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Effect of Farm Size on Efficiency of Wheat Production in Moretna-Jirru District in Central Ethiopia

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I

INTRODUCTION

In the highlands of Ethiopia, the production of wheat and tef *(Eragrostis abyssinica)* make a significant contribution to the farm household food security status. The question remains as to how farmers will survive when production units 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, the traditional farmers remove the straws for livestock feed, fuel and building materials. These practices leave no crop residue to restore soil nutrients and organic matter.

With dwindling land resources and population increase, increased food production has to come mainly from technological innovation to increasing productivity particularly of small-holders who are the 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 indicated that the existing low levels of technical efficiency, hinder efforts to achieve progress in food security of the 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 tailored 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. The small-holder farmers' productivity and

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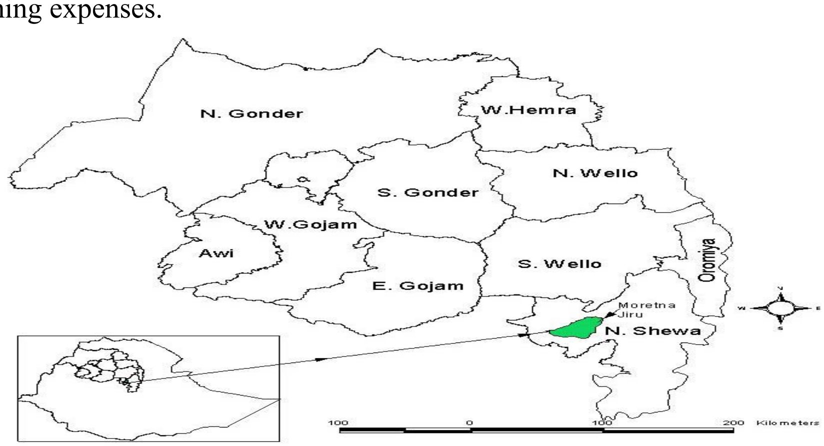
income can be increased through efficient allocation of existing resources, if there are inefficiencies and through adoption of improved technologies (Kenea *et al*., 1999). The small-holders in Ethiopia operate varying farm sizes. But no data are available on whether these small-scale producers have the same or different levels of technical efficiency.

Under these circumstances, it is important to know whether the small-scale producers have the same or different levels of technical efficiency under varying farm sizes. The study therefore tries to assess the technical efficiency differentials in wheat production among farm households that differ in farm size. Hence the aim of this empirical study is to measure technical efficiency of the small farm sector, identify its determinants, and the relationship between farm size and household food production in the central highlands of Ethiopia.

II

METHODOLOGY

The study area, Moretna-Jirru is one of the districts of North Shewa in the central highlands of Ethiopia. It is characterised as an agricultural area lying at an altitude ranging from 1500-2650 meters above sea level, and with an average annual rainfall of 800mm. According to the records of the Regional Bureau of Agriculture, currently almost all of the total land area is under cultivation. The soil of the cultivated area is primarily characterised as vertisols, while others exist in small proportions. The area is well known primarily for the production of crops such as wheat followed by tef (*Eragrostis abyssinica*), chickpea, lentil, grass pea and faba bean. However, the farms are not specialised. Most of the farmers in the area are mainly subsistence farmers who produce mainly to meet the household food requirements using family labour. Any excess of output is sold to earn cash so as to meet other household needs and farming expenses.



Map1. Location of the Study District

The study is based on farm-level data of 198 sample farm households in the Moretna-Jirru, which is one of the major wheat and tef producing districts in the central highlands of Ethiopia. The survey was conducted for the 2003-2004 cropping year. The sample farmers were randomly selected from the small-holder farmers in the study area. A two-stage sampling 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 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 frame to randomly select the households who had official access to arable land. The total sample of farmers was then classified into two groups based on farm size. Farm size is designated as the size of total cultivated land operated by the farm households. Accordingly, based on the farm size, households were classified into large farm households (> than 2 ha) and small farm households (≤ 2 ha). Out of the total sampled farmers (198), 95 households were classified as large farm size (group) and the remaining 103 as small farm size (group).

In order to obtain sufficient sampled farmers and to facilitate a comparison of technical efficiency between small and large farm sizes, data were collected initially for a sample of 300 households. When observations with missing values and incorrect land measurement was identified and removed, consequently, the sample size was reduced to 198 farm households, with sufficient data.

Following data collection from the field, data was coded and entered into SPSS Version 10.1 computer software for further analysis. Analytical techniques initially 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 then run to detect statistically significant differences in the continuous variables representing the characteristics of farmers who have small farm size versus large farm size. The chi-square test was run for discrete variables to detect any systematic association between farm size and specific farm characteristics.

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

TABLE 1. VARIABLE DEFINITIONS FOR STOCHASTIC FRONTIER AND INEFFICIENCY EFFECTS FOR WHEAT PRODUCTION IN THE MORETNA-JIRRU DISTRICT, 2003/2004 CROPPING SEASON

(1)	(2)
Stochastic Frontier	
Output	Output of wheat, kg/ha
Input categories	
Area	The size of wheat area, ha
Seed	Wheat seed rate used, kg/ha
Phosphorous (P_2O_5)	The amount of phosphorous applied on wheat, kg/ha
Nitrogen (N_2)	The amount of nitrogen applied on wheat, kg/ha
Labour	Labour input used in wheat production, man-hours/ha
Traction	Oxen input used in wheat 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 possess
Distance	Average distance between parcels, minutes
Oxen	No. of oxen owned
Family size	Family size of a household
Income	Total income of the household, Birr

The Stochastic Frontier Model

Stochastic frontier function was employed to analyse the data set collected for the two groups of farmers. The basic stochastic frontier model was first proposed by Aigner *et al.,* (1977) and Meeusen and van den Broeck (1977). Various other models have been suggested and applied in the analysis of cross-sectional and panel data on producers. Reviews of some models and their application are given by Bauer (1990), Battese (1992), Bravo-Ureta and Pinheiro (1993) and Coelli (1995). Some models have been proposed in which the technical inefficiency effects in the stochastic frontier models are also modeled in terms of other observable explanatory variables. Kumbhakar *et al.,* (1991), Huang and Liu (1994) and Battese and Coelli (1995) presented different models for the technical inefficiency effects.

Stochastic frontier production functions, using the Frontier 4.1 program of the type proposed by Battese and Coelli (1995), were estimated by merging the small and large farms together, and then the mean technical efficiencies were determined separately in order to compare the results between the two groups.

The stochastic frontier model for farmers who produce wheat is defined by

$$\ln (Y_i) = \beta_0 + \beta_1 \ln (Area_i) + \beta_2 \ln (Seed_i) + \beta_3 \ln (P_2O_5) + \beta_4 \ln (N_2) + \beta_5 \ln(Labour_i) + \beta_6 \ln (Traction_i) + Vi - Ui \quad ....(1)$$

Where the subscript ‘i’ indicates the i-th farmer in the sample (i =1, 2,……, N);

ln represents the natural logarithm (i.e., logarithm to base e);

Y_i is the yield of wheat (kg/per household);

Wheat area, seed, phosphorous (P_2O_5), nitrogen (N_2), labour and traction power employed for wheat production were all expressed per household level are provided as defined in Table 1.

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

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

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.

The stochastic frontier model for merged farms (small and large) of wheat 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 wheat 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 the 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 distance 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:

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

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 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 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 per cent efficiency level.

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

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

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).

$$Y_i^* = Y_i/TE_i \qquad \text{....(5)}$$

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

III

EMPIRICAL RESULTS

Summary of Variable Values

A summary of the values of the variables, for the wheat frontier analysis, is presented in Table 2. It is observed from the summary that, on an average, the large farm households tend to perform better than small farm households in terms of output produced, cultivated land operated, total fertiliser applied (phosphorus and nitrogen), land allocation to wheat, and labour and traction inputs per hectare.

TABLE 2. SUMMARY STATISTICS OF VARIABLES FOR SMALL AND LARGE FARM SIZE HOUSEHOLDS IN WHEAT PRODUCTION IN THE MORETNA-JIRRU DISTRICT, 2003/2004 CROPPING SEASON

Variables (1)	Farm groups							
	Small farm (n =103)				Large farm (n =95)			
	Mean (2)	Std. Dev. (3)	Min value (4)	Max value (5)	Mean (6)	Std. Dev. (7)	Min value (7)	Max value (8)
Output	2685.10	341.33	2000.00	3000.00	3186.34	286.54	2050.00	3640.00
Area	0.61	0.24	0.25	1.13	1.22	0.45	0.38	2.50
Seed	139.26	23.39	76.69	180.00	127.39	27.94	80.00	220.00
Phosphorus	52.01	9.30	43.85	69.00	68.86	9.67	46.00	75.90
Nitrogen	83.80	11.28	63.08	113.14	100.60	11.34	64.00	110.00
Labour	502.97	69.63	352.00	668.00	519.54	86.55	368.00	744.00
Traction	62.71	12.49	44.00	88.00	65.35	13.76	48.00	128.00
Age	38.10	10.69	23.00	65.00	41.41	10.71	25.00	80.00
Experience	13.76	7.83	3.00	35.00	18.54	10.51	3.00	44.00
Education	0.65	0.48	0.00	1.00	0.76	0.43	0.00	1.00
Parcel	3.99	1.16	2.00	7.00	6.06	1.93	3.00	10.00
Distance	18.88	7.25	5.00	35.00	22.38	9.67	5.00	60.00
Oxen	0.99	0.47	.00	2.00	1.55	0.52	.00	2.00
Family size	5.36	1.83	2.00	9.00	6.75	2.00	2.00	11.00
Income	1281.21	762.61	120.00	3269.00	2126.75	1545.89	192.50	5980.20

Source: Survey data, 2003.
Note: n = number of wheat growers selected for frontier function.

Maximum Likelihood Estimation

One can use either a farm group or a merged analysis to determine the maximum likelihood estimation, depending on the best approach to determine 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 shared the same institutional structures. The efficiency scores in the stochastic frontier model are determined relative to the best farms in the sample (Coelli, 1996). 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, one can conclude that the merged farm analysis was found to be a better option than independent analysis.

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.

TABLE 3. MAXIMUM-LIKELIHOOD ESTIMATES FOR PARAMETERS OF THE STOCHASTIC FRONTIER WHEAT PRODUCTION AND INEFFICIENCY MODELS FOR FARM HOUSEHOLDS IN THE MORETNA-JIRRU DISTRICT, 2003/2004 CROPPING SEASON

	Merged sample		
Variable (1)	Parameter (2)	Coefficients (3)	Standard error (4)
Stochastic Frontier			
Constant	β_0	5.9622***	0..5079
ℓn (Area)	β_1	0.2531***	0.0492
ℓn (Seed)	β_2	0.1943***	0.0375
ℓn (P_2O_5)	β_3	0.1622**	0.0254
ℓn (N_2)	β_4	0.1247***	0.0174
ℓn (Labour)	β_5	- 0.0030	0.0403
ℓn (Traction)	β_6	0.0405*	0.0169
Returns to scale		0.7718	
Inefficiency Model			
Constant	α_0	0.4941***	0.0174
Age	α_1	0.0005	0.0074
Experience	α_2	0.0029	0.0131
Education	α_3	0.0028	0.0133
Parcel	α_4	0.0244***	0.0064
Distance	α_5	0.0016***	0.0072
Oxen	α_6	- 0.0442**	0.0207
Family Size	α_7	- 0.0106***	0.0030
Income	α_8	- 0.0010**	0.0005
Variance parameters	σ^2	0.0325***	0.0148
	γ	0.8697***	0.0251
Log-Likelihood Function		84.55	
Average Technical Efficiency		0.80	

***, ** and * indicate statistical significant differences from zero at 1, 5 and 10 per cent level.

The estimated coefficients of all the input variables in the production function have positive signs as expected except for the labour input. An increase in wheat area by 10 per cent, *ceteris paribus,* will increase wheat output by about 2.53 per cent. A similar increase in seed is expected to result in an increase in wheat output by 1.94 per cent. Application of phosphorus (P_2O_5) and nitrogen (N_2) also led to significant increase in output. The results indicate that area and seed contributed the most to growth in wheat output. The causes of inefficiency in farms were determined with the stochastic frontier model in single-stage maximum likelihood estimation. From the estimated coefficients of the inefficiency variables, land parcels, distance between parcels, number of oxen, family size and family income were statistically significant.

Owning more oxen, increased family size and more income per household reduce inefficiency whereas increase in land parcels and distance between parcels reduce the technical efficiency of farmers because farmers have to spend more time moving stuff from place to place. The coefficients of age, experience and education are positive but were found to have no statistical significant influence on the technical efficiency of farmers. A possible reason is that with the static conditions of traditional agriculture, farming experience and education will have little profound effect to improve productivity, since the peasant producers are already relatively efficient at what they perform. Farming experience and education may be advantageous to help farmers learn to adjust resource use to changing conditions so as to maintain high levels of efficiency (Norton and Alwang, 1993). This result is supported by the finding of Chilot *et al.* (1996), that level of education of farmers has no impact on the adoption decision of modern wheat varieties in Addis Alem district of Ethiopia.

The sum of the output elasticities is calculated to be less than one (0.77), which indicates that farms are operating in the rational zone of production (decreasing returns to scale).

Frequency Distribution of Technical Efficiency

The frequency distribution of the predicted technical efficiency and the summary statistics for small and large farmers are presented in Table 4. The predicted technical efficiencies for the large farms vary between 0.70 and 0.97, with the mean value calculated to be 0.84. Small farms on the other hand are operating at mean technical efficiency of 0.76, which ranges between 0.63 and 0.96. Looking at the standard deviation and coefficients of variations of the data, one can conclude that the technical efficiency of small farms is more stable than that of large farms. The small farms exhibit a variability of 9.61 per cent as against 9.76 per cent for the large farms.

TABLE 4. FREQUENCY DISTRIBUTION TECHNICAL EFFICIENCY IN THE STOCHASTIC WHEAT PRODUCTION FRONTIERS FOR SMALL AND LARGE FARM SIZE HOUSEHOLDS IN THE MORETNA-JIRRU DISTRICT, 2003-2004

	Small farm size		Large farms		Total sample	
Efficiency intervals (1)	N (2)	Per cent (3)	N (4)	Per cent (5)	N (6)	Per cent (7)
0.630 - 0.700	14	13.6	8	8.4	22	11.1
0.701 - 0.750	23	22.3	9	9.5	32	16.7
0.751 - 0.800	25	24.3	22	23.2	47	23.7
0.801 - 0.850	15	14.6	23	24.2	38	19.2
0.851 - 0.900	18	17.5	13	13.7	31	15.7
0.901 - 0.950	6	5.8	14	14.7	20	10.1
0.951 - 1.000	2	1.9	6	6.3	8	4.0
Number of observations	103		95		198	
Mean	0.76		0.84		0.80	
Minimum	0.63		0.70		0.63	
Maximum	0.94		0.97		0.97	
Std.Dev.	0.073		0.082		0.085	
CV (per cent)	9.61		9.76		10.63	
T-value			45.46***			

*** indicates significant difference of efficiency index at 1 per cent test level between groups.

Comparatively speaking, about 46.6 per cent of the small farms are clustered between 0.70 and 0.80 whereas 47.4 per cent of the large farms are clustered around 0.75 to 0.85. Fourteen farms from the small size group and eight farms from the large farm size group operated between 0.63 and 0.70 efficiency level. Stating otherwise, eight farms operated at frontier level (0.95-1.00), with six farms (6.3 per cent) from the large size group and two (1.9 per cent) from the small size group. The overall t-value indicated that there is a statistical significant difference in the efficiency index at 1 per cent test level between the groups.

IV

SUMMARY AND CONCLUSIONS

The results revealed that large farmers are technically more efficient than small farmers. The technical efficiencies of large farm range from 0.70 to 0.97, with the mean technical efficiency estimated to be 0.84. For small farm size, the technical efficiencies range from 0.63 to 0.94, with the mean technical efficiency calculated to be 0.76. It is important to note, that on an average the potential exist for large and small farms to reduce the use of all inputs by 16 per cent and 24 per cent respectively, without reducing output.

The gains in output leading to improvements in productivity and efficiency are important to Ethiopian agriculture considering that the opportunities to increase farm production by bringing additional virgin lands into cultivation have significantly diminished in recent years while at the same time population pressure has been on the rise. In the analysis, land size remains a key variable explaining differentiation in output, especially to keep farmers near to or on the frontier. Reduction in farm size, and land fragmentation are likely to have contributed to technical inefficiencies. Therefore, a number of policy interventions are required if small-scale farmers are to improve technical efficiency. These include adjusting particularly through adoption of proven technology to minimum land size for those motivated farmers so that they operate viably by avoiding frequent redistribution of land.

Based on the results of the stochastic frontier production function estimated in this study, significant technical inefficiencies of production exist between small and large farm groups. This suggests that there exists some scope for raising agricultural output through improvements in technical efficiency, without resort to new improved technologies. The results depicted that the mean technical efficiency of the large farm group is statistically significant different from that of the small farm group. The main reasons for differences in technical efficiency were that large farms allocated a larger area to newly released wheat varieties, and that the amount of fertiliser and traction used per hectare were higher than that for small farms.

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