cows. The data further reveals that

[2] LIVES - Livestock and Irrigation Value Chains for Ethiopian Smallholders – is a project engaged in a research for development activity in order to support the development of commodity value chains in several livestock and irrigated crops in the four major regions (Amhara, Oromia, SNNPR and Tigray) of Ethiopia. It is financed by the Canadian Department of Foreign Affairs, Trade and Development (DFATD) and implemented by the International Livestock Research Institute (ILRI) in collaboration with the International Water Management Institute (IWMI) and Ethiopian partners.

Table 3. Summary of descriptive statistics of the dummy variables.

Variable	Category	Frequency	Percent	Cumulative
	Female	142	11.12	11.12
$HSEX$	Male	1135	88.88	100.00
	Total	1277	100.00	100.00
	Has no crossbred cow	1,188	93.03	93.03
$CCOW$	Has crossbred cow	89	6.97	100.00
	Total	1277	100.00	100.00
	Lowland	279	21.85	21.85
AEZ	Highland	998	78.15	100.00
	Total	1277	100.00	100.00

Table 4. Summary of descriptive statistics of the continuous variables.

	Obs	Mean	*Std. dev.*	Minimum	Maximum
$TOTM$	1277	321.9 453	427.4399	2.5	5040
$NCOW$	1277	1.403289	0.7539375	1	8
$LABR$	1277	1.618432	1.099241	0.2141328	14
$GLAND$	1277	0.1530393	0.2647411	0.0001766	3.8391
$CROPRD$	1277	1396.972	2563.348	3.2	30000
$PFORAGE$	1277	162.814	437.8954	0	4000
$PSUPP$	1277	129.1633	536.2894	0	8750
$HELH$	1277	36.77608	91.80133	0	1200
$HAGE$	1277	45.76899	12.0314	20	90
$HEDUC$	1277	2.510572	3.191032	0	15
DWT	1277	162.3602	116.9535	5	760
DDA	1277	30.81844	31.31202	0	240
$HWEAL$	1277	47108.56	63445.43	2080	584955

on average a household fed 1,396.9 kilograms of crop residue from own production to dairy cows during the production period.

In addition to own crop residue and green pasture, farmers also purchase forage and supplements for dairy cows. As can be seen from Table 3, during the production year farmers on average spent about 163 ETB [3] and 129 ETB on forage and supplements, respectively. Moreover, on average, farmers spent 36.8 ETB on animal health expenses during the year. This amount might seem insignificant but it should be noted that most health related services are provided by the government through the extension system free of cost or in highly subsidized manner.

The mean age of the head in the sample households is 46 years and the highest grade completed by the head is 2.5. The average wealth of a household is 47,108.6 ETB, and is highly skewed to the left. Apart from household characteristics, the geographic location with respect to institutions such as agricultural office and markets for inputs and outputs is also expected to have a bearing on the inefficiency in milk production. The data shows that 50% of the sample farmers lie within 162 and 30.8 walking minutes from the district town and development agent's office, respectively.

Econometric result

The maximum likelihood estimates of the stochastic production frontier function and the technical inefficiency model are presented in Table 5. All estimated coefficients in the production frontier have the expected signs with the exception of purchased forage. The number of cows owned during the production year, number of labor available for dairy production and management, purchased supplements such as concentrates and industrial by-products, ownership of crossbred cows and the agro-ecological zone have positive and significant effects on the amount of milk production.

[3] ETB Ethiopian Birr) is the legal currency of Ethiopia. 1ETB = 0.0496 USD as of October 30, 2014.

Table 5. Maximum likelihood estimates of the stochastic production frontier and inefficiency effects models.

Variables	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
Frontier						
$lnNCOW$	0.9661175***	0.0515804	18.73	0.000	0..8650218	1.067213
$lnLABR$	0.065612*	0.0347109	1.89	0.059	-0.0024201	0.1336441
$lnGLAND$	0.0049814	0.0144493	0.34	0.730	-0.0233387	0.0333014
$lnCROPRD$	0.0247726	0.0165806	1.49	0.135	-0.0077248	0.05727
$lnPFORAGE$	-0.0057334	0.0073815	-0.78	0.437	-0.0202008	0.0087341
$lnPSUPP$	0.018285*	0.0094103	1.94	0.052	-0.0001588	0.0367289
$lnHELH$	-0.0095624	0.010551	-0.91	0.365	-0.030242	0.0111171
$CCOW$	1.19137***	0.0745044	15.99	0.000	1.045344	1.337396
AEZ	0.1239078***	0.0464481	2.67	0.008	0..0328712	0.2149444
Constant	5.430576***	0.1405915	38.63	0.000	5.155022	5.70613
Mu (inefficiency model)						
$HAGE$	-0.0106672	0.0490112	-0.22	0.828	-0.1067275	0.0853931
$HAGESQ$	-0.1520167	0.2872949	-0.53	0.597	-0.7151043	0.411071
$HSEX$	0.0001471	0.0004738	0.31	0.756	-0.0007815	0.0010756
$HEDUC$	-0.0815338*	0.0450849	-1.81	0.071	-0.1698985	0.006831
DWT	0.0019493**	0.0009811	1.99	0.047	0.0000265	0.0038722
DDA	0.0015506	0.0029306	0.53	0.597	-0.0041934	0.0072945
$lnHWEAL$	-0.5878623***	0.2364799	-2.49	0.013	-10.051354	-0.1243702
Constant	4.829882***	1.787545	2.70	0.007	1.326359	8.333405
σ_u	1.2998***	0.2320713	5.60	0.000		
σ_v	0.4312083***	0.0294664	14.63	0.000		
λ	3.014321***	0.2199617	13.70	0.000		
L. Likelihood	-1356.5460					
χ^2	835.19***					
N	1277					

*P <0.10; **P <0.05; ***P <0.01.

The five statistically significant variables determine the position of the efficient production frontier of milk production for the producers in the sample. Based on the estimated efficient frontier, the stochastic frontier methodology computes technical inefficiency levels depending on the distance of each farmer from the frontier.

The estimated coefficients of the inefficiency effect in Equation 9 are the main interest of this study. The signs of all coefficients in the inefficiency model are consistent with what is theoretically expected. The result in Table 5 indicates that coefficients associated with education, household wealth and distance to district town (proxy for access to input and output markets and institutions) were found to be statistically significant with expected signs. The log of household wealth was found to be highly significant at 1% level while distance to district town and education level of the household head were found to be significant at 5 and 10% levels, respectively. These results are consistent with the findings of Asres et al. (2013) who reported positive and significant effect of education, extension contact, farm size and off-farm income opportunities.

This study model did not detect statistically significant relationship between technical inefficiency and other household attributes such as age, sex and distance to DA post (proxy for access to extension services). Furthermore, the joint effect age and age square on technical inefficiency were found to be insignificant. However, the test of joint significance of all variables in the inefficiency model reveals that these variables are both relevant in explaining the efficiency levels of a households. The model estimates technical efficiency at household level. The result shows that on average, dairy producers are only 55% efficient when compared with the frontier (Table 6). The result further indicated that 95% of the households lie within 54 and 56% efficiency range.

The technical efficiency level found is higher than that reported by Asres et al. (2013), which reported an average technical efficiency of about 26%, based on data

Table 6. Estimate of technical efficiency.

	Obs	*Mean*	*Std. Err.*	*[95% Conf. Interval]*	
Mean efficiency	1277	0.5502247	0.005654	0.5391325	0.5613169

from three districts in North-Western Ethiopia. The same study found that only 19% of dairy producers in their study area had mean technical efficiency of more than 50%, showing significant room for improving dairy production by improving technical efficiency. In a developed country setting and a more commercialized dairy system in Pennsylvania, Wang (2001) found a mean technical efficiency of 85%, and that large farms were technically more efficient than small farms.

A number of tests were conducted to evaluate the specification of the model and reliability of results. The non-stochastic inefficiency hypothesis with a null hypothesis that the standard deviation of u_i equals zero is strongly rejected at 1% level of significance. The joint significance of the coefficient estimates for the variables in the inefficiency model have also been tested by the generalized likelihood ratio test. The null hypothesis that the coefficient estimates for the seven explanatory variable $\eta_1 = \eta_2 = \eta_3 = \eta_4 = \eta_5 = \eta_6 = \eta_7 = 0$, is rejected at the 1% level of significance. The test suggests that the combined effect of all the explanatory variables in the inefficiency model is significant although some variables are found to have individually statistically insignificant effects on technical inefficiency.

In general, the results of the above model specification test suggest that a conventional production function is not an adequate representation of the data and the inclusion of the inefficiency effect in the model is an improvement over the stochastic frontier which does not involve a model for technical inefficiency effect.

DISCUSSION

The result of the stochastic production frontier suggests that total number of lactating cows and ownership of improved cows in the herds have positive contributions to the amount of total annual milk production at household level. In addition, the agro-ecological zone in which the household resides determines the level of household milk production. Controlling for other factors, farmers who live in the highlands with more favorable rainfall and climatic conditions for dairy production produce more milk than those living in the low land areas. This could be because the heat and water stress in the dry and hot lowlands reduce milk output. This result suggests that highland and cooler areas may have better comparative advantage in milk production and that interventions may need to target these areas.

The availability of labor supply and purchased supplements are also found to be important factors for milk production at household level. This means that the higher the number of able workers per household available to manage the cows, the higher the milk output by the household. In addition, the more concentrate and other nutritious supplementary feed the household buys for the cows, the more milk output per household. This result suggests that feed and management in dairy production may be important consideration to increase milk production.

These results are consistent with other studies on dairy (Asrers et al., 2013; Lachaal et al., 2002; Kimenchu et al., 2014). The estimates of the frontier production function seem to suggest that input use and technology adoption (improved cows) primarily determine the level of milk production at household level. Furthermore, the results clearly show that external factors such as agro-ecology also determine the amount of milk output from a given input set.

More importantly, the technical inefficiency model provided important results that are relevant for research, development and policy decisions. The negative coefficients for education and wealth in the inefficiency model imply that the effects of both variables on milk production efficiency are positive. High education level is associated with low inefficiency. This could be because farmers with more years of schooling can better process information and use trainings and advice received through the extension services or other sources more effectively as compared to those who have lower education. Similarly, 'wealthier' households are more efficient as compared to their poorer counterparts. In addition, the result indicated that access to markets is a very important determinant of technical inefficiency. Those farmers who are further away from district towns are less efficient as compared to those who are relatively close, suggesting the importance of market incentives for dairy efficiency.

CONCLUSION AND IMPLICATIONS

The study used a cross section data collected from 1,277 rural farm households selected from the major four regions of the country to assess the level of technical efficiency and identify factors that are associated with the observed inefficiency in a stochastic production frontier framework. The result indicates that input use, adoption of improved technology and agro-ecology determine the amount of milk production at household level. Improving the availability of inputs and the efficiency of input markets are likely to increase milk production in the highlands of Ethiopia. Moreover, milk production in the dairy sector can be increased by promoting improved dairy technologies including improved genetic resources.

The result of the inefficiency effect model suggests that there is a room to significantly increase milk production per household by simply improving the technical efficiency. The mean efficiency of 55% implies that considerable gain in milk production is possible using the same amount of resources and technology. Education is an important variable for dairy efficiency. Our results imply that the education system should take into account the basic education needs of farmers whose literacy can be improved through formal and informal education. Targeted trainings and other capacity development activities may also be used to counter the negative effect of low literacy. Another short run remedy is to provide practical training on milk production and dairy management to farmers with no or low education. The current practical-oriented rural adult education programs seem to be appropriate interventions and move in the right direction, perhaps, not only for dairy but to improve agricultural efficiency in general. The need to improve infrastructure for increased access to major markets and institutions should also be a point of attention for policy.

Conflict of interests

The authors declare that no conflict of interest exists in relation to the content of the article.

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