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

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AERC Research Paper 152
African Economic Research Consortium, Nairobi
January 2006

THIS RESEARCH STUDY was supported by a grant from the African Economic Research Consortium. The findings, opinions and recommendations are those of the author, however, and do not necessarily reflect the views of the Consortium, its individual members or the AERC Secretariat.

Published by: The African Economic Research Consortium
P.O. Box 62882 - City Square
Nairobi 00200, Kenya

Printed by: The Regal Press Kenya, Ltd.
P.O. Box 46166 - GPO
Nairobi 00100, Kenya

ISBN 9966-944-80-X

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Acknowledgements

The author is grateful to the African Economic Research Consortium (AERC) for financial support for carrying out this study. The author also wishes to thank resource persons and peers of the AERC biannual research workshop for the their invaluable comments and inputs on initial drafts of the study. Finally, the author is grateful to external reviewers of this paper for well-articulated comments and observations. However, the author remains solely responsible for the views and shortcomings of the study.

Abstract

It is argued that technical efficiency is determined by individual farm- and farmer-specific characteristics. 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 the decisions at the farm level. The principal objectives of this study are to explore the potential for improving production efficiencies of farmers and to identify factors that influence such efficiencies.

The study uses cross-section 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 socioeconomic 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, the availability of credit is improved and there is less fragmentation of land, then there will be an improvement in technical efficiency of farmers in Uganda.

1. 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 production levels. In recent decades, the Green Revolution (or new technology) has been recognized by policy makers as an important tool for increasing agricultural productivity. Thus, the primary objective of agricultural policies is to examine and then eliminate the constraints on the adoption of new technology. This is based on the assumption that productivity will be increased once new technology is adopted.

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 extensive literature on this since the late 1950s.

The whole issue of the appropriate balance in emphasis between efficient choice of technology and efficient use of the chosen technology has received less attention in Uganda. It is being assumed, erroneously, by policy makers that farmers can operate the technologies efficiently, but can't select them efficiently. Thus, from a policy viewpoint it is imperative to examine how efficiently farmers in Uganda are using 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 realize 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:

- Technology improvement: by introducing new technologies; and
- 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 realized.

The techniques of input applications, the second approach, is equally important and deserves attention by policy makers. With the existing resource structure and technology, it is possible to raise agricultural output by simply improving 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 existing technologies is important. Policies to promote agricultural output via technique improvement can then address those constraints.

The principal objective of this study, using 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 technical efficiency differentials among tobacco farmers. The rest of the paper is structured as follows. Section 2 discusses the technical efficiencies and their determinants, while Section 3 addresses the analytical framework. Empirical results are provided in Section 4. The summary and policy discussions in Section 5 conclude the paper.

2. Technical efficiency measures and their determinants

Measurement of technical efficiency is one of the very important topics of research in both developing and developed countries. Applications vary in content because most studies in developing countries are focused on agriculture,[2] while in developed countries, the interest on technical efficiencies has been confined to the industrial sector, or the manufacturing sector, in general.

Technical efficiency measures

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

- The non-parametric programming approach, and
- 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.[3] 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 rather than all the observations in the sample. Thus the technical efficiency measures are susceptible to outliers and measurement errors (Forsund et al., 1980). Second, 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; Meeusen and van den Broeck, 1977). The latter approach uses a varying coefficients production function formulation (Kalirajan and Obwona, 1994; Obwona, 1995).

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 varieties (HYVs) of paddy 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 a 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 that 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.

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.

3. 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:

$$y_i = f(X_1; \alpha)\exp(v_i - u_i); \; i = 1, \ldots\ldots N \quad (1)$$

where 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 , captures technical inefficiency relative to the stochastic frontier.

The random errors, v_i, are assumed to be independently and identically distributed as $N(0,\acute{\sigma}_v^2)$ 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 specifications of the distribution of the asymmetric error include a truncated normal distribution (Stevenson, 1980) and the gamma density (Greene, 1980).

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:

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

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

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

and

(4)

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

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

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

$$\varpi = v - u;$$
$$\sigma^2 = \sigma_u{}^2 + \sigma_v{}^2; and$$
$$\gamma = \sigma_u{}^2/\sigma^2, \quad (6)$$

where γ lies in the interval (0, 1).

The likelihood function of the sample is then written as:

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

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:

$$E(u|v-u) = \int uf(u|v-u)du \quad (8)$$

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

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

where *F(.)* is the standard normal distribution function.
Now,

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

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) (11)

4. Empirical results

The study uses a cross-section 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 socioeconomic and demographic factors.

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% 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 constructed sample frame.

A pre-tested structured questionnaire was used to obtain both qualitative and quantitative information on the relevant variables such as the physical quantities of production inputs and outputs (refer to the Appendix for description and values of the variables). 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, etc.

Technical efficiencies and their determinants

Following Battese and Coelli (1993), a one-step maximum likelihood estimation procedure was used. This is done by incorporating the model for technical inefficiency effects in the translog production function specified as:

$$\ln y = \beta_0 + \sum \beta_i \ln x_1 + \tfrac{1}{2} \sum \sum \beta_{ij} \ln x_i \ln x_j + v - u; u \geq 0 \qquad (12)$$

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
u	=	farmer-specific characteristics related to production efficiency
v	=	statistical disturbance term

The demographic and socioeconomic factors hypothesized as technical efficiency determinants and incorporated into Equation 12 are:

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)

A summary of the production function variables is shown in Table 1. 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% to 97.3% with mean efficiency level of 76.2% (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	6,500	3.5	287	350
Average	650	0.6	175	160
St. 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 t-ratio	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*
Ln(Labour)^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
(*Ln*Fert.)^2	β_{22}	-0.1162	3.001*
*Ln*Fert..*ln*Land	β_{23}	0.0071	1.292
(*Ln*Land)^2	β_{33}	-0.0473	0.717
	γ	0.6015	2.145*
	σ	0.0929	2.891*
	$\sigma^2 v$	0.921	
	$\sigma^2 u$	0.1263	
Log-likelihood		327.324	

Notes: Total observations 65.
* Significant at 5%.

Table 3: 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	

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 higher education as such, but vocational and adult education that really matter. The policy implication is that government should strengthen vocational and adult education in such areas to improve farmer literacy.

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

Table 4: Determinants of technical efficiencies

Parameters		**Coefficients**	**t-ratio**
δ_0	Constant	1.2712	1.60
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*
Resource factors			
δ_6	Off-farm income	-0.0002	-0.91
δ_7	Hired workforce	-0.0124	-2.82*
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

Notes: F-Stat (12,53) 14.09
Number of observations: 65
*Significant at 5%.

The coefficients of other variables 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 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 (e.g., fertilizing or seeding), giving workers an incentive to shirk. Hence, the negative impact on technical efficiency of hired workforce.

5. 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 socioeconomic 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% 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 socioeconomic and demographic factors. The factors that have been identified as contributing positively towards improving farmers' efficiency include: accessibility to credit, extension services and education.

Poor health status of farmers or members of their family as expected negatively affects efficiency, particularly in the case of HIV/AIDS. This is mainly because HIV/AIDS patients not only drain the farmer's resources, but also affect the farmer's time allocation. Government could assist by providing better health care facilities such as hospices for supportive care for terminally ill patients.

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

Notes

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

2. For a survey of applications in agriculture, see Battesse (1992).

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

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 the farm unit, for example, weather, etc. None of the other approaches makes any accommodation for such phenomena.

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

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Appendix. Description and value of variables

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	≤ 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		Person-hours

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