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Determinants of technical efficiency differentials amongst small and medium scale farmers in Uganda: A case of tobacco growers

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Abstract

It is argued that technical efficiency **is** determined by individual farm- and farmer-specific characteristics (Shapiro and Muller, 1977). Such characteristics may be divided into two groups – **demographic characteristics,** which dominate the decision-making process of the farmer and **socio-economic and institutional characteristics,** which influence a farmer's capacity to apply his decisions at the farm level. The principal objectives of this study are to explore the potential of improving production efficiencies of farmers and identify factors that influence such efficiencies.

The study uses cross-sectional data from a sample of 65 small and medium scale farmers. A stochastic production frontier approach is used to estimate the farmer-specific technical efficiencies. The estimated efficiencies are then explained by socio-economic and demographic factors.

It is shown that, education, credit accessibility and extension services contribute positively towards the improvement of efficiency. These results therefore suggest that if more resources are invested in extension services, improved availability of credit, with less fragmentation of land, then there will be an improvement in technical efficiency of farmers in Uganda.

I Introduction

Following Schultz's policy conclusions on traditional agriculture that no significant increase in agriculture production is possible by reallocating the factors at the disposal of farmers, any agricultural policy discussion is centred around the issue of raising the production levels. In recent decades, the green revolution (or new technology) has been recognized by policy makers as an important tool to increase agricultural productivity. Thus, the primary objective of agricultural policies is to examine and to eliminate the constraints on the adoption of new technology. This is based on the assumption that productivity will be increased once there is adoption of new technology.

Productivity increases do not depend on adoption rate only. What is also needed is the *effective* use of available technology. The importance of the efficient use of technology, otherwise called technical efficiency, is seldom realized by policy makers. The term technical efficiency, generally, refers to the performance of processes of transforming a set of inputs into a set of outputs. It is a relative concept which means that the performance of the economic unit in question should be compared with a standard model. In the context of establishing a standard criterion, there has been an extensive literature on this since the late 50s.

The whole issue of the appropriate balance in emphasis between efficient ***choice*** of technology and efficient ***use*** of chosen technology has received less attention in Uganda. It is being assumed, erroneously though, by policy makers that farmers can operate the technology efficiently, but can't select them efficiently. Thus, from a policy viewpoint it is imperative to examine how efficiently farmers in Uganda are using the existing technology at the farm level. Most importantly, policy makers need to know, for example, what factors constrain farmers from operating at the ***frontier*** of the existing technology. Such information can then be used in designing policies that will enable farmers to first realise the potential output from a given technology before resorting to the more expensive alternatives of introducing advanced technologies.

Productivity can be improved in the following ways: (i) ***Technology improvement***: by introducing new technologies; and (ii) ***Technique improvement***: by improving the techniques of input application for a given technology.

Most efforts in Uganda focus extensively on the first method[1] but much less attention has been paid to the latter approach. As Feder et al. (1985) have argued, unless the potential of an existing technology is completely exploited, benefits from new technologies may not be realised.

The techniques of input applications, the second approach, is equally important and deserves some attention by policy makers. With the existing resource structure and technology, it is possible to raise agricultural output by simply improving on the techniques of input application. This is particularly useful in the context of Uganda where the resource constraints are quite apparent if new technologies are the targets.

Furthermore, identification of the factors that constrain farmers from fully exploiting the existing technologies is important. Policies to promote agricultural output via techniques improvement can then address those constraints.

The principal objective of this study, using the tobacco farmers as a case study, is to identify factors that influence their technical efficiencies. The specific objectives are twofold: First, the study seeks to estimate farmer-specific technical efficiencies. Second, the study attempts to identify the factors that influence such technical efficiency differentials among tobacco farmers.

The rest of the paper is structured as follows. Section II discusses the technical efficiencies and their determinants while section III addresses the analytical framework. Empirical results are provided in Section IV. The summary and policy discussion in Section V conclude the paper.

[1] National Agricultural Research Organisation (NARO), a World Bank funded project, and other agricultural research institutes are engaged mainly in developing new agricultural technologies and high yielding varieties. It is believed that to improve productivities, the answer lies only in the adoption of these new technologies by farmers.

II Technical efficiency measures and their determinants

Technical efficiency measures

The literature emphasizes two broad approaches to production frontier estimation and technical efficiency measurement:

(a) The non-parametric programming approach, and
(b) The statistical approach.

The programming approach (Farrell, 1957; Afriat, 1972; Hanoch and Rothchild, 1972; Diewert and Parkan, 1983) requires one to construct a free disposal convex hull in the input-output space from a given sample of observations of inputs and output[2]. The convex hull, which is generated from a subset of the given sample, serves as an estimate of the production frontier, depicting the maximum possible output. Now, a measure of production efficiency of an economic unit (farm) is measured as the ratio of the actual output to the maximum possible output on the convex hull, corresponding to the given set of inputs.

A major criticism of this approach is that the convex hull, representing the maximum possible output, is derived using only marginal data and not utilizing all the observations in the sample. Thus the technical efficiency measures are susceptible to outliers and measurement errors (Forsund et al., 1980). Secondly, the method has very demanding data needs. Finally, being non-parametric, no statistical inferences on the estimates can be carried out.

The statistical approach can be subdivided into the neutral-shift frontiers and the non-neutral shift frontiers. The former approach measures the maximum possible output and then production efficiencies by specifying a composed error formulation to the conventional production function (Aigner et al., 1977 and Meeusen and van den Broeck, 1977). The latter approach uses a varying coefficients production function formulation (Kalirajan and Obwona, 1994; Obwona, 1995).

[2] For an excellent exposition of the programming approach to measuring production efficiency, see Fare et al. (1985).

Measurement of technical efficiency is one of the very important topics of research in both developing and developed countries. Application vary in content because most studies in developing countries are focused on agriculture[3] while in developed countries, the interest on technical efficiencies has been confined to the industrial sector, or manufacturing sector, in general.

Determinants of production efficiency

Hayami and Ruttan (1970) found that educational level was an important determinant of differences in agricultural productivity among countries. In a survey of research on education and farmer productivity, Lockhead et al. (1980) confirmed that education had a positive effect on farmers' efficiency in all 37 data sets included in their review.

Kalirajan and Shand (1985), in their study of high yielding paddy varieties (HYVs) in India, found that although schooling is productive for the individual, a farmer's education is not necessarily significantly related to yield. They argue that a farmer may gain improved knowledge of the technology with experience of using it or by observing others.

Kalirajan (1981) estimated a stochastic frontier Cobb-Douglas production function using data from 70 rice farmers for the *rabi* season in a district in India. The variance of farm effects was found to be highly significant component in describing the variability of rice yields. Kalirajan (1981) proceeded to investigate the relationship between the difference between the estimated maximum yield function and the observed rice yields and such variables as farmer's experience, educational level, number of visits by extension workers, etc. In this second-stage analysis, Kalirajan (1981) noted the policy implications of these findings for improving crop yields of farmers.

Ali and Flinn (1989) estimated a stochastic profit frontier of modified translog type for Basmati rice farmers in Pakistan's Punjab. After estimating the technical efficiency of individual farmers, the losses in profit due to technical inefficiency were obtained and regressed on various farmer- and farm-specific variables. Factors which were significant in describing the variability in profit losses were level of education, off-farm employment, unavailability of credit and various constraints associated with irrigation and fertilizer application.

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[3] For a survey of applications in agriculture, see Battesse(1992).

Kalirajan and Shand (1989) estimated the time-invariant panel-data model using data for Indian rice farmers over five consecutive harvest periods. The farm effects were found to be a highly significant component of the variability of rice output. A regression of the estimated technical efficiencies on the farm or farmer

-specific variables indicated that farming experience, level of education, access to credit and extension contacts had significant influences on the variation of farm efficiencies.

III Analytical framework

In this study we intend to use the stochastic production frontier[4] also called `composed error' model of Aigner et al. (1977) and Meeusen and van den Broeck (1977).

The stochastic production frontier is defined as

$$y_i = f(X_i;\alpha)\exp(v_i\text{-}u_i);\ i = 1,....N \qquad (1)$$

where y_i is the production of the i*th* firm; x_i is a kx1 vector of input quantities of the i*th* firm,

v_i is the usual symmetric noise associated with the random factors not under the control of the firms/farmers, while the one-sided error u_i with $u_i \geq 0$, captures technical inefficiency relative to the stochastic frontier.

The random errors, v_i, are assumed to be independently and identically distributed as $N(0,\sigma_v^2)$ random variables, independent of u_i's. The u_i's are also assumed to be independently and identically distributed as, for example, exponential (Meeusen and van den Broeck, 1977) and half normal (Aigner et al. 1977). Other proposed specification of the distribution of the asymmetric error include a truncated normal distribution (Stevenson, 1980) and the gamma density (Greene, 1980).

[4] The biggest advantage of the stochastic frontier approach is that unlike other approaches, it introduces a disturbance term representing noise, measurement errors and exogenous shocks beyond the control of farm unit, for example, weather, etc. None of the other approaches makes any accommodation for such phenomena.

Technical efficiency (TE) of an individual firm is defined as the ratio of the observed output (y) to the corresponding frontier output (y*), conditional on the levels of inputs used by the firm. Thus the technical efficiency of firm i in the context of the stochastic frontier production function (1) is

$$\begin{aligned} TE_i &= y_i/y^{*}_{i}{}^{**} \\ &= f(X_i;\alpha)\exp(v_i-u_i)/f(X_i;\alpha)\exp(v_i) \\ &= \exp(-u_i). \end{aligned} \quad (2)$$

Following Jondrow et al. (1982), the density function of u and v can respectively be written as

$$f(u) = 1/\sqrt{(2\pi)}(1/\sigma_u)\exp(-u^2/2\sigma^2_u); \qquad u\geq 0 \quad (3)$$

and

$$f(v) = 1/\sqrt{(2\pi)}(1/\sigma_v)\exp(-v^2/2\sigma^2_v); \quad -\infty \leq v \leq \infty \quad (4)$$

The density function of y which is the joint density of (v-u) is given as

$$f(y) = 1/\{\sigma\sqrt{(\pi/2)}\} \exp(-\omega^2/2\sigma^2)[1 - F\{(\omega/\sigma)(\gamma/(1-\gamma))\}] \quad (5)$$

where F(.) is the cumulative distribution function of the standard normal random variable and

$\omega = v-u$;

$\sigma^2 = \sigma_u^2 + \sigma_v^2$; and

$\gamma = \sigma_u^2/\sigma^2$, (6)

where γ lies in the interval (0, 1).

The likelihood function of the sample is then written as:

$$L(y;\theta) = \Pi[1/\sigma\sqrt{(\pi/2)}\exp(-\omega^2/2\sigma^2)(1 - F\{(\omega/\sigma)(\gamma/(1-\gamma))\}] \quad (7)$$

where θ is the parameter to be estimated and is equal to the production parameters, σ^2 and γ.

Measurement of u for individual observations is derived from the conditional distribution of u, given (v-u) (Jondrow et al., 1982; Kalirajan and Flinn, 1983). Given the normal distribution for v and a half-normal distribution for u[5], the conditional mean of u given (v-u) is

$$E(u|v-u) = \int u\, f(u|v-u)du \tag{8}$$

where $f(u|v-u) = f(u,v-u)/f(v-u)$. The density function of u, given (v-u), using equations 3 and 4 is equivalent to

$$f(u|v-u) = 1/\sqrt{2\pi}\sigma/\sigma_u\sigma_v \exp[-\sigma^2/2\sigma_u^2\sigma_v^2\,(u+\sigma_u^2/\sigma^2)^2]\;1/\{1-F(.)\} \tag{9}$$

where F(.) is the standard normal distribution function.

Now,

$$E(u|v-u) = (-\sigma_u\sigma_v/\sigma)\,[f(.)/(1-F(.)) - (v-u)/\sigma\,\sqrt{(\gamma/(1-\gamma))}] \tag{10}$$

where f(.) and F(.) are the values of the standard normal and cumulative normal density functions, respectively.

Estimates of E(u|v-u) are obtained by evaluating equation (10) at the ML estimates of γ, σ_v and σ_u . Technical efficiency for each farmer is then calculated as

$$TE = \exp(E(u|v-u) \tag{11}$$

[5] For other distributions such as exponential and truncated normal, see Greene (1980).

IV Empirical results

Survey area, sampling technique and data collection

The data collection was carried out during the months of October-December 1998. The study area purposively selected is Terego county, Arua district in West Nile Region. Tobacco is the lifeline of Arua district. About 70 percent of Uganda's home grown tobacco comes from Arua district and three quarters of tobacco farmers in Arua live in Terego county.

A list of all farmers – the sample frame - in the county was compiled with the help of the Local Council One (LC1) Chairmen, BAT (U) Arua branch and the district agricultural production unit staff. A systematic random sampling was used to draw 65 farmers from the contructed sample frame.

A pre-tested structured questionnaire provided in the Appendix was used to obtain both qualitative and quantitative information on the relevant variables such as the physical quantities of production inputs and outputs. To identify factors that influence efficiency, detailed information about the farmers was collected on characteristics such as, age and level of education, experience, income sources assets.

Technical efficiencies and their determinants

A number of empirical studies (eg. Pitt and Lee, 1981; Kalirajan and Shand, 1985) have estimated stochastic frontiers and predicted firm-level efficiencies using these estimated functions, and then regressed the predicted efficiencies upon firm-specific variables (such as managerial experience, ownership characteristics, etc.) in an attempt to identify some of the reasons for differences in predicted efficiencies between firms in an industry. This has long been recognised as a useful exercise, but the two-stage estimation procedure has long been recognised as one which is inconsistent in it's assumptions regarding the independence of the inefficiency effects in the two estimation stages. The two-stage estimation procedure is unlikely to provide estimates which are as efficient as those that could be obtained using a single-stage estimation procedure.

This issue was addressed by Battese and Coelli (1993) and Reifschneider and Stevenson (1991) who propose stochastic frontier models in which the inefficiency effects (u_i) are expressed as an explicit function of a vector of firm-specific variables and a random error.

Thus, following Battese and Coelli (1993) we specify our model as:

$$lny = \alpha_0 + \Sigma\alpha_i lnX_i + 1/2\Sigma\Sigma\alpha_{ij}\, lnX_i lnX_j + v_i - u_i \qquad (12)$$

Where

y = value of tobacco in shillings,

X_1 = labour used in person days

X_2 = fertilizer cost in shillings

X_3 = area under tobacco in acres

vi are random variables which are assumed to be iid $N(0, \sigma^2_v)$ and independent of ui which are non-negative random variables which are assumed to account for the technical inefficiency in production and are assumed to be independently distributed as truncations at zero of the $N(m_i, \sigma^2_u)$ distribution; where

$$m_i = Z_i\delta \qquad (13)$$

where Z_i is a px1 vector of variables which may influence the efficiency of a farm and δ is a 1xp vector of parameters to be estimated by a one-step maximum likelihood estimation procedure.

The Z vector consists of the following demographic and socio-economic factors:

FS = Family size (number)

SEX = Sex of household head

AGE = Age of household head

EDU = Education of household head

HS = Health status

OFI = Off farm income

HWF = Hired workforce

CD = Credit accessibility

FG = Degree of fragmentation

EXT = Contact and meeting of extension service

SIZE = Farm size (small scale takes value 1 if $\leq$ 1.5 acres and 0 otherwise)

The results of the estimated translog production frontier and technical efficiencies are presented in Tables 2 and 3. There was great variation in the levels of efficiency among farmers ranging from 44.8 percent to 97.3 percent with mean efficiency level of 76.2 percent (see Table 3). The determinants of technical efficiencies obtained from the one-step maximum likelihood procedure are presented in Table 4.

Table 1: Summary statistics for the production function variables

	Value (y)	*Land area*	*Labour*	*Fertilizer Cost*
	Shs. '000	acres	person-days	Shs.'000
Min	150	0.2	80	12
Max	6500	3.5	287	350
Average	650	0.6	175	160
Std. Dev	217.5	19.7	51.5	170.4

Source: Author's computation from Survey results

Table 2: MLE estimates of translog frontier production function

Variable	*Parameters*	*Coefficients*	*t-ratio*
Constant	β_0	2.8116	2.129*
Ln(Labour)	β_1	0.3128	3.142*
Ln(Fertilizer)	β_2	0.2468	2.865*
Ln(Land)	β_3	0.4861	2.922*
$(LnLabour)^2$	β_{11}	0.0187	0.124
*ln*Labour.*ln*Fert.	β_{12}	0.0054	0.823
*Ln*Labour.*Ln*Land	β_{13}	-0.0172	-1.629
$(LnFert.)^2$	β_{22}	-0.1162	3.001*
*Ln*Fert.*Ln*Land	β_{23}	0.0071	1.292
$(lnLand)^2$	β_{33}	-0.0473	0.717
	γ	0.6015	2.145*
	σ	0.0929	2.891*
	σ^2_v	0.0921	
	σ^2_u	0.1263	
Log-likelihood		327.324	
Total observations		65	

* significant at 5 per cent.

Table 4: Distribution of Farmer-specific technical efficiencies

Efficiency	*Number of farmers*	*Percentage*
40 <50	5	7.7
50 < 60	6	9.2
60 < 70	12	18.5
70 < 80	16	24.6
80 < 90	18	27.7
90 < 100	8	12.3
Total	65	100.0
Mean	78.4	
S. D.	10.8	
Min	44.5	
Max	98.1	

Table 4: Determinants of technical efficiencies

Parameters		Coefficients	t-ratio
δ_0	Constant	1.2712	1.60
A. Demographic characteristics			
δ_1	Family size	0.0142	3.53*
δ_2	Sex	0.0017	1.86
δ_3	Age	-0.0082	-0.63
δ_4	Education	0.0251	2.19*
δ_5	Health status	-0.0724	-2.82*
B. Resource factors			
δ_6	Off farm income	-0.0002	-0.91
δ_7	Hired workforce	-0.0124	-2.82*
C. Institutional factors			
δ_8	Credit accessibility	0.0247	3.16*
δ_9	Land fragmentation	-0.0089	-2.78*
δ_{10}	Extension services	0.0064	3.01*
δ_{11}	Farm size	-0.0141	-1.29
F-Stat (12, 53)		14.09	
Number of observations		65	

* Significant at 5 per cent

Family size has a positive and significant effect on efficiency because at the time of peak seasons (planting and harvesting between February and April), there is shortage of labour and hence family labour is a critical input.

Education has a positive and significant impact on technical efficiency as expected. On further investigation, it was found out that it is not the higher education as such but it is the vocational and adult education that really matter. The policy implication is that government strengthens vocational and/or adult education in such areas to improve on the farmer literacy.

Credit facilities (financial or in non-financial forms) improve farmers efficiency. Technical efficiency increases with the number of extension contacts and this is with conformity with earlier findings in the literature. Extension services improve efficiency as better management and information utilisation should lead to greater benefits to farmers.

The coefficients of other variablès are not significant although they have expected signs. For example, although the coefficient is insignificant, off-farm income shows a negative impact on efficiency. This could be that off-farm income is mainly from wage earnings which implies less time is allocated for farm work, hence a negative impact on technical efficiency. Similarly, fragmented land reduces the efficiency index.

Timing between stages of tobacco production is very crucial. A slight variation in timing (as little as 3-10 days) associated with soil preparation, planting, fertilizer application, thinning and removing tobacco buds or harvesting can have damaging consequences. A farm owner is usually reluctant to hire workers for such crucial tasks, when their effort cannot be monitored or measured adequately.

A hired workforce that is dispersed over a large area is more costly to monitor and its output more difficult to measure (eg. fertilising or seeding), giving workers an incentive to shirk. Hence, the negative impact on technical efficiency of hired workforce.

V Summary and Conclusions

In this study we have estimated the stochastic production frontier and predicted farmer-specific technical efficiencies for a sample of 65 tobacco farmers. We have also explained the predicted technical efficiency levels by socio-economic and demographic factors.

The results show that the potential for improving the production efficiency of tobacco farmers is immense as some farmers are operating at as low as 45 percent level of efficiency. This implies that tobacco production can still be increased with the present levels of inputs by simply improving farmers' level of efficiency.

The production efficiency at farm level depends on a number of socio-economic and demographic factors. The factors that have been identified which can contribute positively towards improving farmers' efficiency include: accessibility to credit, extension services and education.

Poor health status of the farmer or members of his/her family as expected impacted negatively on efficiency. This is mainly because the AIDS/HIV patients drain not only farmer's resources but also affect the farmer's time allocation. Government could assist by provid
ing better health care facilities such as hospices for supportive care for such terminally ill patients.

The participation of the private sector such the BAT and other players in the industry who provide credits, inputs and extension services to farmers need to be encouraged and strengthened in order to improve farmers' production efficiency.

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Appendix A

Variables	Value	Description
Dummy variables		
Credit access	0	no credit used
	1	credit used
Extension contact	-	Number of visits
Education	0	No or less than 7 years of schooling
	1	At least 7 years of schooling
Farm size	1	$\leq$ 1.5 acres
	0	> 1.5 acres
Hired workforce	1	If uses hired workforce
	0	if does not use
Off-farm income	0	no off-farm income
	1	off-farm income
Sex	0	female farmer
	1	male farmer
Continuous variables		
Age of farmer		Years
Total cropped area		acres
Labour		man-hours

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