Journal of Agricultural Economics and Development Vol. 1(1), pp. 10-20, April 2012
Available online at http://www.academeresearchjournals.org/journal/jaed
ISSN 2327-3151 ©2012 Academe Research Journals

Full Length Research Paper

Economic efficiency of mixed crop-livestock production system in the north eastern highlands of Ethiopia: the Stochastic frontier approach

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Accepted 29 March, 2012

This study analyzed the efficiency of crop-livestock production and assessing their potential for improvement in North-East Ethiopian highlands. Cross-sectional data were used to analyze the economic efficiency of mixed crop and livestock production system and identify its determinants factors from 252 farmers who were selected using probability proportional to sample size sampling technique. The parametric method stochastic frontier approach was employed to measure economic efficiency. The parametric methods of efficiency measurement indicated that most farmers in the study area were not efficient suggesting that efficiency improvement is one of the possible avenues for increasing agricultural production with available resource and technology. The mean Technical Efficiency (TE), Allocative Efficiency (AE) and Economic Efficiency (EE) of the household calculated from parametric approach of stochastic frontier analysis were 62%, 51% and 29%, respectively. The production efficiency of mixed crop-livestock farming system was determined by farm size, livestock ownership, labour availability, off/non-farm income participation, total household asset, total household consumption expenditure and improved technology adoption. This study found that improved agricultural technology adoption significantly improved production efficiency of households. Such actions may, in turn, alleviate the current problem of food insecurity and lead in the long run to economic development in the country.

Key words: Economic efficiency, parametric frontier, technical efficiency, technology.

INTRODUCTION

The national economy of Ethiopia is highly dependent on traditional agriculture and agricultural based activities. The overall economic growth of the country is highly correlated to the success of the agricultural sector. Agriculture accounts for 43% of the country's Gross Domestic Product (GDP) and 85% of all exports (coffee, livestock and livestock products and oil seeds). The industrial sector is small in size contributing, on average, to less than 13% of the GDP (FAO, 2007; MoFED, 2010). Agriculture provided employment for 85% of the population in 2008/09 and raw materials for 70% of the industries in the country (MOFED, 2006; MoFED, 2010). The bulk of the agricultural GDP for the period 1960-2009 had come from the production of crops and livestock (FAO, 2007; MoFED, 2010). Especially, the role of agriculture in securing the food needs of the fast growing population is considerable. However, the productivity of the agricultural sector has been very low for several decades. The reasons for the low growth rate of agriculture and GDP were mainly severe weather fluctuations, inappropriate economic policies and low adoption of improved agricultural technologies and production efficiency and prolonged civil unrest (Hailu, 2008).

In the north eastern highland part of Ethiopia, where this study was conducted, crop and livestock productions were the means of livelihood of the people to meet the

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household consumptions and to generate income. The major crops grown by sample households were improved and local wheat, barley, teff (Eragrostis tef), local and improved horse bean, field pea, maize, local and improved potato, oat, fenugreek, garlic, lentil, chickpea, grass pea, sorghum, haricot bean and linseed. The major livestock reared by sample households were dairy cow, poultry, beehives, sheep and goat products. The outputs of crops and livestock were used mainly for home consumption and for markets to obtain cash income. The straws of crops were used for animal feed. Animals like oxen were also used for draft power in plowing and planting. Moreover, the wastes of animal in the form of manure were used for improvement of soil fertility. The integration of crop and livestock production also serves as a means to cope up with the market and the environmental risks. This would also help as improve the food security of the producers. However, the productivity of agricultural system in the study area is very low. Due to this, more than 700 thousand farmers are in chronic food insecurity in the study area. Improving the productivity of crops and livestock would influence the food security of the private peasant households in the study area. Therefore, assessing the factors responsible for low production and productivity of smallholder mixed crop-livestock farmers in Ethiopia in general and in north eastern highlands of Ethiopia in particular was paramount importance. This study aimed at filling this gap. The specific objectives of the study were to: (1) estimate the farm level efficiency of the mixed crop-livestock production system; and (2) identify the sources of efficiency differential among the farmers.

METHODOLOGY OF THE STUDY

Description of the study area

This study was carried out in South Wollo. It is located in the North East highland part of Ethiopia. It is one of the eleven administrative zones of the Amhara National Regional State. It is situated between the Eastern highland plateaus of the region and the North Eastern highland plateaus of Ethiopia. It is divided into 20 administrative districts (weredas) and has two major towns (Kombolcha and Dessie) and 18 rural districts. Among the eighteen rural districts, Dessie Zuria and Kutaber are selected for this study. South Wollo is located between latitudes $10^{0}10'$N and $11^{0}41'$N and longitudes $38^{0}28'$ and $40^{0}5'$E. According to the Central Statistical Agency's population census data, in 2007 the total population of South Wollo was 2,519,450 of which 50.5% were females and 88% were rural residents (CSA, 2008). The total land area in South Wollo, Dessie Zuria and Kutaber is 1,773,681 hectares, 180,100 hectares and 72,344 hectares, respectively. The cultivated land area accounts for 39%, 20% and 35.3% of the total area of Dessie Zuria, Kutaber and South Wollo, respectively.

Sample size and sampling procedure

Dessie Zuria and Kutaber districts were selected purposively based on their accessibility and relevance of the study. The relevance of the study was concerned with the importance of improved dairy production in the study districts. A multistage random sampling method was used for the selection of the sample respondents. In the first stage of sampling, 6 Peasant Associations (PAs) were selected randomly from a total of 54 FAs (3 from Dessie Zuria and 3 from Kutaber). Since there are equal numbers of Peasant Association in the two districts, three Peasant Associations were selected from each district using simple random sampling procedure. In the second stage, a total of 252 farmers were selected using probability proportional to sample size sampling technique.

Data collection and sources

A structured questionnaire was designed, pre-tested and refined to collect primary data. Experienced numerators were recruited and trained to facilitate the task of data collection. Farm visit, direct observation and informal interview were undertaken both by the researcher and the enumerators. The secondary data were extracted from studies conducted and information documented at various levels of Central Statistical Agency, Ministry of Agriculture and Rural Development and Finance and Economic Development Offices in the study area.

Stochastic frontier approach to measure efficiency

The theory and concept of measurement of efficiency has been linked to the use of production functions. Some authors measure performance of firms by computing productivity using output over inputs. However, this is not the appropriate measurement techniques in efficiency. Different techniques have been employed to either calculate (non-parametric) or estimate (parametric) the efficient frontiers. These techniques are classified as parametric and non-parametric methods. Farrell (1957) was the first to formulate a non-parametric frontier method to measure production (economic) efficiency of a firm. According to him, efficiency ratios are calculated from sample observations. He defined technical, allocative and economic efficiencies. Technical efficiency (TE) reflects the ability of a firm to obtain maximum output from a given resources. Allocative efficiency (AE) reflects the ability of a firm to use inputs in optimal proportion given the input prices and production technology. Economic efficiency (EE) is the overall efficiency of a decision making units (firms or farmers). It is the multiplicative effect of technical and allocative efficiencies. This study estimates the overall efficiency of farm households. Hence, the reader could understand for economic efficiency and production efficiency as the same to mean estimating technical, allocative and economic efficiency.

The parametric frontier method can be classified into deterministic and stochastic frontier techniques. The deterministic parametric frontier approach is formulated with the production behavior of firms. It can be expressed as

$$Y_i = f(X_i;\beta)\exp(-U_i) \quad (1)$$

i=1,2,…,N

Where f (X_i;β) is a suitable functional form, β is vector of unknown parameters, U assesses the socioeconomic, institutional and technological factors that are responsible for low production and productivity of the firm. U_i is a non-negative random variable associated with technical inefficiency of the i^{th} firm which implies that exp (-U_i) is bounded between 0 and 1. Y_i is the vector of output.

The stochastic frontier approach splits the deviation (error term) into two parts to accommodate factors which are purely random and are out of the control of the firm. One component is the technical inefficiency of a firm and the other component is random shocks (white noise) such as bad weather, measurement error, bad luck, omission of variables and so on. The model can be expressed as:

$$\ln Y_i = \beta_0 + \ln \sum \beta_i X_{ij} + \exp^{e_i} \quad (2)$$

Where ln denotes the natural logarithm; i represents the i^{th} farmer in the sample, Y_i represents value of output of crop and livestock of the i^{th} farmer, X_{ij} refers to the farm inputs of the i^{th} farmer, e_i= v_i-u_i which is the residual random term composed of two elements v_i and u_i. The v_i is a symmetric component and permits a random variation in output due to factors such as weather, omitted variables and other exogenous shocks. The v_is are assumed to be independently and identically distributed N(0,σ^2_v), independent of ui. The other component, u_is, is non-negative random variable and reflects the technical inefficiency relative to the stochastic frontier. The uis are assumed to be independently and identically distributed as half-normal, u~|N(0, σ^2_v)|. The parameters β, σ^2= σ_v^2+σ_u^2 and γ= σ_u^2/ σ^2 of the above stochastic production function can be estimated using maximum-likelihood method, which is consistent and asymptotically efficient (Aigner *et al*., 1977). The dual cost frontier of the production function is given by:

$$\ln C_i = \alpha_0 + \ln \sum \alpha_i W_{ij} + \alpha_l \ln Y_i * \quad (3)$$

Where i refers to the i^{th} sample farmer, C_i is the minimum cost of production, W_{ij} are input prices, Y_i* represents the value of output adjusted for noise v_i; and α_i are parameters.

Following Bravo-Ureta and Rieger (1991) for a given level of value of output (Y_i*), the technically efficient input vector of the i^{th} farmer, X_{it}, is derived by solving (2) and the observed input ratio $X_1 / X_i = m_i \, (i > 1)$ simultaneously. Assuming that the production function in equation (2) is self dual (e.g., Cobb-Douglas), the dual cost frontier is derived algebraically and written in the following form:

$$C_i = C(W_i, Y_i *, \alpha) \quad (4)$$

Where C_i is the minimum cost of the i^{th} farm associated with the adjusted value of output Y_i* and α is a vector of parameters to be estimated. The economically efficient input vector of the i^{th} farm, X_{ie} is derived by applying Shepard's Lemma and substituting the firm's input prices and adjusted value of output level into the resulting system of input demand equations

$$\partial C_i / \partial W_k = X_{ke}(W_i, Y_i *, \psi). \quad (5)$$

Where k represents the total number of inputs used. The observed, technically and economically efficient costs of production of the i^{th} farm are then equal to $W_i' X_i$, $W_i' X_{it}$ and $W_i' X_{ie}$, respectively. According to Sharma *et al.* (1999) these cost measures are used to compute technical efficiency (TE),

$$TE_i = W_i' X_{it} / W_i' X_i \quad (6)$$

Economic efficiency (EE),

$$EE_i = W_i' X_{ie} / W_i' X_i \quad (7)$$

Following Farrel (1957) allocative efficiency (AE) can be derived from equation (6) and (7) as,

$$AE_i = W_i' X_{ie} / W_i' X_{it} \quad (8)$$

indices of the i^{th} farm. The production frontier was estimated using frontier model whereas the cost frontier is derived analytically from production assuming self dual.

Empirical studies on measuring efficiency in mixed crop and livestock production system

Several researchers have estimated production efficiency of mixed farming system in developing countries and a few of them are reviewed below. Taylor *et al.* (1986) used the Cobb-Douglas production function to evaluate the effectiveness of an agricultural credit program. They used a deterministic frontier production function to fit data collected from Brazilian farmers that were participant or non-participant in the program. Their technical and allocative efficiencies were determined by farm size positively and significantly. Liu and Zhuang (2000) used a stochastic frontier production function model to analyze the determinants of technical efficiency in Post-Collective Chinese agriculture from farm-level data of households. They found out that efficiency levels were affected by farm size, access to credit, nutrition intake, education attainment, and farming experience. Yohannes *et al.* (1993) used stochastic frontier production function method to examine crop and milk production efficiency among peasants in Ada and Selale districts of the central highlands of Ethiopia. They found out that the production efficiency of a farm household was determined by experience, education, worker to consumer ratio, and improved technologies used positively and significantly. Jema (2007) studied the determinants of efficiency of vegetable-dominated mixed farming system in two districts of eastern Ethiopia. He employed the non-parametric DEA to calculate technical, allocative, and economic efficiencies of vegetable-dominated mixed crop farmers and he used Tobit regressions to identify factors that explained efficiency differentials among farmers. He found out that asset, off/non-farm income, farm size, extension visits, and family size were the significant determinants of technical efficiency, whereas asset, crop diversification, consumption expenditure and farm size had significant impact on allocative and economic efficiency. The results of all these authors depicts that production efficiency is low in developing country and determined by various socioeconomic and institutional setting. They have estimated the efficiency by converting the quantity of output into value of output. This research has followed the same procedures but in different agro-ecological and socioeconomic and institutional setting. Moreover, it incorporates agricultural technology adoption as a covariate in identifying efficiency determinant.

Estimation of the determinants of production efficiency

In efficiency analysis, factors that influence efficiency are of paramount importance. Following the quantification of the production efficiency measures, a second stage analysis involved a regression of these measures on several hypothesized socioeconomic, institutional and technological factors that affect the efficiency of the farmers. The most common procedure is to examine the determinants of efficiency, in that the inefficiency or efficiency index is taken as a dependent variable and is then regressed against a number of other explanatory variables that are hypothesized to affect efficiency levels (Bravo-Ureta and Rieger, 1991; Sharma *et al.*, 1999; Arega, 2003; Jema and Andersson, 2006). However, few authors (e.g., Kumbhakar *et al.*, 1991; Battese and Coelli, 1995) used a specific model that allowed researchers to estimate the efficiency scores and simultaneously to test the effects of explanatory variables. For the former approach, technical, allocative and economic efficiency estimates were regressed, using Tobit model (Sharma et al., 1999; Jema and Andersson, 2006) or linear regression model (Sharma *et al.*, 1999; Arega, 2003) on the farm specific explanatory variables that might explain variations in efficiency across farms. Technical, allocative and economic efficiency estimates derived from Stochastic Production Frontier (SPF) were regressed, using a censored Tobit model on the following farm-specific explanatory variables that might explain variations in production efficiencies across farms. The rationale behind using the Tobit model was that there were a number of farms for which efficiency was one and the bounded nature of efficiency between zero and one (Jackson and Fethi, 2000). That is, due to large number of fully efficient SPF estimates, the distribution of efficiency measures was censored above from unity. Estimation with Ordinary Least Square (OLS) regression of the efficiency scores would lead to biased parameter estimates since OLS assumes normal and homoscedastic distribution of the disturbance and the dependent variable (Greene, 2003). As the distribution of the estimated efficiencies are censored from above at the value one, Tobit regression (Tobin, 1958) is specified as

$$E_i^* = \sum_i \beta_i X_i + V_i$$
$$E_i = 1....if....E_i^* \geq 1$$
$$E_i = E_i^*....if....E_i^* < 1 \qquad (9)$$

Where E_i is an efficiency score, and V~N(0,σ2) and β_j are the parameters of interest.

Description of variables for efficiency measurement

Production function variables

The variables that were used in the stochastic frontier model were defined as follows.

i. Outputs: physical yield of crops and livestock and their respective prices were used to compute the value of output of the farm. The value of crop and livestock output was derived from output of improved and local wheat, barley, *teff*, local and improved horse bean, field pea, maize, local and improved potato, oat, fenugreek, garlic, lentil, chickpea, grass pea, sorghum, haricot bean, linseed, milk of improved and local dairy cow milk, improved and local poultry, local and improved beehives, number of sheep and goat products. These outputs were multiplied by their respective market price to obtain the value of crop and livestock output. The respective monthly market prices were collected from South Wollo department of agriculture and rural development office.

The averages of these prices were used for computational analysis.

Table 1. Descriptive results of input-output variables

Variable	Mean	SD	Min	Max
Value of output in Birr[1]	10,144	6,423	205	32,201
Land area in hectare	0.72	0.45	0.02	2.28
Hum labour in man days (MD)	180	97	4	652
Oxen labour in oxen days (OD)	29	16	2	78
Material input cost in Birr	1971	1,387	8.2	7,079

Source: Own survey, 2009

ii. Inputs: these were defined as the major inputs used in the production of crop and livestock. They were:
Land: This represented the physical unit of cultivated land and grazing land in hectares;
Human labour: This was man days worked by family, exchange and hired labour for land preparation, planting, weeding, or cultivation, irrigation, harvesting and rearing livestock;
Oxen labour: This was oxen days worked by the household using oxen labour for land preparation, planting and threshing;
Material inputs: This included the cost of veterinary, feed, organic and chemical fertilizers, improved and local seeds and pesticides used by the farm household.
Cost function variables:

iii. Input prices: the input prices of land, human labour and oxen labour needed for deriving the dual cost frontier in the parametric method were collected. Moreover, the value of the output of crop and livestock was used as computed above and adjusted for statistical noise.

Variables included in the determinants of efficiency model

The dependent variable was the production efficiency scores, which were computed from parametric methods of efficiency measurement. Production efficiency in this context denotes technical, allocative and economic efficiencies.

iv. Efficiency factors: these denoted various factors hypothesized to explain differences in production efficiency among farmers. These were:
Age: this was the age of the household head in years.
Farm size: it was defined as the total area of cultivated and grazing land in hectare.
Education: it was a continuous variable defined as years of formal schooling;
Labour available: it was defined as the total active labour available in the family in man equivalent.
Livestock ownership: it was defined as the total livestock available in TLU.
Off/non-farm income: this included income from off-farm and non-farm activities. It was a dummy variable that the variable was 1 if the household earned off/non-farm income and 0 otherwise.
Credit service: it included access to credits for farm inputs and other farm production activities from formal and semi-formal sources. It was a dummy variable defined as 1 if the farmers have received credit and 0 otherwise.
Extension service: it was defined as whether the farmer had access to the extension service during the survey year or not. It was a dummy variable defined as 1 if the household had access to extension service and 0 otherwise
Expenditures: it was the total yearly consumption expenditure of the household in goods and services.
Assets: it was defined as the sum of current values of all furniture, farm implements and other equipments and livestock owned by the household.
Technology adoption: this was whether or not the household adopted at least one improved agricultural technology. It was a dummy variable defined as 1 if the farmer had been adopted at least one improved technology and 0 otherwise. The improved agricultural technologies considered were improved wheat seed, chemical fertilizer, improved forage and dairy.

RESULTS AND DISCUSSION

The descriptive statistics of output and input variables used in stochastic frontier approach are summarized in Table 1. As it was explained in the methodology, the total value of crop and livestock outputs were derived from output of improved and local crop and livestock products. These outputs were multiplied by their respective average market price to obtain the value of crop and livestock output. The average value of the output per farm was Birr 10,144 with minimum and maximum values of Birr 205 and Birr 32, 201, respectively. The average total land area was 0.72 hectare. The mean of the human and oxen labour for the farm households for which the production function was estimated was 180 man-days and 28 oxen-days, respectively. The mean of the material inputs applied by the farm households for the sample period was Birr 1,971 with a minimum of Birr 8

Table 2. Cobb-Douglas stochastic production frontier Maximum likelihood and OLS estimate

Variable	Parameter	OLS estimate	ML estimate
		Coefficient (standard error)	**Coefficient (standard error)**
Intercept	β0	4.46*** (0.29)	7.125***(0.25)
Land in ha	β1	0.064 (0.05)	0.1032*** (0.0298)
Human labour in MD	β2	0.268*** (0.057)	0.232*** (0.0443)
Oxen labour in OD	β3	0.379*** (0.06)	0.161*** (0.0468)
Material inputs in birr	β4	0.28*** (0.039)	0.113*** (0.0266)
F(4, 247)		125.02***	
Adjusted R-squared		0.6640	
σ^2(Sigma)			0.082*** (0.0114)
γ (gamma)			0.485*** (0.104)
Log-L			-22.8
LR test of the one-sided error			250***

***, ** and * implies significant at 1%, 5% and 10% probability level, respectively
MD=Man Days OD=Oxen Days LR=Likelihood ratio
Source: Own computation, 2009

and a maximum of Birr 7,079. 1 birr is the local currency which is exchanged at 17 birr for a dollar.

The maximum likelihood estimates of the parameters of the Cobb-Douglas stochastic production frontier function were estimated by using a computer program FRONTIER 4.1c (Coelli, 1996). The results are summarized in Table 2. The signs for input elasticities of the stochastic production frontier were all positive and significant at 1% probability level. This implies the significant contribution of land, labour and material inputs in producing crops and livestock activities.

The Cobb-Douglas production function was fitted due to its well behaved property in deriving the dual cost frontier and its convenience in estimation and interpretation of parameter estimates. Because of estimating technical and economic efficiency using stochastic production frontier, Cobb-Douglas production function was used in estimating the parameters of interest and hence measure efficiency indices. The estimated value of sigma squared (σ^2) was significant at less than 1% probability level. This means the conventional average production function was not an adequate representation of the data. That is, the stochastic production frontier model is very different from the deterministic model specification in which there is a statistical noise in the production frontier.

The estimation result presented in Table 3 showed that the returns to scale for this study were 0.609. The result indicated that crop and livestock farmers in the study areas operated under decreasing returns to scale. Thus, the production structure, given these inputs and production technology, was characterized by decreasing returns to scale. The dual cost frontier was derived from the production frontier by incorporating Lagrangian multiplier and by taking partial derivative of the input demand equation. The dual Cobb-Douglas cost frontier derived using equation (4) from the maximum likelihood estimate of the Cobb-Douglas production function (Table 3) is defined as follows:

$$\ln C_K = -10.35 + 0.169 \ln W_1 + 0.382 \ln W_2 + 0.264 \ln W_3 + 0.185 \ln W_4 + 1.64 \ln Y_K^* \quad (10)$$

Where C_k is the minimum cost of the K^{th} farmer in producing crop and livestock;
Y^*_k is the value of crop and livestock output of the K^{th} farmer adjusted for statistical noise;
W_1 is the average tax paid for a hectare of land estimated at 50 Birr;
W_2 is the wage rate estimated at 20 Birr/day;
W_3 is the rental value of one pair of ox estimated at 30 Birr/day; and
W_4 is the price index of materials inputs (fertilizers, seeds, veterinaries, feeds and herbicide and pesticide chemicals) assumed at unity.

Table 3. Frequency distribution of technical (TE), allocative (AE) and economic (EE) efficiency from parametric frontier method

Efficiency in %	Stochastic production frontier		
	TE	AE	EE
<10	0	3	8
10_20	7	26	42
20_30	14	48	99
30_40	29	68	65
40_50	46	44	29
50_60	33	25	9
60_70	25	18	0
70_80	29	10	0
80_90	24	7	0
>90	45	3	0
Mean (%)	61.61	50.94	28.9
S D (%)	23.28	20.37	11.23
Minimum (%)	15.64	4.18	3.24
Maximum (%)	97.87	100	58.78

N=number of farmers SD=Standard Deviation
Source: Own computation, 2009

Lack of farm level price related data, coupled with little or no input price variation across farms in Ethiopia precludes any econometric estimation of cost or profit frontier functions. Therefore, the use of self-dual production frontier functions allows the cost frontier to be derived and used to estimate economic efficiency in situations where producers face the same input prices. The frequency distribution and summary statistics of technical (TE), allocative (AE) and economic (EE) efficiency scores from parametric methods are presented in Table 3.

The average TE, AE and EE scores for SPF approach were 62%, 51% and 29%, respectively. They indicate that there were considerable inefficiencies in production and hence rooms for production gain through efficiency improvement. This suggests that farm households can reduce their production costs by 38%, 49% and 71% if they could operate at full technical, allocative and economic efficiency levels, respectively. For example, the number of farmers whose technical, allocative and economic efficiency scores were greater than 90% in SPF was 45, 13 and 0, respectively.

Determinants of production efficiency of mixed crop-livestock farm household

Here, the determinants of efficiencies were identified by incorporating agricultural technology adoption as a covariate. Agricultural technology adoption was understood to mean, improved crop and livestock technologies used to enhance productivity at a household level. It was hypothesized that the application of improved agricultural technologies, among other socioeconomic factors, affected farm household technical, allocative and economic efficiencies while the improved technology adoption dummy itself is an endogenous variable which can be affected by farmers' production efficiencies. A simultaneous equation Tobit model was employed to test these hypotheses and to identify the factors that influence household production efficiencies and improved technology adoption. Therefore, the model result revealed that the estimated parameter coefficient for the predicted error term (residual) was not statistically different from zero. As a result, the null hypothesis that there is no a simultaneity relationship between household efficiencies and improved technology adoption was accepted. This implies that the efficiencies of the farmers can be modeled by using the normal single equation standard Tobit model and by directly incorporating improved agricultural technologies dummy, along with other explanatory variables.

Crop and livestock producers' differences in technical, allocative and economic efficiencies levels were hypothesized to be due to several farm and farmers attributes, mainly reflecting their managerial ability and access to information. This procedure is to identify the determinants of production efficiency among farmers using the Tobit model. This was done by regressing the efficiency levels obtained from stochastic frontier method. The Tobit model estimates and the respective marginal effects are provided in Tables 4-6.

The Tobit model results indicated that technical efficiency was positively and significantly affected by size of livestock, off/non-farm income, total household asset, and technology adoption. Technical efficiency was negatively and significantly related to the total household consumption expenditure.

The allocative efficiency of the farm household was positively and significantly influenced by the farm size, total household asset and improved technology adoption. It was negatively and significantly affected by household consumption expenditure. This study found out that large farm size was expected to have a significant positive effect on allocative efficiency levels because such farms realize increasing returns to scale. The negative effect of farm size might be related to small farm size (Coelli *et al.,* 2002; Getachew, 1995; Jema and Andersson, 2006). The positive and significant influence of livestock ownership, off/non-farm income and household asset on allocative efficiency of the household might be due to the fact that the income was used to improve the skill and human and physical capital of the farm household, serve as additional funding to farm activities and improve managerial skills. Moreover, farmers with these resources had more information and capacity for optimal allocation of resources.

The economic efficiency of the farm household was positively and significantly affected by total household asset and improved technology adoption. The rest of the variables, including labour force available, size of farm, size of livestock, access to extension and credit service and education had the expected positive signs but insignificant effect on economic efficiency at less than 1% probability level. The statistically significant negative effect on the estimated coefficients on all efficiency scores for the household consumption expenditure may reveal a situation where household that spent excessively on consumption goods were unable to support their agricultural activities. Therefore, these households became less efficient (Jema and Anderson, 2006).

The household asset or wealth significantly and positively affected economic efficiency of the crop and livestock farmers. This means that relatively wealthier farm households were more economically efficient than less wealthy ones. That is, the farmers' capacity to self-finance may increase as they get wealthier, reducing demand for credit. However, if wealthier farm households expand their farm operations and demand additional external resources, they will be more creditworthy and less rationed in the credit market than the less wealthy farmers. The positive and significant effect of the total household asset is consistent with the results obtained by Jema and Anderson (2006) and Hussien and Öhlmer (2007). The positive and significant effects of farm households' improved technology adoption on all efficiency scores were related to the fact that the households were adapting improved practice and technology, acquiring and analyzing information. This suggested that better utilization of improved agricultural technologies such as chemical fertilizers, improved dairy cows, forage seeds and wheat varieties improved the technical, allocative and economic efficiencies of mixed crop and livestock farmers.

SUMMARY AND CONCLUSIONS

The general objective of the study was to estimate the production efficiency of the mixed crop-livestock farmers in two districts of north eastern highlands of Ethiopia. The parametric methods of efficiency measurement indicated that most farmers in the study area were not efficient suggesting that efficiency improvement is one of the possible avenues for increasing agricultural production with available resource and technology. The mean TE, AE and EE of the household calculated from parametric approach of stochastic frontier analysis were 62%, 51% and 29%, respectively. This technical efficiency index indicated that these farmers could, on average, produce as much as 38% of the value of output without utilizing additional inputs. The economic (production) efficiency of mixed crop-livestock production system was determined by farm size, livestock ownership, labour availability, off/non-farm income participation, total household asset, total household consumption expenditure and improved technology adoption.

The empirical results showed that emphasis should be given to improve the efficiency of mixed crop-livestock production system. In this regard, scaling up strategy to increase the number of best performing farmers should be given priority. Best performing farmers were those farmers whose economic efficiency scores were 100%.

These farmers operated at the frontier. There is a possibility of increasing farm income and resource use by integrating crop and livestock enterprises for all farm households. This could be attained by improving the production and productivity of different crops and animals.

Therefore, there is a need to design appropriate policy for improving crop and livestock production systems by solving the shortage of seed, feed and health problem and providing various technical and advisory support services. This implies that improving the asset of crop-livestock farmers can ultimately bring about improvement in agricultural productivity by improving production efficiency. Based on the results of this study,

Table 4. Determinants of technical efficiency of smallholder mixed crop and livestock farmers

Variables	Coefficient	Std. Err.	Marginal effect
Age	-0.000795	0.000783	-0.000791
Education	-0.00331	0.00344	-0.00329
Labour available	-0.00732	0.0067	-0.00728
Farm size	0.01247	0.0219	0.01241
Livestock ownership	0.0197***	0.006	0.0196
Off/non-farm income	0.0461**	0.023	0.0458
Household asset	0.1011***	0.015	0.1005
Household expenditure	-0.1449***	0.024	-0.1441
Extension service	0.0222	0.024	0.0221
Credit service	0.0253***	0.0025	0.0251
Technology adoption	0.0642***	0.024	0.0638
Constant	1.824***	0.056	
Test statistics	LR χ^2*** (11) = 215 Log –L*** = 116		

*** and ** implies significant at 1% and 5% probability level, respectively
Log-L stands for Log Likelihood function
Source: Own computation, 2009

Table 5. Determinants of allocative efficiency of smallholder mixed crop and livestock farmers

Variables	Coefficient	Std. Err.	Marginal effect
Age	-0.00084	0.00082	-0.00083
Education	-0.0043	0.0036	-0.0042
Labour available	0.012	0.007	0.011
Farm size	0.0736***	0.0229	0.0735
Livestock ownership	0.004	0.006	0.004
Off/non-farm income	0.048	0.023	0.047
Household asset	0.0615***	0.0162	0.0614
Household expenditure	-0.0653***	0.0253	-0.0652
Extension service	-0.0086	0.0251	-0.0084
Credit service	0.0068	0.0254	0.0065
Technology adoption	0.0606**	0.0258	0.0603
Constant	0. 852***	0.222	
Test statistics	LR χ^2*** (11) = 85 Log –L*** = 107		

*** and ** implies significant at 1% and 5% probability level, respectively
Log-L stands for Log Likelihood function
Source: Own computation, 2009

it is suggested that the technology adoption and production efficiency of the crop-livestock farmers should be improved by raising their education, farm household asset formation and by providing extension and credit services. Such actions may, in turn, alleviate the current problem of food insecurity and lead in the long run to economic development.

ACKNOWLEDGEMENTS

The authors are very grateful to data collectors Ahmed, Alemu, Alifya, Mohammed and Seid. The support of

Table 6. Determinants of economic efficiency of smallholder mixed crop and livestock farmers

Variables	Coefficient	Std. Err.	Marginal effect
Age	-0.00083	0.0008	-0.00082
Education	0.0048	0.0038	0.0043
Labour available	0.0124	0.0073	0.0124
Farm size	0.0424	0.023	0.0423
Livestock ownership	0.011	0.006	0.014
Off/non-farm income	0.0438	0.025	0.0436
Household asset	0.0739***	0.017	0. 0737
Household expenditure	-0.1176***	0.0265	-0.1175
Extension service	0.0096	0.026	0.0094
Credit service	0.0113	0.0267	0.0112
Technology adoption	0.0541**	0.027	0.0540
Constant	-1.587	0.2326	
Test statistics	LR χ^2***(11) = 133 Log –L*** = 94		

*** and ** implies significant at 1% and 5% probability level, respectively.
Log-L stands for Log Likelihood function.
Source: Own computation, 2009

ministry of education for data collection is also appreciable. We are very grateful to two anonymous reviewers for very useful comments that helped us improve upon the paper.

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