EFFECT OF FARM SIZE ON TECHNICAL EFFICIENCY OF TEF PRODUCTION: A CASE STUDY OF THE MORETNA-JIRRU DISTRICT, CENTRAL ETHIOPIA

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ABSTRACT

In Ethiopia, where small farming households are predominantly subsistence producers, efficiency plays a significant role in boosting food production. Especially, as land resources are becoming limited (scarce) with population expansion, increased food production is coming mainly from more effective use of existing resources and technological innovation. Although the Ethiopian government, since 1980, focused on achieving food self-sufficiency, the problem of food insecurity still persists in the country.

The objectives of this paper are to reflect on the technical efficiency of small farmer households, the determinants of technical efficiency, and the relationship between farm size and household food production in the cêntral highlands of Ethiopia. The study employed the stochastic frontier production function approach and applied it to a total of 199 sampled farm households to examine efficiency of tef. *The results revealed that large farms are technically more efficient than small farms. The mean technical*

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efficiency is calculated to be 0.74 for large farms and 0.68 for small farms. This means that average levels of large and small farms were below the frontier by 26% and 32%, respectively. Stated differently, the total output can be increased by up to 26% for large farms and 32% for small farms above the actual output levels attained in the study area during the survey year. In the stochastic frontier analysis, six input factors (land area, seed, DAP, urea, labour and traction) are considered, of which four factors (land area, labour, quantity of DAP and urea used) had a statistically significant positive influence on yield at 1% and/or 5% probability level. Among the eight inefficiency factors postulated to influence technical efficiency of tef, *five of them have been found to be statistically significant at 1% and/or 5% probability level. These were land parcels, distance between parcels, number of oxen owned, family size, and income per household. It is, hence, important to give attention to existing resource use and technical efficiency determining factors to enhance productivity at farm level in the Moretna-Jirru district of Ethiopia.*

INTRODUCTION

The agricultural sector in Ethiopia is characterized by seven major agro-ecological zones: arid, semi-arid, sub-moist, moist, sub-humid, humid and per-humid. Tef grows in all four agro-climatic zones (MoA, 1998).

Tef is spelled in three different ways: *tef, teff* and *t'ef* in the literature, but the spelling '*tef*' is the most widely used. Its scientific name is *Eragrostis tef* (Zucc.). It is the only cereal crop cultivated from the genus *Eragrostis*, which contains about 350 species (Hailu and Seyfu, 2000).

At present, *tef* constitutes 28.4% of the land area in Ethiopia devoted to seven cereal crops, followed by maize (19.5%), sorghum (18.3%), wheat (15.7%) and barley (13.1%). During the 2003/04 cropping year, the share of *tef* production was 18.6% from the seven cereals, surpassed only by maize (28.3%) only (CSA, 2004). It is a well-known fact that *tef* is one of the staple foods of Ethiopia. It has existed in Ethiopia since the recorded history of the country and some authors believe that it might have been domesticated by the pre-Semitic inhabitants (Shaw, 1976). *Tef* has originated and diversified in Ethiopia. Ethiopian farmers have grown it for centuries because of its various merits; otherwise, it would not have existed after the introduction of other cereals (e.g. wheat, maize, etc.). In fact, its area of cultivation is increasing over time and currently it is the number one crop in this aspect. On the whole, the area devoted to *tef* cultivation is increasing owing to the versatile merits of *tef* to the farmers. Firstly, both the grain and straw fetch a relatively higher price in the market in comparison to other cereal crops. Secondly, *tef* is an adaptive crop to the changing environments in the country and therefore farmers face low risk. In some environments, where farmers face a complete crop failure due to moisture stress, *tef* is their choice to get some harvest.

In the highlands of Ethiopia, the production of *tef* and wheat are considered to make a significant contribution to the farm household food security status. The question remains as to how farmers will survive when production factors are not efficiently used on the farm. Traditional cereal farming is not only low-yielding but also results in the mining of plant nutrients from the soil. After harvest, traditional farmers remove the straws for livestock feed, fuel and building materials. These practices leave no crop residue to restore soil nutrients and organic matters.

As land resources are becoming increasingly scarce and population increases, increased food production has to come mainly from technological innovation and productivity increases, particularly of small-holders as main food producers in developing countries.

The growth of crop production by small-scale producers depends on the need to improve productivity of farmlands. It is evident that productivity growth may be achieved through either technological progress or efficiency improvement, such as improved farmer education, to ensure that farmers use the existing resources more efficiently (Coelli, 1995). Several studies indicate that the existing low levels of technical efficiency hinder efforts to achieve progress in food security of the small households (Belete et al., 1991; Seyoum et al., 1997).

Currently, the Ethiopian government has taken some measures and incentives to raise productivity by helping farmers to reduce technical inefficiency and fostering the adoption of improved production technologies. A prominent example has been the establishment of a strong extension component directed to the dissemination of improved technology to small-scale farmers and the improvement of farmers' practices.

The need to improve total factor productivity of small-scale food producers so as to raise the level of output to meet the country's food consumption requirement would be a coherent and fundamental issue. Small-holder farmers' productivity and income can be increased through efficient allocation of existing resources, if there are inefficiencies, and through adoption of improved technologies (Kenea et al., 1998). Small-holders in Ethiopia operate varying farm sizes and it is uncertain whether these small-scale producers have the same or different levels of technical efficiency.

Under this premise, it was important to test whether the small-scale producers have the same or different levels of technical efficiency under varying farm sizes. Hence, the aim of this article is to report technical efficiency of the small farm sector, indicating its determinants, and the relationship with farm size.

DESCRIPTION OF THE STUDY AREA

The study area, Mortena-Jirru, is one of the districts of Semien (North) Shewa in the central highlands of Ethiopia. It is an agricultural area lying at an altitude ranging from 1500-2650 meters above sea level, and has an average annual rainfall of 800 mm. According to the records of the Amhara Regional Bureau of Agriculture, currently almost all of the land area is under cultivation (BPED, 1999). The soil of the cultivated area is primarily vertisols. The area is well known for the production of crops such as wheat and *tef* followed by lentil, chickpea, grass pea and faba bean. Most of the farmers in the study area are food growers who produce mainly to meet household food requirements using family labour. Any excess of crop output is sold to earn cash so as to meet other household needs (salt, oil, kerosene, etc.) and farming expenses.

METHODOLOGY

Survey Design and Sampling

The results of this article are based on farm-level data of 197 sampled farm households in the Moretna-Jirru district, which is one of the major wheat and *tef* producing districts in the central highlands of Ethiopia. The survey was conducted between January and September 2001. Sample farmers were selected randomly from the smallholder farmers in the study area. A two-stage selection technique was employed, where the first stage involved the random selection of peasant associations (villages) and the second the random selection of sample farmers who were registered as members of a peasant association and who had official access to at least 0.5 hectare of arable land through the peasant association. A census carried out in March 1994 provided a sampling framework to randomly select the households who had official access to state land. The total sample of farmers was classified into two groups based on farm size. Farm size is designated as the size of total cultivated land operated by the farm households. Based on the farm size, those whose farm size was larger than two hectares (statistically significant) are classified as large farm size households while those whose farm size was equal or less than two hectares were classified as small farm size households. Out of the total 197 sampled farmers, 95 were classified as having large farm size and 102 as having small farm size.

For the purpose of efficiency analysis, information was collected on *tef* output, as the dependent variable in the analysis. Six input categories and eight inefficiency effects that might explain efficiency differentials among farm households were defined and used in the production function model (Table 1).

Analytical Procedure

Following data collection, data were coded and entered into SPSS Version 10.1 computer software for analysis. Analytical techniques applied included t-test, chi-square test, ANOVA and correlation analysis. Frequency and group means were also computed for different variables. The t-test was run to detect statistically significant differences in the continuous variables representing the characteristics of farmers who have small farm size versus those who have large farm size. The chi-square test was run for discrete variables to detect any systematic association between farm size and specific farm characteristics.

The Stochastic Frontier Model

Stochastic frontier function was employed to analyze the data set collected for the two groups of farmers. The stochastic frontier model for merged farms (small and large), of the type proposed by Battese and Coelli (1995), was run to estimate the coefficients of the selected variables and mean technical efficiency. The same variables were used for both groups to compare the results of technical efficiency between the two groups.

The stochastic frontier model for farmers who produce *tef* is defined by

$$\ln (Y_i) = \beta_0 + \beta_1 \ln (Area_i) + \beta_2 \ln (Seed_i) + \beta_3 \ln (DAP_i) + \beta_4 \ln (Urea_i + \beta_5 \ln(Labor_i) + \beta_6 \ln (Traction_i) + Vi - Ui \quad (1)$$

Where the subscript i indicates the i-th farmer in the sample

(i = 1, 2,..., N);

ln represents the natural logarithm;

Y_i is the yield of *tef* (kg/ha);

Area, seed, diammonium phosphate (DAP), urea, labour and traction are as defined inTable 1, below.

The βs are unknown parameters to be estimated;

The V_is are assumed to be independent and identically distributed random errors having a normal $(0, \sigma_v^2)$ distribution; and

The U_is are non-negative random variables, called technical inefficiency effects, which are assumed to be independently distributed such that U_i is defined as α by the truncation (at zero) of the normal distribution with mean, μ_i, and variance, σ^2; where μ_i is defined by:

$$\mu_i = \alpha_0 + \alpha_1 (\text{Age}_i) + \alpha_2 (\text{Experience}_i) + \alpha_3(\text{Education}_i) + \alpha_4(\text{Parcel}_i) + \alpha_5 (\text{Distance}_i) + \alpha_6 (\text{Oxen}_i) + \alpha_7 (\text{Family size}_i) + \alpha_8 (\text{Income}_i) \text{ ------------------------ } (2)$$

Where α-coefficients are unknown parameters to be estimated, together with the variance parameters, which are expressed in terms of age, experience, education, parcels, distance, oxen, family size and income as defined in Table 1.

Table 1. Variable definitions for stochastic frontier and inefficiency effects for *tef* production in the Moretna-Jirru district, 2000/2001 cropping season

Variables	Descriptions
Yield	Yield of *tef*, kg/ha
Input categories	
Area	The size of *tef* area, ha
Seed	*Tef* seed rate, kg/ha
DAP	The amount of DAP applied to *tef*, kg/ha
Urea	The amount of urea applied to *tef*, kg/ha
Labour	Labour input used in *tef* production, man-hours/ha
Traction	Oxen input used in *tef* production, oxen-hours/ha
Inefficiency effects	
Age	Age of the household head, years
Experience	Farming experience of the household head, years
Education	Dummy variables (1= if educated and 0= otherwise)
Parcel	No. of parcels or plots of land the household possesses
Distance	Average walking distance between parcels, in minutes
Oxen	No. of oxen owned by household
Family size	Family size of a household
Income	Income of the household, Birr

The stochastic frontier model for the combined small and large farms of *tef* producers is defined by equations (1) and (2). The production function, defined by equation (1), specifies that the two groups may have different mean levels of *tef* output.

The model for the technical effects, defined by equation (2), specifies that the technical inefficiency effects in the stochastic frontier (1) are a function of age, farming experience, education, parcels of land, distance between parcels, number of oxen owned by household, family size and total income per household. More years of formal education and farming experience with larger family size, higher income per household, and more oxen are expected to result in smaller values of the technical inefficiency effects, whereas the older farmers, more parcels of land and larger distances between land parcels are expected to have greater inefficiencies.

The maximum- likelihood estimates for the parameters of the stochastic frontier were obtained by using the program, the FRONTIER Version 4.1 (Coelli, 1996). Estimates of the variance parameters are as follows:

$$\sigma_s^2 = \sigma_v^2 + \sigma^2 \quad \text{--- (3)}$$

$$\gamma = \sigma^2 / \sigma_s^2 \quad \text{---}$$

The γ-parameters indicated above have a value between zero and one. The discrepancy parameter (γ) is an indicator of the relative variability of the two error component. If γ approaches to zero, this implies that the random effect dominates the variation between the frontier output level and the actually obtained output level. Conversely as γ approaches to one, it can be assumed that the variations in output are determined by technical inefficiency.

The technical efficiency of a farmer is defined as the ratio of the observed output to the frontier output that could be produced by a farm operating at 100% efficiency.

The technical efficiency of production of the i-th farmer (TE_i) in the appropriate data set, given the levels of inputs, is defined by:

$$TE_i = \frac{Y_i}{F(X_i;\beta)\exp(V_i)} = \exp(-\mu_i) \quad \text{------------} \quad (4)$$

The technical efficiency of the farmer is between zero and one and is inversely related to the level of the technical inefficiency effect. The technical efficiencies can also be predicted using the Frontier Program, which calculates the maximum-likelihood estimator of the predictor for equation (4) that is based on its conditional expectation (Battese and Coelli, 1988).

The stochastic frontier outputs, which include the effects of the random errors in the production but not the technical inefficiencies of production, are important in comparing the productivity of small and large farms. Given the specifications of the stochastic frontier models (1) and (2), the stochastic frontier output for the i-th farmer, Y_i* is the observed output divided by the technical efficiency (TE_i).

$$Y_i * = Y_i / TE_i \qquad (5)$$

The mean frontier outputs are estimated for average input values for small and large farms in order to compare the overall technical efficiency of the two groups of farmers.

EMPRICAL RESULTS AND DISCUSSION

Technical Efficiency for *Tef* Production

A summary of the values of the variables, which were used in the *tef* frontier analysis, are presented in Table 2. It is observed from the summary that there is no major yield difference between the two farm groups. Large farms allocated on average more land to *tef*, used more oxen and applied more fertilizer (DAP and urea) per hectare than small farms. The average age of farmers, farming experience and education level were 41.46, 18.69 and 0.76 years for large farms and 40.17, 16.40 and 0.65 years for small farms, respectively. The average number of land parcels on large and small farms was 6.06 and 4.04, respectively. The average time required to walk between parcels on large farms was 22.38 minutes, whereas on small farms it was 18.88 minutes. Large farms have bigger family sizes and higher household incomes (2,077.44 Birr) than small farms (1,288.71 Birr).

Table 2. Summary statistics of variables for small and large farm size households in *tef* production in the Moretna–Jirru district, 2000/2001 cropping season

Variables	Small farm (n* =102)				Large farm (n =95)			
	Mean	Std Dev	Min value	Max value	Mean	Std Dev	Min value	Max value
Yield	1403.27	368.92	800.00	2160.00	1601.81	352.69	800.00	2240.00
Area	0.36	0.13	0.13	0.75	0.56	0.21	0.25	1.50
Seed	34.80	5.04	24.00	44.00	34.44	5.78	20.00	60.00
DAP	113.20	20.27	95.32	150.00	149.53	21.07	100.00	165.00
Urea	137.56	22.32	98.00	197.04	160.22	22.20	100.00	175.00
Labour	1094.63	164.34	768.00	1416.00	1073.44	44.40	152.00	374.00
Traction	83.88	13.86	56.00	136.00	90.57	15.35	64.00	128.00
Age	40.17	13.69	23.00	79.00	41.46	10.76	25.00	80.00
Experience	16.40	12.02	3.00	50.00	18.69	10.46	3.00	44.00
Education	0.65	0.48	0.00	1.00	0.76	0.43	0.00	1.00
Parcel	4.04	1.22	2.00	8.00	6.07	1.94	3.00	13.00
Distance	19.74	8.50	5.00	45.00	22.40	9.71	5.00	60.00
Oxen	1.02	0.51	0.00	3.00	1.56	0.52	0.00	2.00
Family size	5.31	1.81	2.00	9.00	6.79	1.97	2.00	11.00
Income	1288.71	761.94	120.00	3269.00	2077.44	1360.20	192.50	5910.00

**n = Number of tef growers selected for frontier function*

Source: *Survey data, 2001*

Maximum-likelihood Estimation

One can use either a farm group or a merged analysis to determine the maximum-likelihood estimation. The question is which approach will be better to estimate the parameters. The merged farm analysis approach is more appropriate when the farms considered are located in the same region, have the same production sets and share the same support structures. When farms do not have the same production function, the analysis for the two groups should be done separately (Assefa and Hidhues, 1996).

Moreover, the efficiency scores in the stochastic frontier model are determined relative to the best farms in the sample (Coelli et al., 1998). Accordingly, the mean efficiency scores from one sample group only reflect the dispersion of efficiencies within that group, but indicate nothing about the efficiency of that sample relative to the other group. Because it was necessary for this study to determine the efficiency of the small farms group relative to that of the large farm group, the merge farm analysis was better.

The maximum-likelihood (ML) results of the estimation of the parameters of the stochastic frontier production function are presented in Table 3. The values of the likelihood ratio (LR), sigma-square (σ^2) and gamma (γ) are statistically significant. This indicates that the frontier model is an adequate representation for the farms considered in the study.

The estimated coefficients of all the input variables in the production function have positive signs as expected (Table 3). Increasing the *tef* area by 10%, *ceteris paribus,* will increase *tef* yield by about 2.87%. Similar increases in DAP and urea application could increase *tef* output by 1.65 and 4.64%, respectively. From the estimated coefficients it is evident that access to land, urea, and DAP used are by far the most important variables explaining differentiation in output. Access to land and application of urea fertilizer led to statistically significant increases in *tef* yield. An increase in the application of DAP also led to a significant increase in *tef* yield for the sampled farms.

Causes of inefficiency in *tef* production on farms were also determined with the stochastic frontier analysis in a single-stage maximum likelihood estimate. From the estimated coefficients of the inefficiency variables, income, oxen, distance between parcels, family size and land parcels were statistically different from zero.

Higher family income and owning more oxen and increased family size per household reduce inefficiency whereas increase in land parcels and distance between parcels in the inefficiency model reduce the technical efficiency of farmers because farmers have to spend more time moving from place to place. The estimated coefficient for farming experience in the inefficiency models is negative. This indicates that as farming experience increases, inefficiency drops, though the magnitude is statistically insignificant. Similarly, the coefficients of age and education are positive but the values are statistically insignificant.

The sum of *tef* output elasticity is more than one (1.231), which indicates that farms are operating at increasing returns to scale.

Table 3. Maximum-likelihood estimates for parameters of the stochastic frontier of *tef* for combined households, the Moretna-Jirru district, 2000/2001 cropping year

Variable	Parameter	Merged farms Coefficients	Standard error
Stochastic Frontier			
ℓn (Area)	β_1	0.2873***	0.1002
ℓn (Seed)	β_2	0.0869*	0.0861
ℓn (DAP)	β_3	0.1654**	0.1308
ℓn (Urea)	β_4	0.4638***	0.1148
ℓn (Labour)	β_5	0.1611**	0.0427
ℓn (Traction)	β_6	0.0668	0.0736
Returns to scale		1.231	
Inefficiency Model			
Age	α_1	0.0089	0.0044
Experience	α_2	- 0.0051*	0.0049
Education	α_3	0.0233	0.0455
Parcel	α_4	0.0004*	0.0161
Distance	α_5	0.0058**	0.0027
Oxen	α_6	-0.0433**	0.0546
Family Size	α_7	-0.0089*	0.0113
Income	α_8	-0.0003***	0.0001
Variance parameters	σ^2	0.0535***	0.0088
	γ	0.9762***	0.2766
Log-Likelihood Function			49.15
Average Technical Efficiency			0.7072

****, ** and * indicate statistically significant differences from zero at 1%, 5% and 10% test level*

Frequency Distribution of Technical Efficiency

The frequency distribution of the predicted technical efficiency and the summary statistics for both groups of farmers are presented in Table 4. The predicted technical efficiencies of large farms vary between 0.44 to 0.98, with the mean technical efficiency close to 0.74. Small farms, on the other hand, operate at a mean technical efficiency of 0.68, which ranges from 0.35 to 0.97. Considering the standard deviation and coefficient of variation of the data distribution, it can be concluded that the technical efficiency of large farms is more stable than that of small farms. The large farms exhibit a variability of 15.95% compared to 25.00% for small farms. There is an overall significant difference in the efficiency index (P=.001) test level between the groups.

The distribution of the predicted technical efficiency for large farms ranges between 0.45 to 1.0, whereas the distribution of technical efficiency for small farms has a wider spread of values, ranging from 0.35 to 1.00. By the same token, about 55% of large farms and only 41% of small farms are clustered at the interval of 0.60 to 0.75. This implies that the majority of large farms achieved higher technical efficiencies than small farms.

Table 4. Frequency distribution predicted technical efficiency in the stochastic *tef* production frontiers and summary statistics for different size households in the Moretna-Jirru district, 2000/2001 cropping season

Efficiency intervals	Large farms		Small farms		Total	
	N	%	N	%	N	%
0.351 – 0.400	0	0	4	3.9	4	2.0
0.401 – 0.450	0	0	3	2.9	3	1.5
0.451 - 0.500	1	1.1	10	9.8	11	5.6
0.501 - 0.550	0	0	6	5.9	6	3.0
0.551 - 0.600	7	7.4	12	11.8	19	9.6
0.601 - 0.650	24	25.3	10	9.8	34	17.3
0.651 - 0.700	18	18.9	10	9.8	28	14.2
0.701 - 0.750	10	10.5	9	8.8	19	9.6
0.751 - 0.800	6	6.3	8	7.8	14	7.1
0.801 - 0.850	11	11.6	7	6.9	18	9.1
0.851 - 0.900	6	6.3	7	6.9	13	6.6
0.901 - 0.950	6	6.3	12	11.8	18	9.1
0.951 - 1.000	6	6.3	4	3.9	10	5.1
No. of observations		95		102		197
Mean		0.741		0.683		0.707
Minimum		0.44		0.35		0.35
Maximum		0.98		0.97		0.98
Std Dev		0.118		0.170		0.148
C.V (%)		15.95		25.00		20.85
t-value			2.95*			

**Indicates significant difference of efficiency index at 1%test level between groups*

One farm from the large farm group and seventeen farms from the small farm group were found to be poorly performing farms (less than 50% efficiency). Similarly, six top performing farms were in the large size group, whereas four farms from the small size group were top performing farms (more than 95% efficiency).

SUMMARY AND CONCLUSION

The mean technical efficiency of *tef* is calculated to be 0.74 for large farms and 0.68 for small farms. This means that average efficiency levels of large and small farms were below the frontier by 26% and 32%, respectively. Stating otherwise, the total output can still be increased by up to 26% for large farms and 32% for small farms above the actual output levels attained in the study area during the cropping year.

According to the analysis, land size remains a key variable in explaining differentiation in output, especially in keeping farmers near to or on the production frontier. Reduction in farm size and land fragmentation contributed to technical inefficiencies.

Based on the results of the stochastic frontier production model estimated in this study, significant technical inefficiencies of production exist between small and large farm groups. This suggests that there is at least some room or scope for raising agricultural output through improvements in technical efficiency, without resorting to new improved technologies. The results found that the mean technical efficiency of the large farm group differs from that of the small farm group on a statistically significant level (P=.001). The main reasons for differences in technical efficiency were that large farms allocated on average more land to *tef*, used more traction (oxen) and applied more fertilizer (DAP and urea) per hectare than that of small farms.

The results that emerged from the technical efficiency differentials between small and large farm groups in the Moretna-Jirru district of Central Ethiopia have policy implications. A number of policy interventions are required if small-scale farmers are to improve technical efficiency. These include, among others, revisiting policies on land size and land distribution. Frequent redistribution and allocation of land has resulted in fragmentation, and in too small farms to support the livelihood. This in turn decreases farm productivity and efficiency. Further studies are also needed to determine the minimum farm size (viable size) to support farm households.

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