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Technical Efficiency of Resource Use in the Production of Irrigated Potato: A Study of Farmers Using Modern and Traditional Irrigation Schemes in Awi Zone, Ethiopia

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Abstract

Based on cross-sectional data collected from randomly selected 80 farmers in four districts of Awi zone in North-western Ethiopia, this study examines the technical efficiency of farmers in the production of irrigated potato. The stochastic frontier production function, which considers deviation from the frontier to be due to the effect of technical inefficiency and random noise, is used for data analysis. Technical efficiency of farmers was estimated independently for the farms under modern irrigation schemes and traditional irrigation schemes. Using likelihood ratio test, Translog production function is found to be an adequate representation of the production behavior of farms under the two types of schemes.

The mean level of technical efficiency was found to be 77 percent and 97 percent respectively for modern and traditional schemes. Therefore, improving the level of efficiency could raise productivity under modern schemes, whereas improving productivity under traditional schemes needs introduction of new technology as the farmers' level of production has approached the frontier. Irrigation experience, commodity rate of production and size of livestock are found to be the important variables that determine the level of efficiency.

Keywords: technical efficiency, stochastic frontier, irrigated potato

1 Introduction

At current per capita fresh water resource of 1924 cubic meters, Ethiopia is one of the countries endowed with the largest fresh surface water resources in Sub-Saharan Africa. More over, Ethiopia's land resource potential for irrigation development, disregarding available water is very large. Despite this potential, Food and Agricultural Organization estimates showed that 49% of Ethiopia's population is undernourished (FAO, 2001). At the root of this problem is the low agricultural productivity. Cereal yields stagnated at around 1.2 tones per hectare between 1980 and 2002. Moreover, the country's agriculture is dependent on unreliable rainfall. Agricultural production may fall by up

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to 20% in years of drought. Untimely and/or excessive rainfall in many areas can also affect grain production negatively.

With little room for further significant increase in the area under cultivation, the solution to the country's food supply problem hinges on raising yields through sustainable growth in the use of external inputs, particularly fertilizer and improved seeds besides the development of irrigation. Since 1992, the government has taken several measures aimed at improving smallholders' productivity such as removing government monopolies and restrictions on private trading, encouraging private sector participation in the agricultural input market, and provision of logistic and technical support for the development of irrigation services.

Three major types of irrigation schemes are practiced in Ethiopia: traditional schemes, modern community schemes and large-scale schemes. Large-scale irrigation is mainly concentrated in Awash Valley and operated by state farms. Traditional irrigation schemes are small-scale irrigation schemes built under the self-help program of peasant farmers on their own initiative. The schemes are operated and maintained by farmers themselves. Traditional water use associations led by elected chiefs, undertake the operation and maintenance of traditional irrigation schemes. Modern community irrigation schemes are largely constructed by the government and/or Non-governmental Organization (NGO) with the participation of farmers. In Awi Zone, five modern community irrigation schemes have been constructed, irrigating a total area of 1,097.4 hectares (ANRSBPED, 2001). Annual crops account for about 87% of irrigated crops in the study area, the dominant irrigated crops (in year 2002) being potato, barley, wheat and shallot in order of their area coverage.

In countries like Ethiopia, where food deficit is prevalent due to recurrent droughts, the challenges of moisture stress could be met with irrigation schemes that make the best of the available irrigation technology. One of the necessary agenda in this context would be a study on resource use efficiency and the factors that contribute to resource use efficiency in the production of irrigated crops. Therefore, this study investigates the level of technical efficiency of irrigated potato farms and identifies the factors that limit the level of efficiency for the schemes under consideration.

2 Objectives of the Study

In general, the objective of this study is to examine as to how to use resources efficiently in order to increase the level of output obtained from irrigated farms in Awi zone, given the available resources and the existing state of the art. It focuses on the assessment of resource use efficiency in the production of irrigated potato under traditional irrigation schemes and modern community irrigation schemes. The specific objectives of the study are:

(a) To evaluate technical efficiency of irrigated potato farms under the traditional irrigation schemes and modern communal schemes, and

(b) To identify the determinants of technical efficiency in irrigated potato production, so as to assist in finding ways and means by which the level of technical efficiency could be increased.

3 The study set-up and Methodology

3.1 Sample Data and Variables

A combination of purposive and random sampling techniques was employed to draw a sample of 40 farmers for the study under each category of schemes. A cross-sectional data for the year 2002/2003-irrigation crop season were collected. The methods used were interviewing and recording through frequent follow-up of the farmer in the production process. Relevant data were collected from both secondary and primary sources.

In the production function analysis, the independent variables are predetermined in the sense that they are the actual inputs for production and the dependent variable is the output. Thus, what may be required here is to make clear how these input variables and output are measured and used in the analysis. Six input variables (area, draught power, labor, operating expenses, asset expenses, and number of days of irrigation) were selected, as they are major ones necessary for irrigated potato production.

3.2 The Stochastic Frontier Model

The stochastic production frontier production functions were used to analyze the data for the two groups of farmers. AIGNER *et al.* (1977) proposed stochastic models assuming that the disturbance term has two components, that is, $\varepsilon_i = v_i + u_i$. The error component v_i represents the symmetrical disturbance that captures random errors caused outside the firms' control such as measurement errors, random shock, and statistical noise. This component is assumed to be identically and independently distributed as $v_i \sim N(0, \sigma^2)$. The u_i component of the error term is the asymmetrical term that captures the technical inefficiency of the observations and assumed to be independent of v_i, and also to satisfy that $u_i \geq 0$. The non-negative component (u_i) reflects that the output of each firm must be located on or below its frontier (BATTESE and BROCA, 1997).

The stochastic frontier model is widely applied in the efficiency analysis. For example, GIMBOL *et al.* (1995), ABRAR SULEIMAN (1995), GETU HAILU *et al.* (1998) and XU and JEFFERY (1998), among others, used stochastic frontier models to estimate technical efficiency of farms. The stochastic frontier model, which was found to be an adequate representation of the data in preliminary analysis, is given by:

$$\ln Y_i = \beta_0 + \sum_{j=1}^{6} \beta_{jk} \ln X_{ij} + \sum_{j \leq k=1}^{6} \beta_{jk} \ln X_{ij} \ln X_{ik} + (v_i - u_i) \quad (1)$$

Where the subscript, i indicates the i-th farmer in the sample ($i = 1, 2, ..., 40$ for each scheme), Y represents physical yield of potato (dt/ha); X_1 represents size of farm land under irrigated potato (ha); X_2 is draught power (oxen-hrs/ha); X_3 is human labour spent in farming the plot (person-hrs/ha); X_4 is operating expenses (Eth. birr/ha);

X_5 represents asset expense (Eth. birr); X_6 is frequency of irrigation (number of times); $\ln$ is natural logarithm (i.e., logarithm to base e); $\ln X_{ij} \ln X_{ik}$ includes the squares and interaction terms of the input variables; β_j's are unknown parameters to be estimated; v_i's are symmetric component of the error term and assumed to be independent and identically distributed having $N(0, \sigma_v^2)$ – distribution; the u_i's are the inefficiency component of the error term, which are assumed to be independently distributed such that u_i is defined by truncation (at zero) of the normal distribution with mean μ_i and variance σ^2 (BATTESE and COELLI, 1995), where μ_i is defined by:

$$\mu_i = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \delta_4 Z_4 + \delta_5 Z_5 + \delta_6 Z_6 + \delta_7 Z_7 + \delta_8 Z_8 + \delta_9 Z_9 \quad (2)$$

where δ's are unknown parameters to be estimated, and $Z_1, Z_2, Z_3, Z_4, Z_5, Z_6, Z_7, Z_8$ and Z_9 represent education level of the household head, credit use, years of experience in irrigation, commodity rate of production, irrigated land size (ha), livestock ownership (TLU), extension contact, farm-home distance and family size, respectively.

Technical efficiency measures are calculated relative to the production function of the fully efficient farm or a unit that is represented by a frontier function. Since in actual practice this frontier value is not known, it must be estimated from a sample of observed yield of each farm, and each farm's performance is compared with the estimated frontier. The purpose of estimating the frontier is to estimate the level of technical efficiency of each observation that is given by exp $(-u_i)$ which lies between zero and one and is inversely related to the level of the technical inefficiency effect. Following COELLI *et al.* (1998), the variance parameters of the stochastic frontier and inefficiency effects, $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2 / \sigma^2$, were also obtained using FRONTIER Version 4.1.

4 Results and Discussion

4.1 Level of Technical Efficiency

In this study, individual farm level of efficiency was estimated independently for the farmers operating under modern irrigation schemes and traditional irrigation schemes in the production of irrigated potato. In order to select the appropriate specification of the functional form a likelihood ratio test has been carried out. In this test, the null hypothesis is that the second order and the interaction terms in the Translog functions are not different from Zero (i.e., $H_0 : \beta_{ij} = 0; i \leq j = 1, 2, 3, 4, 5, 6$). The likelihood ratio test rejected the null hypothesis, implying that the Translog form adequately captures the production behavior of irrigated potato farms in Awi Zone, under both types of schemes (Table 1).

The problem of the presence of higher collinearity among the input variables in the Translog function was examined looking the value of Variance Inflation Factor (VIF) of the variables. The results indicated that there is no serious multicollinearity problem.

The computer program FRONTIER version 4.1 gave the values of the parameter estimates for the frontier model, the value of σ^2 and the value of log-likelihood function for both the ordinary least squares estimation and maximum likelihood estimation techniques, in the model output (Table 2). In addition, the maximum likelihood estimation

Table 1: Likelihood ratio test for selecting the functional form.

Efficiency estimation	*Log-likelihood value*		*LR*	$\chi^2_{(21)}$
	Cobb-Douglas (Lc)	*Translog (Lt)*		
Modern schemes	-12.327	10.626	45.906	32.671
Traditional schemes	-22.486	10.532	60.036	32.671

gave the individual and mean level of technical efficiency, the value of the parameter estimates for the inefficiency effects model (i.e., parameter estimates of the explanatory variables for u_i) and the value of gamma (γ).

Making use of the values of the model output the null hypothesis that technical inefficiency effects are not in the model ($H_0 : \gamma = 0$) was tested against the alternative hypothesis that inefficiency effects is in the model ($H_1 : \gamma > 0$). The likelihood ratio test also rejected the null hypothesis ($\gamma = 0$) at 5% level of significance in the case of farms under modern irrigation schemes and accepted it in the case of farms under traditional schemes.

The value of gamma for the frontier of farms under modern irrigation schemes ($\gamma=$ 0.3689) is also statistically significant at 10% level of significance in terms of t-statistic. Hence there is indeed an inefficiency effect associated with irrigated potato farms under modern irrigation schemes. Therefore, the data for this group of farms can be better represented by the stochastic frontier than the average response function. On the other hand, gamma was not statistically different from zero for those farms operating under traditional irrigation schemes, implying that there is no need to include the inefficiency effect in the model. In other words, the data for the farms under traditional irrigation schemes can be represented by the average response function, which means these farms are technically efficient. Thus, whereas productivity of farms under modern irrigation schemes can be raised through increasing the level of technical efficiency at the existing level of technology and inputs, it needs the introduction of new technologies to increase productivity of farms under the traditional irrigation schemes.

The mean technical efficiency of irrigated potato farms under modern irrigation schemes was found to be 77% with a range of 41 to 98.5%, showing a wider difference in the individual farms' efficiency level. For farms under traditional irrigation schemes, the mean technical efficiency was 97% with a range of 95 to 99.4%. Despite its indication of the general efficiency performance of farms, the mean technical efficiency level may not indicate the actual picture of the distribution of individual efficiency levels. Hence frequency distribution of individual technical efficiency of farms is presented in Table 3.

A statistical test has also confirmed that the mean technical efficiency of the two groups of farms is significantly different at 1% level of significance. Therefore recommendations to be given for the two groups of farms should consider their technical efficiency difference.

Table 2: Maximum-likelihood estimates for the parameters of the Translog stochastic frontier production function for irrigated potato in Awi zone, Ethiopia.

Modern scheme			*Traditional scheme*		
Parameter	*Coefficient*	*t-ratio*	*Parameter*	*Coefficient*	*t-ratio*
β_0	6.439 ***	9.602	β_0	3.720***	3.722
β_1	-355.700***	-373.935	β_1	-205.359***	-206.509
β_2	-181.201***	-190.827	β_2	19.216***	19.342
β_3	-240.955***	-254.443	β_3	-734.626***	-743.139
β_4	891.209***	941.144	β_4	-417.288***	-422.896
β_5	977.626 ***	1031.951	β_5	-94.010***	-94.394
β_6	821.701 ***	-86.702	β_6	-868.590***	-871.135
β_{11}	221.390 ***	288.804	β_{11}	218.221***	223.238
β_{12}	-14.223***	-18.571	β_{12}	42.395***	435.425
β_{13}	712.020 ***	929.007	β_{13}	-218.976***	-229.689
β_{14}	-340.409 ***	-444.809	β_{14}	61.930***	65.476
β_{15}	-15.027***	19.565	β_{15}	51.505 ***	154.029
β_{16}	39.725***	51.752	β_{16}	586.519***	593.487
β_{22}	201.052***	223.622	β_{22}	618.744***	619.659
β_{23}	-97.338***	-107.876	β_{23}	321.673***	322.162
β_{24}	675.089***	751.038	β_{24}	-97.194***	-97.391
β_{25}	-347.710***	-386.105	β_{25}	-695.825***	-696.413
β_{26}	-516.854****	-574.099	β_{26}	-378.471***	-378.662
β_{33}	-80.430 ***	-89.434	β_{33}	431.903***	447.628
β_{34}	-212.558 ***	-236.201	β_{34}	-403.992***	-419.709
β_{35}	-36.311***	-40.377	β_{35}	-791.908***	-808.870
β_{36}	336.968***	374.766	β_{36}	41.557 ***	42.304
β_{44}	81.043 ***	89.788	β_{44}	402.111***	423.285
β_{45}	-378.289***	-418.228	β_{45}	23.968 ***	24.689
β_{46}	-707.755***	-787.205	β_{46}	-7.132 ***	-7.323
β_{55}	-914.857***	-1014.485	β_{55}	803.917***	830.037
β_{56}	161.249 ***	179.249	β_{56}	-411.489***	-423.715
β_{66}	729.226 ***	811.132	β_{66}	450.549***	456.777
σ^2	0.041***	3.248	σ^2	0.0362	0.0684
γ	0.370*	1.898	γ	0.050	0.05003
LL	10.626		LL	10.532	

Note: The β coefficients represent the estimated coefficients for the independent variables defined with Translog function and also square and interaction effects.

Table 3: Frequency distribution of estimated efficiencies.

Estimated efficiencies	*Frequency (%)*	
	Modern schemes	*Traditional schemes*
0.40 - 0.60	15	0
0.61 - 0.70	22.5	0
0.71 - 0.80	20	0
0.81 - 0.90	15	0
0.91 - 0.95	17.5	65
0.96 - 100	10	35

4.2 Determinates of Technical Efficiency

One of the objectives of measuring efficiency is to identify what factors affect its level so as to tackle the problem of low productivity accordingly. Nine socio-economic variables (i.e., education level of the household head, credit, irrigation experience, proportion of the produce marketed, size of the total irrigated land, livestock, frequency of extension supervision, farm-home distance and family size) were used to estimate the model. The coefficients were estimated in combination with the production frontier, the inefficiency component of the error term being considered as the dependent variable, and indicate their effects on inefficiency (Table 4).

Both individual and overall significance tests of the coefficients of the inefficiency variables for the farms under traditional irrigation schemes are not significantly different from zero confirming that there is no inefficiency effect. For farmers under the modern schemes, individual tests for three variables (irrigation experience, livestock and commodity rate of production) were significant. Though individual tests of coefficients of most of the inefficiency variables were not significant, the generalized likelihood ratio test of the overall significance of the coefficients was highly significant indicating the joint effect of these variables on the inefficiency. Therefore, the relationship between the variables (individually or jointly) and technical efficiency of farms needs to be thoroughly discussed.

The effect of education on performance of the agricultural sector in developing countries is sometimes not clear. In this study although it was not statistically significant, the relation between the efficiency level of farmers and education level of the household head was negative, which is different from most of others' empirical findings. Kalirajan and Shand (1988) and Parikh and Shah (1995) for India, Sharif and Dar (1996) for Bangladesh, Xu and Jeffery (1998) for China, Day *et al.* (2000) for Philippines and Mulat Demeke (1989), Abay Asfaw and Assefa Admassie (1996) and Getu Hailu *et al.* (1998) for Ethiopia have found a positive relationship between efficiency and education. Where as Sriboonchitta and Wiboonpongse (2000) found a negative relationship between education and technical efficiency of rice production in

Table 4: The maximum-likelihood estimates for parameters of the inefficiency using Translog stochastic frontier production function for irrigated potato production in Awi Zone.

Variables	*Modern Schemes*		*Traditional Schemes*	
	Coefficient	*t-ratio*	*Coefficient*	*t-ratio*
Constant	-0.280	-0.464	0.0001	0.0001
Education level of the HH head (Z_1)	0.248	1.265	-0.0011	-0.0011
Credit (Z_2)	-0.111	-0.813	0.0034	0.0036
Experience on irrigation (Z_3)	-0.018**	-2.385	-0.0014	-0.0036
Proportion of the produce marketed (Z_4)	0.773**	2.505	0.0011	0.0011
Size of total irrigated land (Z_5)	0.013	0.101	-0.0014	-0.0014
Livestock (Z_6)	0.481*	1.742	0.0048	0.0056
Frequency of extension supervision (Z_7)	-0.083	-0.953	-0.0066	-0.0093
Farm-home distance (Z_8)	-0.024	-1.018	-0.0036	-0.0033
Family size (Z_9)	0.059	1.28	0.0021	0.0023

* , **: differences are significant at 10% and 5% level respectively

Thailand. Where as WHARTON (1965) was unable to establish a meaningful relationship between agricultural production and education level of farmers, and suggested that the contribution of education in the early stages of developing agriculture is uncertain.

In this study we found out that the relationship between irrigation experience and education level of the household head was negative suggesting that those farmers with relatively better years of schooling lack irrigation experience. This is because most of the farmers with relatively higher level of education were having lesser years of irrigation experience. When we look at the coefficient of the variables for the inefficiency effect, irrigation experience has a positive and significant relationship with technical efficiency while the sign of the relationship between education and technical efficiency was negative. From this we can conclude that the art gained through experience had more effect than the effect of education on technical efficiency of irrigated potato farms in Awi Zone. This may be due to the fact that no adequate information (especially in irrigation agronomy) is provided to the farmers so as to benefit educated farmers from it. Further more, the farmer being the planner and decision maker in the production process, long agricultural experience enhances its technical efficiency. The implication here is that farmers can increase their productivity of irrigated crops through acquiring knowledge from those farmers who have the best practice, which they have developed through experience.

Empirical findings also indicate that credit may have different relations with the level of efficiency. In this study, credit has positive relation with the level of technical efficiency though it is not statistically significant. This may be due to the reason that farmers who have got the credit may not use it as intended. In other words, some of them might have used the credit for other purposes.

The results of this study indicated that commodity rate of production has a significant negative effect on the level of technical efficiency, showing the other way the negative impact of self-sufficiency on efficiency. In this analysis, the commodity rate of production is calculated directly by taking the ratio of the produce sold to the total produce. Therefore, the higher the commodity rate of production the less would be the amount of produce left for family consumption. From microeconomics background, this can be explained by the "backward bending" nature of the supply curve for subsistence farmers. For subsistence farmers, the usual price-supply relationship doesn't hold true. The farmer increases supply of the produce until he gets the amount of money desired even if the price decreases, at the expense of his family consumption or he sells only some portion of the produce and consumes the rest of it, if the price is favorable. Therefore, the lesser the price of the produce the higher the ratio of produce sold to the total produce and the lesser would be the amount of produce left for family consumption. Consequently, the proportion of produce sold had a significant negative relation to the level of technical efficiency.

The livestock holding can be a proxy for the wealth position of the farmers, though in some cases, a farmer may have less livestock but can be wealthier at times. Livestock provides draught power, transport service, manure and cash income to finance crop production. Therefore, the relationship between technical efficiency and number of livestock was expected to be positive. The results of this study indicated that livestock negatively affect the level of technical efficiency at 10% level of significance. This may be due to competitive nature of the two enterprises as livestock production competes with crop production for labor and other resources. The other explanation for the negative relationship between livestock and level of efficiency was given based on observation of the real situation during data collection. Most of the sample farms were located around homesteads. The maximum farm-home distance is only a 20 minutes walk, while the average distance takes about 5 minutes walk. Consequently, these farms were exposed to livestock. The proposition was the more the size of livestock a farmer has the more likely would be the extent of crop damage by livestock.

This proposition was verified including farm-home distance in the model. For this analysis, the sign of the coefficient indicated that there is a positive relationship between farm-home distance and technical efficiency. This implies that farms near to homes are less efficient than those located at relatively far distances, supporting on the other way the proposition given for the relationship between livestock and level of efficiency. Whatever the justification may be, the possible policy implication here is that farmers should be advised to have an optimum size of livestock. However, further studies that consider efficiency of all crops under irrigated production would have better implication, as livestock is involved in the production of other irrigated crops too.

Empirical findings of this study have also indicated that extension contact has positive relationship with technical efficiency though it is not statistically significant. This result is not different from the findings of Kalirajan and Shand (1988), which stated that extension contact has no significant relationship to technical efficiency as extension agents do not have new information to provide farmers. Therefore, the policy implication here is to provide regular trainings to extension agents so that they can give new information to the farmers. Moreover, extension services rendered should consider the socio-economic circumstances of the farmers such as resource base and experience.

The effect of family size on efficiency is mainly justified on the ground that those farmers with big family sizes can better manage their crops. This was again based on the assumption that there is strong correlation between the work force (i.e. economically active members of the family) and family size. Results of this study indicated there is a negative relationship between family size and technical efficiency though it is not statistically significant. This result is in fact related to the findings of Mulat Demeke (1989). However, similar justification should not be given to this situation, as farmers may have irrigated farms under other crops that the family labor is engaged on.

5 Summary and Conclusions

The central theme of this study was that efficient utilization of resources enhances productivity of irrigated farms. The research questions: are the farmers efficient? and what are the causes for inefficiency? were the stepping stones for this study. If inefficiencies exist, then increasing the efficiency level would be an effective means of increasing production. But, if farmers are efficient in utilizing the available resources with the existing technology, then there is a need to introduce new technologies so as to improve productivity.

This study was conducted using a sample of 80 farmers selected from four districts of Awi Zone, so as to detect where do inefficiencies exist and identify the possible causes. Following many of the previous empirical works, stochastic frontier production was employed to analyze the data. This method was used for its better ability to detect the level of efficiency through decomposing the error term into random noise and inefficiency effect.

The findings of the study indicated that farmers operating under traditional irrigation schemes are efficient; hence, improving productivity requires introduction of new technology. On the other hand, farmers producing under modern community irrigation schemes have a significant inefficiency so that the productivity of these farmers can be raised through improving their efficiency. The main causes of inefficiency were identified to be inadequate irrigation experience and discouraging price of the produce. Higher size of livestock was also identified as one of the causes of inefficiency.

According to the findings of this study farmers producing under modern community schemes can increase their production at the existing level of technology and inputs through improving efficiency. Therefore, development strategies should consider technical efficiency differences among farmers so as to effect on appropriate interventions.

The most important policy implications drawn from this study include, among others, first increasing the productivity of farmers operating under modern community irrigation schemes is possible through improving their level of technical efficiency while for those operating under traditional schemes it needs introduction of new technologies. This may be in the form of upgrading traditional irrigations so that farmers can have reliable supply of water to the crop. Secondly, unfavorable price of the produce impedes efficient production. Hence better prices enhance efficiency of farmers. This may be achieved through organizing them in marketing cooperatives. Thirdly, farmers with less irrigation experience can increase their productivity if they can acquire the skill from experienced farmers, and this may be accomplished through arranging farmers' field days.

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