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Technical Inefficiency Determinants in Agricultural Production: The Case of Potato Farmers in Ethiopia

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Abstract:

Purpose: *The study identified the factors that cause variation in the level of efficiency in potato production. The study used household-level cross-sectional data collected in 2019/20 from 196 sample farmers selected by multistage sampling technique.*

Design/Methodology/Approach: *For the data collection, a personally administered structured questionnaire was used. Descriptive statistics, a stochastic frontier model (SFM), and a two-limit Tobit regression model were employed in the analyses. Tobit's model revealed that technical efficiency was positively and significantly affected by education, land tenure status, extension service, credit, and soil fertility. In contrast, variables such as sex of household head, age of household head, farm size, and land fragmentation affected it negatively.*

Findings: *Therefore, the study suggested the need for policies to discourage land fragmentation and promote education, extension visits, access to credit, and soil fertility to improve technical efficiency.*

Practical Implications: *The results of the study observed that the efficiency of potato farmers varied due to the presence of inefficiency effects in potato production which is a reason to search alternative production methods. For example, technical efficiency is positively and significantly affected by education, land tenure status, extension service, credit, and soil fertility, whereas variables such as sex of household head, age of household head, farm size, and land fragmentation affected it negatively.*

Originality/Value: *It is the first time in authors' knowledge using land fragmentation, education, extension visits, and access to credit, to improve technical efficiency in agricultural production.*

Keywords: *Potato, smallholder, technical efficiency, determinants, Ethiopia.*

JEL Classification: *Q1.*

Paper type: *Research article.*

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1. Introduction

Potato (Solanum tuberosum L.) is the third most important food crop after rice and wheat for human consumption, and over a million people on earth eat potatoes (CIP, 2014). Potato is short-cycle crops (3 to 4 months) and thus well suited to the double-cropping seasons, particularly the rain-fed system (Nteranya and Mbabu, 2015). In 2007, potato production reached a record of 325 million metric tons becoming the first non-grain commodity for humanity (FAO, 2009). However, demand for both food and energy is rising, and it is expected to keep the same trend with increases in global population and average income (Lobell *et al.,* 2009).

Efficiency measurements are carried out using frontier methodologies, which shift the average response functions to the maximum output or the efficient firm. Efficiency measurements involve a comparison of actual performance with optimal performance located on the relevant frontier. Since the true frontier is unknown, an empirical approximation is required.

2. Literature Review

Empirical studies suggest that most underdeveloped and developing countries are still facing the problem of high poverty levels. Most farmers in these countries practice subsistence farming with low productivity. Farmers use different production inputs and management levels depending on their infrastructural facility and socio-economic, institutional, and environmental conditions. This ultimately results in variability in the inefficiencies of potato production. The ability of a country to achieve growth in agricultural productivity and output depends on its ability to use the available resources efficiently and make an efficient choice among alternative paths of technical changes (Mulat, Said, and Jayne, 1997; Xu and Jeffrey, 1998).

Farmers lack access or less information on efficiency, and low literacy levels limiting interpretation of such information to guide them in commercial production. Further, less access to such information may be attributed to the few studies carried out in these areas. To realize increased production and efficiency, small-scale farmers in developing countries need to efficiently utilize the limited resources accessed for improved food security and farm income generation (Amos, 2007).

The findings indicated that productivity could change due to differences in production technology, differences in the efficiency of the production process, and differences in the environment in which production takes place. This suggests that attention to productivity gains arising from the efficient use of existing technologies is justified. From this point of view, it is interesting to search the sources of the inefficiency and identify the determinants.

3. Research Methodology

The study was conducted in Welmera district, 29 km away from the capital city of Addis Ababa in the central highlands of Ethiopia. The district is known for potato production and source of potato supply for Addis Ababa and other urban markets. The area ranges in elevation from 2,000 to 3,000 masl.

Multi-stage sampling techniques were used. The district was selected purposively because potato is a common crop in the area. In the district, six villages were selected purposively based on potato cultivated land and potato farmers in the district. Finally, respondents were selected in proportion with the frame by using systematic random sampling techniques. The sample size of potato producers was computed by Statistics Canada (2010): that is a step-by-step approach where, first an initial sample size is calculated and then it is adjusted for the population, design effect and the response rate. Based on the formulation, a sample size of 196 respondents was selected through random sampling. The sample was supposed to contain potato farmers.

Data were obtained from both primary and secondary sources using appropriate data collection instruments. Primary data was collected from 2015/16 cropping season using personally administered structured questionnaires. Secondary data was gathered from the country's statistical report, crop variety register, annual reports, research papers, websites, books, and unpublished reports. Descriptive and Econometric analyses were used to analyze the data. Descriptive statistics were employed to describe the demographic, socio-economic, and institutional characteristics of the potato farmers. A stochastic frontier model (SFM) and a two-limit Tobit regression model were employed to derive efficiency scores for the potato producers and determine technical inefficiency factors. The data was analyzed using the frontier 4.1c program and STATA software.

A Parametric Stochastic Frontier Production Function was used to assess the technical efficiency of potato producers in the study area. A Cobb-Douglas frontier production function with self-dual characteristics was used to derive efficiency scores for the potato producers. The double log form of the Cobb-Douglas production function model proved to be a superior alternative on theoretical and econometric grounds. The specific Cobb-Douglas production model estimated is given by:

$$Y_i = \beta_0 * \prod_{i=1}^{6} X_i^{\beta_i} * e^{(v_i - u_i)} \qquad (1)$$

By transforming it into double log-linear form;

$$\ln Y_i = \ln \beta_o + \beta_i \sum_{i=1}^{6} \ln X_i + (v_i - u_i) \qquad (2)$$

Where, Y_i - represents potato output and X_i - represents potato production inputs by i^{th} farmer. Whereas β_0 & β_i - are the regression parameters to be estimated and ln - is natural logarithm. The term $v_i - u_i$ is a composed error term where v_i represents randomness (or statistical noise) and u_i represents technical inefficiency.

From the error term component ($v_i - u_i$), v_i is a two sided ($-\infty < v < \infty$) normally distributed random error ($v \sim N[0, \sigma^2 v]$) that represents the stochastic effects outside the farmer's control. (example weather, natural disasters etc), measurement errors and other statistical noise while U_i is a one-sided ($u_i \geq 0$) efficiency component which is independent of v_i and is normally distributed with zero mean and a constant variance ($\sigma^2 u$) allowing the actual production fall below the frontier but without attributing all short falls in output from the frontier as inefficiency.

Following Khan and Saeed (2011) and Bealu *et al.* (2013) the stochastic frontier production functions model will be specified as follows:

$$Y_i = f(X_i; \alpha_i) + \varepsilon_i \qquad \text{for } i = 1, 2, \ldots, n \tag{3}$$

Whereby Y_i is the output of farmer i, X_i are the input variables, α_i are production coefficients and ε is the error term that is composed of two elements, that is: $\varepsilon_i = v_i - u_i$

The technical efficiency (TE) of an individual farm is defined in terms of the ratio of the observed output (Y_i) to the corresponding frontier output (Y_i^*), conditioned on the level of inputs used by the farm and mathematically expressed as:

$$TE = \frac{Y_i}{Y_i^*} = \frac{E(Y_i / u_i, X_i)}{E(Y_i / u_i = 0, X_i)} = e^{-[E(u_i/e_i)]} \tag{4}$$

The determinants of technical efficiency were estimated using a two-limit Tobit model with the dependent variable, as the technical efficiency indices. Following Amemiya (1981) and Endrias *et al.,* (2013), the two-limit Tobit model was defined as:

$$Y^*_{i\ TE} = \delta_0 + \sum_{j=1}^{n} \delta_j z_{ij} + u_i \tag{5}$$

Where Y_i^* is latent variable representing the efficiency scores, δ_0, $\delta_1, \ldots, \delta_n$ are parameters to be estimated, and TE is, technical efficiency of the i^{th} farmer. Z_i - demographic, socioeconomic and institutional factors that affect efficiency level. And u_i - an error term with mean zero and variance δ^2 ($u_i \sim IN(0, \delta^2)$) and farm specific efficiency scores for the smallholder potato producers’ range between zero and one.

$$Y_i = \begin{cases} 1, & \text{if } Y_i^* \geq 1 \\ Yi^*, & \text{if } 0 < Y_i^* < 1 \\ 0, & \text{if } Y_i^* \leq 0 \end{cases} \quad (6)$$

Two-limit Tobit model allows for censoring in both tails of the distribution (Greene, 2003). The log likelihood that is based on the doubly censored data and built up from sets of the two - limit Tobit model is given by;

$$\ln L = \sum_{Y_i = L_{oi}} \ln \varphi \left[\frac{l_{oi} - X'_i \beta}{\sigma} \right] + \sum_{y_i = y_i^*} \ln . \frac{1}{\sigma} \phi \left[\frac{Y_i - X'_i \beta}{\sigma} \right] + \sum_{Y_i = l_{1i}} \ln \left[1 - \phi (\frac{l_{1i - X'_i \beta}}{\sigma}) \right] - \quad (7)$$

Where L_{oi} = 0 (lower limit) and L_{1i} = 1 (upper limit) where **φ** and ϕ are normal and standard density functions.

The regression coefficients of the two-limit Tobit regression model cannot be interpreted like traditional regression coefficients that give the magnitude of the marginal effects of change in the explanatory variables on the expected value of the dependent variable.

The marginal effects of changes in explanatory variables from Tobit regression analysis were computed following the procedure proposed by McDonald and Moffitt (1980) and later developed by Gould *et al.* (1989). McDonald and Moffitt showed that a change in the independent variable x has three effects:

- It affects the conditional mean of y in the positive part of the distribution.
- It affects the probability that the observation will fall in that part of the distribution.
- The sum of both effects gives the unconditional effect.

The marginal effects for the unconditional expected value of the dependent variable, E(y*), where y* = max (a, min (y, b)), where a is the lower limit for left censoring and b is the upper limit for right censoring.

$$\frac{\partial E(y)}{\partial X_j} = \left[\varphi(z_u) - \varphi(z_{L)} \right] . \frac{\partial E(y^*)}{\partial X_j} + \frac{\partial \left[\varphi(z_u) - \varphi(z_L) \right]}{\partial X_j} + \frac{\partial \left[1 - \varphi(z_u) \right]}{\partial X_j} \quad (8)$$

The influence of explanatory variables on the expected value of the dependent variable conditional on it being larger than the lower bound. The marginal effects for the expected value of the dependent variable conditional on being uncensored, E(y | a<y<b), where a is the lower limit for left censoring and b is the upper limit for right censoring.

$$\frac{\partial E(y^*)}{\partial X_j} = \beta_m \cdot \left[1 + \frac{\{z_L\phi(z_L) - z_u\phi(z_u)\}}{\{\varphi(z_u) - \varphi(z_L)\}}\right] - \left[\frac{\{\phi(z_L) - \phi(z_u)\}^2}{\{\varphi(z_u) - \varphi(z_L)\}^2}\right] \quad (9)$$

The influence of explanatory variables on the probability of dependent variable to fall in the uncensored part of the distribution.

$$\frac{\partial[\varphi(z_u) - \varphi(z_L)]}{\partial X_j} = \frac{\beta_m}{\sigma}[\phi(z_L) - \phi(z_u)] \quad (10)$$

Where, φ(.) = the cumulative normal distribution, ϕ(.) = the normal density function, $Z_L = \frac{-X'_i\beta}{\sigma}$ and $Z_u = \frac{(1 - X_i\beta)}{\sigma}$ are standardized variables that came from the likelihood function given the limits of y* and σ = standard deviation of the model.

4. Results and Discussion

4.1 Descriptive Results

The majority (86.2%) of sampled respondents were male-headed households. Sampled age of respondents was aged between 18 to 73 years. Most of the sampled HHHs were relatively old. Farmer's experience in potato activities was ranged from one to thirty years. The HHS with small household sizes had one person, while those with large HH sizes had 13 persons, with an average of six members per household. About 52.5% of the total sampled HHs had at least six persons in the household.

This indicates that the majority of the farmers depend on on-farm activities to generate income. The average livestock holding per household in the study area was 8.7 TLU (Tropical Livestock Unit). The average landholding size per household in the study area was 2.4 ha. The majority of the farmers (58.2%) own below average landholding size (2.4 ha). 48.8 percent of the total operated area was under owner-operated land. On the other hand, contracted land (either cash rented, sharecropped, gifted, or borrowed) was observed to operate on 82.1 ha, which covered 51.2 percent substantially more significant than the average size of owner-operated land.

A majority of the sampled HHs (91.8%) did not access any credits for potato production and marketing. 80.6% of the respondents had access to extension services on potato production in the scheme. This study shows that only 27% of the farmers in the study area received off-farm income. The average number of years in formal education is five years, which is primary education. 16.8% of the HH heads having not attended any formal school at all. The number of plots cultivated by a household ranges from one to eleven. Fragmentation of land holdings is severe, and four plots are cultivated per household. The land quality measure was rated by farmers' perceptions of the quality of their plots. 89.8% of the cultivated area in the study area reported better quality soil with 37.8% and 52% for highly and moderately fertile soil, respectively.

4.2 Empirical Results

The maximum likelihood estimates (MLE) of the Cobb-Douglas based stochastic production function was specified to determine the possible relationships between the production of potato and inputs used. The results of MLE of variance parameters explain that variance parameter gamma (γ) is the ratio of variance of farm specific technical efficiency to the total variance of output and has a value 0.86 which shows that out of total variation in potato production 86 percent variation is due to technical inefficiency u_i.

Table 1. *MLE of the Variance Parameters*

Input Variables	coefficient	standard-error	t-ratio
Plot Size	0.21416064	0.56909651	0.37631691
Amount of seed	0.19014809	0.44986308	0.42267992
Amount of fertilizer	0.14872105	0.42500346	0.34992904
Amount of chemicals	0.77022855	0.20334298	0.37878295
Oxen days	0.23933915	0.82721297	0.28933196
Labor days	0.19641556	0.58023390	0.33851101
sigma-squared	0.53994401	0.87086913	0.33851101
Gamma	0.86325026	0.60872807	0.14181213
log likelihood function = 0.13383290			

Source: *Own creation.*

The estimated values of output elasticities for all inputs are positive and significant influence on potato output growth.

Technical Efficiency Level: The mean TE of sample households during the survey period was 62.6%. The efficiency scores indicate that there were wide ranges of differences in TE among potato-producing farmers. Results indicate a considerable amount of efficiency variation among potato producer farmers, implying significant potential in potato production that can be developed.

Factors Influencing Technical Efficiency: The results obtained from the first stage estimations indicated that the average efficiency scores were low, and there existed efficiency variations among farmers. The TE estimates derived from the model were regressed on factors that explain variations in efficiency across farm households using the Tobit model (Table 2).

***Table 2.** Tobit regression (determinant factors in technical efficiency)*

Variables	Coefficient (TE)	Std. Err.	t	P>|t|
Sex of household head	-0.0340026***	0.005815	-5.850	0.000
Age of household head	-0.010998***	0.000387	-28.440	0.000
Education level of household head	0.0047574***	0.000721	6.600	0.000
Size of household head	0.0002115	0.000443	0.480	0.634
Land holding	-0.0423106***	0.004445	-9.520	0.000
Land tenure status	0.0075885**	0.003761	2.020	0.045
Land fragmentation	-0.0023509**	0.000920	-2.560	0.011
Tropical livestock unit (TLU)	0.0007838*	0.000473	1.660	0.099
Of farm income	0.0001235	0.000168	0.730	0.464
Extension contact	0.0051273***	0.000832	6.170	0.000
Credit service	0.0008965***	0.000283	3.170	0.002
Soil fertility status	0.0114919**	0.005175	2.220	0.028

Note: **** Significant at 1%, ** Significant at 5% and * Significant at 10%*
Source: *Own creation.*

The sex of the household head showed a negative effect on TE of the potato farms, and it was significant at a 1% level. Female-headed households would have better opportunities to carry out frequent follow-up and supervision of the farm activities on their plot, and female farmers are more likely to attend meetings and adopt the best production practices. The result was similar to that of (Tewodros, 2001) and (Susan, 2011).

Age of household head showed a negative effect on TE of the potato farms and was significant at 1% level. The finding is attributed to the fact that older potato farmers in the study area are relatively more resistant to adopt new practices and better technologies; instead, they prefer to hold to the traditional farming methods, thus become more technically inefficient compared to their younger counterparts. Younger farmers were relatively more efficient than older farmers. This is because younger farmers are comparatively more educated than the older farmers and had more contacts with extension agents, plot demonstrations, and agricultural meetings. The finding was consistent with (Abdur, 2012; Bealu *et al.,* 2013; Sibiko *et al.,* 2013).

The education level of the household head showed a positive effect on TE of the potato farms, and it was significant at the 1% level. More educated producers are more efficient in their acquisition and processing of technical knowledge. This may lead to a better assessment of the importance and complexities of good farming decisions, including efficient use of inputs and improved technologies, faster because they understand the benefits of technology, hence increasing their efficiency. Thus more years of schooling of the household head would lead to higher TE. Daniel (2009), Tewodros (2001), and Khan and Saeed (2011) found the same.

Farm Land size harmed the TE of the potato farms, and it was significant at a 1% level. This finding suggests that an increasingly larger farm size diminishes the timeliness of input use, and farmers may encounter more problems in applying farm inputs at the right time, hence an inefficient use of farm inputs. Perhaps, timely and appropriate agricultural operation on larger land size given the traditional techniques may not be practical, which leads to a higher level of inefficiency. Similar findings were obtained by (Abdur, 2012; Essa, 2011).

Farmer ownership to land-related positively to technical efficiency and significant at 5% level. This happened due to comparatively more inputs in owner-operators than another tenure arrangement, which caused higher yield obtained in owner-operators than another tenure arrangement. A farmer cultivated on his land will be economically efficient because the farmer's paying is lower than the land rent the farmer has to pay. The increase in production cost will imply a decrease in economic efficiency. In contrast, tenant cultivation is inefficient because of the adverse effect of tenure insecurity on long-term investments. Abdur (2012) and Riatania (2014) found the same.

Land fragmentation harmed the TE of the potato farms as was hypothesized, and it was significant at a 5% level. The results indicate fragmented farms create difficulties in oxen and labor use, affecting negatively and significantly. More considerable fragmentation of widely scattered plots made it difficult for farmers to work on all their fields simultaneously. However, having so many fields reduces the labor and other resources invested by farmers, particularly in their distant fields. Available organic materials, such as manure and crop residues, are used only on fields nearest the homestead. Besides being difficult to reach (many fields are over 60 minutes walking from the home), the far distant fields are also challenging to guard against incursion by grazing cattle. Households nearer to the plot can better manage and see growing potatoes, which will improve potato productivity. This is the same result as that of Essa (2011) and Erdal (2010).

Livestock Ownership (TLU) had a positive effect on the TE of the potato farms, and it was significant at a 1% level. Farmers who owned much livestock were technically more efficient than those who owned more miniature livestock in potato production. This is because livestock provides a working power (oxen for draught power), manure fertilizer, and is a source of income that can be used to purchase the necessary agricultural inputs, avoids inadequate and late land preparation. Endrias *et al.* (2013) and Saulos (2015) found for the same.

Access to Credit had a positive effect on TE at a 1% significant level. The positive and significant impact of Credit on TE implies that credit availability enables farmers to make timely purchases of inputs that they cannot provide otherwise from their resources by overcoming liquidity constraints which may affect their ability to apply inputs and implement farm management decisions on time. This result is consistent with Khan and Saeed (2011) and Obare *et al.* (2010).

Extension Contact positively affected the TE of the potato farms at a 1% significant level. Furthermore, such farmers respond fast to new technologies and appreciate correct management practices like timely planting and weeding, the correct amount of fertilizer to be applied, correct seed rate, and general management of the farm. Therefore, households that receive regular extension visits by extension workers appear to be more technically and economically efficient than their counterparts. The result is consistent with Daniel (2009) and Bealu *et al.* (2013). Soil Fertility had a positive effect on the TE of the potato farms, and it was significant at a 5% level. This implies that farmers with fertile farms were more efficient than farmers with the infertile farm. This is because a farmer holding infertile soil needs further inputs and input costs to conserve the soil for better production. The result is consistent with that of Alemayehu (2010) and Ruth (2011).

The estimated parameters on the inefficiency model presented in Table 3 only indicate the effects of the variables on efficiency levels. The results from the Tobit model were subjected to post estimation test using marginal effect analysis to estimate the trivial change from each factor that influences TE. Quantification of these variables' marginal effects is essential to estimate the change that will occur concerning a change in one unit of that variable - Table 3.

Table 3. *The marginal effects of change in explanatory variables (TE)*

Variables	∂ **E (y)**	∂ **E (y*)**
Sex of household head	-0.03191	-0.02611
Age of household head	-0.01022	-0.00841
Education level of household head	0.00437	0.00352
Size of household head	0.00018	0.00015
Land holding	-0.01227	-0.01015
Land tenure status	0.00715	0.00585
Land fragmentation	-0.00219	-0.00179
Tropical livestock unit (TLU)	0.00074	0.00060
Of farm income	0.00011	0.00009
Extension contact	0.00473	0.00388
Credit service	0.00083	0.00068
Soil fertility status	0.01060	0.00864

Source: *Own creation.*

The result shows that a change in the dummy variable representing the sex of household head from (0=F, 1=M), in the age of household head, in farm size, and the land fragmentation in an increasing order would decrease the probability of a farmer being technically efficient by about 3.19%, 1.02%, 1.23%, and 0.22% respectively and the mean level of TE by about 2.61%, 0.84%, 1.02%, and 0.18% respectively.

A unit change in the educational level of the household head, in land tenure arrangement (0=rental, 1=owner), in number agricultural extension contact, in the utilization of credit, and the dummy variable representing the soil fertility of the plot

(0 = bare land, 1= fertile land) and several livestock owned in an increasing order would increase the probability of a farmer to be technically efficient by 0.44%, 0.72%, 0.47%, 0.08%, and 1.06% respectively and the expected value TE by 0.35%, 0.59%, 0.39%, 0.07%, and 0.86% respectively.

5. Conclusion and Recommendation

Ethiopia has a high potential for potato production and consumption. However, production does not meet the demand because of low productivity, despite many research and development efforts made on high-yielding varieties. In Ethiopia, 36 improved potato varieties were released since 1987 through its research centers.

However, national average yields are still far below attainable yields. Farmers use different production inputs and management levels depending on their infrastructural facility and socio-economic, institutional and environmental conditions. The study observed that the efficiency of potato farmers varied due to the presence of inefficiency effects in potato production. Technical efficiency was positively and significantly affected by education, land tenure status, extension service, credit, and soil fertility, whereas variables such as sex of household head, age of household head, farm size, and land fragmentation affected it negatively. Therefore, the study suggested the need for policies to discourage land fragmentation and promote education, extension visits, access to credit, and soil fertility to improve technical efficiency.

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