

SOURCES OF TECHNICAL EFFICIENCY AMONG SMALLHOLDER MAIZE FARMERS IN SOUTHERN MALAWI

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Abstract

The agricultural sector in Malawi is vital to the economy for incomes and food security and accounts for 35 percent of national income, generates 90 percent of foreign exchange and provides paid and self-employment to 90 percent of the rural population. One constraint in achieving food security has been the smallness and fragmentation of land holdings among a large proportion of households in Malawi. Nonetheless, there have been several attempts by the government to improve the productivity of food crops on small farms, particularly for maize, since independence including the development of high yielding maize varieties, subsidization of farm inputs, provision of credit facilities, liberalisation of farm produce prices and liberalisation of farm produce marketing. While there have been several studies on food production in Malawi the focus has mainly been on technology development and adoption, production constraints, the impact of structural adjustment policies, the impact of price and marketing liberalization. This paper estimates technical efficiency among smallholder maize farmers in Malawi and identify sources of inefficiency using plot-level data. We find that smallholder maize farmers in Malawi are inefficient; with an average efficiency score of 53.11 percent and 58 percent of the plots have efficiency scores below 60 percent. The results of the study reveal that inefficiency falls with plot size, on plots that used hired labour, on plots that use hybrid seeds and membership to a farmer club or association.

1. Introduction

Background

The agricultural sector is central to economic activities in Malawi accounting for 35 percent of real gross product, more than 90 percent of the country's foreign exchange earnings and provides paid and self-employment to 92 percent of the population. The government distinguishes between smallholder farmers and estate farmers, in which the latter are large scale commercial farmers (Malawi Government, 1987). The smallholder sector is divided into three sectors: net food buyers, intermediate farmers and net food sellers. Net food buyers are those farmers with less than 0.7 hectares who cannot produce food to satisfy their subsistence needs given the technology and remain dependent on off-farm activities. Intermediate smallholder farmers are those with land holding between 0.7 hectares and 1.5 hectares who produce just enough for their survival but have very little for sale. Net food sellers are those farmers with land holdings of more than 1.5 hectares and produce more than their subsistence needs for survival during the year. Nearly 35 percent and 40 percent of smallholder farmers in Malawi fall in the categories of net food buyers and intermediate farmers, respectively. Alwang and Siegel (1999) note that about 70 percent of Malawian smallholder farmers cultivate less than 1.0 hectare and the median area under cultivation is about 0.6 hectares, and devote about 70 percent of the land to maize, the main staple food crop. It is apparent that the success of the agricultural sector in Malawi is critical for raising the standard of living and for food self sufficiency and as a sustainable source of livelihood for a large population.

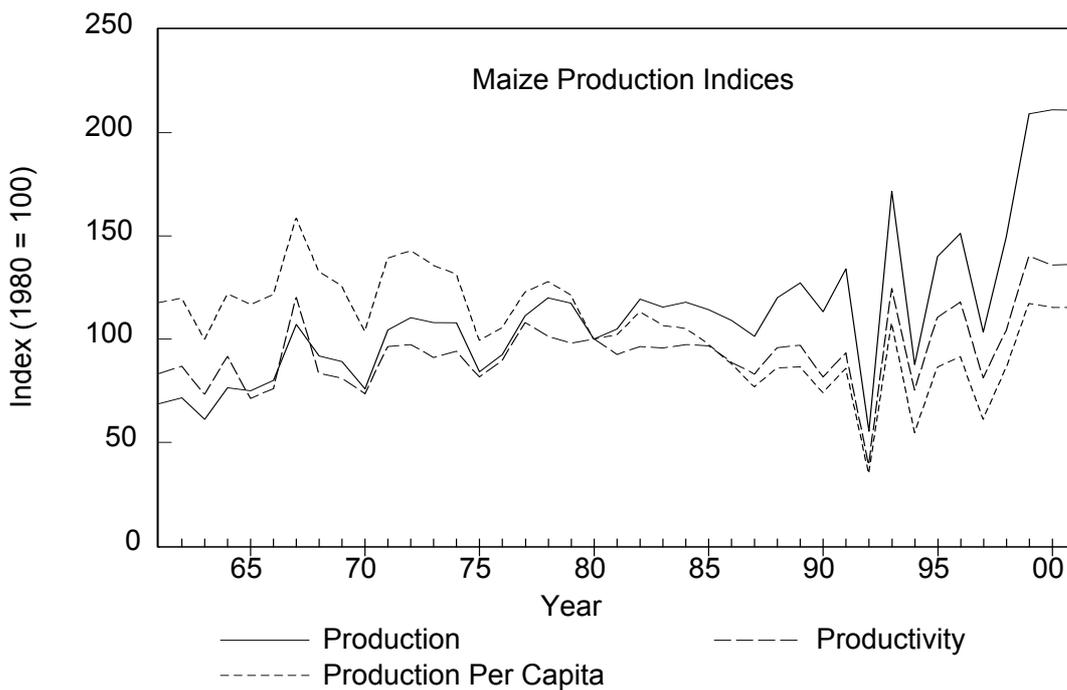
Since independence in 1964, government agricultural policy has emphasized increasing the participation of Malawians in economic activities more generally and in improving the productivity of smallholder farmers (Malawi Government, 1971, 1987). The government food security and smallholder incomes' policy focussed on increasing the productivity of maize grown by almost 70 percent of smallholder farmers. According to the Malawi Government (1987: 9) it was observed that during the 1960s and 1970s, the principal determinants of productivity change were seen as the adoption of improved seed varieties, particularly hybrids, and the application of fertilizer. There was considerable public sector investment in series of integrated rural development projects with a range of services introduced through these projects, including extension services and rural credit facilities. More particularly, there is evidence that technological developments such as seed variety development, fertilizer adoption and integrated farming system have been central to these efforts in Malawi (Malawi Government, 1971 and 1987; Smale, 1995; Smale et al., 1995; Lele, 1989) and structural adjustment policies aimed at creating price incentives for crop production (Sahn and Arulpragasam, 1991).

Research problem

The role of maize is central to agricultural policy decisions as a prime staple food for food security reasons and for the overall development of the agricultural sector and the economy. In the 1960s, 78 percent of cultivated land estimated to be under maize was monocropped with little fertilizer application (Malawi Government, 1971). In 1987, the government conceded that despite its investment in technology development, adoption and extension services, smallholder maize production only increased by 2 percent between 1970 and 1986, with 1.2 percent attributed to increases in acreage (Malawi Government, 1987). The available

studies on the productivity gains in maize production in spite of government investment in the agricultural sector suggests little improvements in productivity and the goal of self-sufficiency in food production remains a long term target. Figure 1 shows no systematic trend in the productivity of maize as measured by output per hectare. The maize productivity marginally improved particularly between 1961 and 1981, but show a declining trend thereafter until the 1990s in which the oscillating pattern is more evident. Incidentally, the period after 1981 is associated with structural adjustment programs in Malawi and this is the period in which productivity in maize production witnessed a declining trend.

Figure 1: Maize production and productivity indices, 1961 - 2001



Source: Computed based on FAO data

The food production trends are similar to the productivity trend. The food production index shows an increasing trend in food production prior to 1990. The downswings in 1992, 1994 and 1997 are a result of the adverse weather conditions in form of drought. This led to substantial maize imports in the 1990s in order to meet the national food requirements. The picture that emerges from the per capita food production index reveals food insecurity over time, particularly in the 1980s despite structural reforms that mainly targeted the agricultural sector.

The above food production trends raise questions about the efficiency of maize production in Malawi even in periods when the country experiences favourable weather conditions. Why has productivity in maize production remained low in Malawi? Previous studies on Malawi have not addressed the question of the efficiency of maize production. Most existing studies in food production in Malawi relate to research on maize varieties and technological adoption (Smale, 1995; Smale et al., 1995; Zeller et al., 1998), the impact of structural adjustment programs (Sahn and Arulpragasam, 1991; Kherallah and Govindan, 1999; Harrigan, 1988), the liberalisation of food produce pricing and marketing (Chirwa, 1998 and 2000; Chilowa,

2000; Goletti and Babu, 1994; Kaluwa, 1992; Scarborough, 1990; Kaluwa and Chilowa, 1991; Mkwezalamba, 1989). Horward (1999) analyses the relationship between farm size and productivity in smallholder agriculture in Malawi and provides evidence of a positive relationship between farm size and productivity. However, there is apparent lack of empirical research on the productive or economic efficiency of smallholder farmers in the Malawian agricultural sector.

This study contributes to the understanding of resource use in smallholder maize producing farms in Malawi, while contributing to the empirical literature with respect to African agriculture more generally, and Malawian agriculture in particular. The significance of this study with respect to policy cannot be understated. First, the Malawi government has been implementing agricultural policies that aim at improving the productivity and efficiency of food production, but the impact of these policies has not been investigated. It will be interesting to determine the technical efficiency of maize production in Malawi and compare efficiency levels found in other studies using similar methodologies in developing countries. Second, studying the significance of technology adoption, farming systems and farmer education will have policy implications on how the government can further influence the efficiency of food crop production.

Objectives

The purpose of this study is to augment to the existing empirical literature on the microeconomics of the smallholder agricultural production in Malawi by focussing on the technical efficiency and factors that influence the technical efficiency of maize production on smallholder farms or plots. With respect to public policy, the government has pursued several strategies to improve agricultural production and this study will provide an indication of the level of technical efficiency that these efforts have achieved and by identifying sources of technical efficiency which government further need to address in order to maximize food production among the many land-constrained smallholder farmers. The specific objectives of the study are to:

- a) estimate mean and plot-specific technical efficiency levels in smallholder farms producing maize, the main staple crop;
- b) examine the impact of technology adoption, such as improved seeds and fertilizer application on the technical efficiency of smallholder farmers;
- c) determine the relative role of gender, farmer education, farmer experience, plot size, distance to the main access road, use of hired labour and membership to an association.

2. Literature review

Household decision-making models

Although, the theoretical models of the household decision making process have been enriched by game-theoretic developments, empirical studies of consumer demand, labour supply and household production are typically based on the assumption that households behave as if they are single individuals (Udry, 1996). Thus, most empirical studies are therefore based on the traditional 'unitary' household model that employs the neoclassical paradigm of utility maximisation. The neoclassical theory is based on individual behaviour

and typically assumes a single individual household. However, in empirical work particularly in households with more than one member, individual preferences are aggregated and the household is assumed to behave as if they were a single individual. While such aggregation is convenient, Udry et al. (1995) argue that such restrictive assumptions may not be capable of investigating intra-household resource allocation and gender differences in agriculture. Many empirical studies of farming households assume that decisions are made at household level and that no conflict arises in the decision making process of households. However, Udry et al. (1995) and Udry (1996) have argued that the neoclassical 'unitary' household decision model may not be appropriate for understanding the behaviour of farming households in sub-Saharan Africa and other less developed countries in which households cultivate on multiple plots controlled by different members of the household.

Alternative models to the neoclassical 'unitary' model of the household have been proposed in the literature (see Browning and Chiappori, 1994; Udry et al., 1995; Udry, 1996; Chen and Woolley, 2001). These models recognize differences in the preferences and bargaining strength of household members in households with more than one individual. As Chen and Woolley (2001) and Udry (1996) note the non-cooperative and cooperative bargaining approaches have emerged in the literature. In non-cooperative models, each family member maximizes his or her own well-being taking the behaviour of others as given. On the other hand, cooperative models require some mechanism of contract enforcement, although families rarely write explicit contracts governing their behaviour. Chiappori (1992) proposes a 'collective' approach to modelling the family based on the cooperative bargaining approach. One assumption about the cooperative bargaining models of a household is that the allocation of resources is Pareto efficient, in addition to other assumptions such as a variety of sharing rules and threat points. In another development, Browning and Chiappori (1994) suggest a model that only assumes that Pareto efficiency is achieved.

In the context of agricultural production in sub-Saharan Africa, Udry (1996) and Udry et al. (1995) recognize the complexity of household decision making in intra-household resource allocation and test the Pareto efficiency hypothesis using plot level information and characteristics. Pareto efficiency in the Browning and Chiappori (1994) tradition implies that factors of production will be allocated efficiently across plots and that there will be no differences in the productivity of different plots with the same crops controlled by different individuals in the household. The results obtained by Udry (1996) and Udry et al. (1995) using plot characteristics, however, show that plots controlled by women produced more inefficiently than plots controlled by men within the same household for the same crops. These results suggest the existence of inefficient allocations of factors of production to different activities within the household.

The Udry et al. (1995) and Udry (1996) approach is more relevant in the analysis of smallholder agricultural production in Malawi for two reasons. First, smallholder agricultural land in Malawi with the growing population has become more fragmented and there is a tendency for households to own several plots in different areas. Thus, plot level characteristics may be important in determining the efficiency of production activities. Secondly, the unitary household model in Malawi is less appealing given the fact that the concept of the family is still strong. In this study we therefore follow the collective household model by testing the Pareto efficient hypothesis in the allocation of factors of production to various plots within the same household.

Definition and estimation of technical efficiency

Technical efficiency is a component of productive efficiency and is derived from the production function. Productive efficiency consists of technical efficiency and allocative or factor price efficiency. Productive efficiency represents the efficient resource input mix for any given output that minimizes the cost of producing that level of output or equivalently, the combination of inputs that for a given monetary outlay maximizes the level of production (Forsund et al., 1980). Technical efficiency reflect the ability of the firm to maximize output for a given set of resource inputs while allocative (factor price) efficiency reflects the ability of the firm to use the inputs in optimal proportions given their respective prices and the production technology. Developments in cost and production frontiers are attempts to measure productive efficiency as proposed by Farrell (1957). The frontier defines the limit to a range of possible observed production (cost) levels and identifies the extent to which the firm lies below (above) the frontier.

The literature suggests several alternative approaches to measuring productive efficiency, grouped into non-parametric frontiers and parametric frontiers. Non-parametric frontiers do not impose a functional form on the production frontiers and do not make assumptions about the error term. These have used linear programming approaches and the most popular non-parametric approach has been the Data Envelopment Analysis. Parametric frontier approaches impose a functional form on the production function and make assumptions about the data. The most common functional forms include the Cobb-Douglas, constant elasticity of substitution and translog production functions. The other distinction is between deterministic and stochastic frontiers. Deterministic frontiers assume that all the deviations from the frontier are a result of firms' inefficiency while stochastic frontiers assume that part of the deviations from the frontier are due to random events (reflecting measurement errors and statistical noise) and part is due to firm specific inefficiency (see Forsund et al., 1980); Battese, 1992; Coelli et al., 1998).

The stochastic frontier approach, unlike the other parametric frontier measures, makes allowance for stochastic errors due to statistical noise or measurement errors. The stochastic frontier model decomposes the error term into a two-sided random error that captures the random effects outside the control of the firm (the decision making unit) and the one-sided efficiency component. The model was first proposed by Aigner et al. (1977) and Meeusen and van den Broeck (1977). Assuming a suitable production function, we define the stochastic production frontier as

$$\ln(y_i) = f(x_{ij}, \beta) + \varepsilon_j \quad (1)$$

where y is the level of output on the j th plot, x is the value of input i used on plot j , $\varepsilon_i = v_j - u_j$ is the composed error term, and v_j is the two-sided error term while u_j is the one-sided error term. The components of the composed error term are governed by different assumptions about their distribution. The random (symmetric) component v_j is assumed to be identically and independently distributed as $N(0, \sigma_v^2)$ and is also independent of u_j . The random error represents random variations in the economic environment facing the production units, reflecting luck, weather, machine breakdown and variable input quality; measurement errors and omitted variables from the functional form (Aigner et al., 1977).

The distribution of the inefficiency component can take many forms, but is distributed asymmetrically. However, there is no *a priori* argument that suggests that one form of distribution is superior to another, although different assumptions yield different efficiency levels. The inefficiency component represents a variety of features that reflect inefficiency such as firm-specific knowledge; the will, skills, and effort of management and employees; work stoppages, material bottlenecks, and other disruptions to production (Aigner et al., 1977; Lee and Tyler, 1978; Page, 1980). Meeusen and van den Broeck (1977) and Aigner et al. (1977) assume that u_j has an exponential and a half-normal distribution, respectively. Both distributions have a mode of zero. Other proposed specifications of the distribution of u_j include a truncated normal distribution - $N(\mu, \sigma_u^2)$ (Stevenson, 1980) and the gamma density (Greene, 1980).

The stochastic model can be estimated by ‘corrected’ ordinary least squares (COLS) method or the maximum likelihood method. We follow the Battese and Coelli (1988) and Battese and Coelli (1995) using Battese and Corra (1977) parameterization. The maximum likelihood (ML) estimates of the production function (1) are obtained from the following log likelihood function

$$\ln L = \frac{N}{2} \ln \left(\frac{\pi}{2} \right) - \frac{N}{2} \ln \sigma^2 + \sum_{j=1}^N \ln \left[1 - F \left(\frac{\varepsilon_j \sqrt{\gamma}}{\sigma \sqrt{1-\gamma}} \right) \right] - \frac{1}{2\sigma^2} \sum_{j=1}^N \varepsilon_j^2 \quad (2)$$

where ε_j are residuals based on ML estimates, N is the number of observations, $F()$ is the standard normal distribution function, $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2 / \sigma^2$. Assuming a half-normal distribution of u , the mean technical efficiency is measured by

$$E[\exp(-u_j)] = 2[\exp(-\gamma\sigma^2 / 2)][1 - F(\sigma\sqrt{\gamma})] \quad (3)$$

where F is the standard normal distribution function. Measurement of farm level inefficiency requires the estimation of nonnegative error u . Given the assumptions on the distribution of v and u , Jondrow et al. (1982) first derived the conditional mean of u given ε . Battese and Coelli (1988) derive the best predictor of the technical efficiency of plot or farm j $TE_j = \exp(-u_j)$ as

$$E[\exp(-u_j | \varepsilon_j)] = \left[\frac{1 - F(\sigma_A + \gamma\varepsilon_i / \sigma_A)}{1 - F(\gamma\varepsilon_i / \sigma_A)} \right] \exp(\gamma\varepsilon_i + \sigma_A^2 / 2) \quad (4)$$

where $\sigma_A = \sqrt{\gamma(1-\gamma)\sigma^2}$. The maximum likelihood estimates of the production function in equation (1) are automated in a computer program, FRONTIER Version 4.1, written by Coelli (1996b). FRONTIER provides estimates of β , $\sigma^2 = \sigma_u^2 + \sigma_v^2$, $\gamma = \sigma_u^2 / \sigma^2$ and average technical efficiencies and plot or farm level efficiencies. FRONTIER also provides the estimate for μ when the symmetric error term follows a truncated normal distribution $u_j \sim N(\mu, \sigma_u^2)$.

Factors influencing technical efficiency

The literature suggests two methodological approaches of analysing the sources of technical efficiency based on stochastic production functions. The first approach is the two-stage estimation procedure in which first the stochastic production function is estimated, from which efficiency scores are derived, then in the second stage the derived efficiency scores are regressed on explanatory variables using ordinary least square methods or tobit regression. This approach has been criticized on grounds that the firm's knowledge of its level of technical inefficiency affects its input choices; hence inefficiency may be dependent of the explanatory variables. The second approach advocates a one stage simultaneous estimation approach as in Battese and Coelli (1995), in which the inefficiency effects are expressed as an explicit function of a vector of farm-specific variables. The technical inefficiency effects are expressed as

$$u_j = z_j \delta \quad (5)$$

where for farm j , z is a vector of observable explanatory variables and δ is a vector of unknown parameters. Thus, the parameters of the frontier production function are simultaneously estimated with those of an inefficiency model, in which the technical inefficiency effects are specified as a function of other variables. The one stage simultaneous approach is also implemented in FRONTIER and in addition to the basic parameters the program also provides coefficients for the technical inefficiency model.

Several factors including socio-economic and demographic factors, plot-level characteristics, environmental factors and non-physical factors are likely to affect the efficiency of smallholder farmers. Parikh et al. (1995) using stochastic cost frontiers in Pakistani agriculture in a two stage estimation procedure find that education, number of working animals, credit per acre and number of extension visits significantly increase cost efficiency while large land holding size and subsistence significantly decrease cost efficiency.

Coelli and Battese (1996) in a single estimation approach of the technical inefficiency model for Indian farmers find evidence that the number of years of schooling, land size and age of farmers are positively related to technical inefficiency. Wang et al. (1996) using a shadow price profit frontier model to examine the productive efficiency of Chinese agriculture find that household's educational levels, family size and per capita net income are positively related to productive efficiency but off farm employment is negatively related to efficiency.

Tadesse and Krishnamoorthy (1997) find significant differences in technical efficiency across the farm size groups with paddy farms on small- and medium-sized holdings operate at a higher level of efficiency than large sized farms. They argue that because accessibility to institutional finance depends on asset position particularly land, small farms will be forced to allocate their meagre resources more efficiently. Seyoum et al. (1998) use the one-stage technical inefficiency model and find technical inefficiency to be a decreasing function education of farmers and hours of extension among farmers participating in the modern technology project while education does not significantly affect the efficiency of farmers using traditional farming methods.

Wadud and White (2000) using stochastic translog production frontier in both one-stage and two-stage technical inefficiency model find that inefficiency decrease with farm size and farmers with good soils were significantly more technically efficient. Weir (1999) and Weir

and Knight (2000) investigate the impact of education on technical efficiency in Ethiopia and find that household education positively influence the level of technical efficiency in cereal crop farms. Owens et al. (2001) explore the impact of agricultural extension on farm production and find that access to agricultural extension services raises the value of crop production by 15 percent in Zimbabwe.

Existing empirical studies in Africa

The literature on productive or technical efficiency in African agriculture is emerging. Globally, there is a wide body of empirical research on the economic efficiency of farmers both in the developed and developing countries (for reviews see Battese, 1992; Coelli, 1995). While the empirical literature on the efficiency of farmers is vast in developed countries and Asian economies, few studies focus on African agriculture. Heshmati and Mulugeta (1996) estimates the technical efficiency of Ugandan matoke-producing farms and find that the matoke-producing farms face technologies with decreasing returns to scale with mean technical efficiency of 65 percent, but find no significant variation in technical efficiency with respect to farm sizes. This study, however, does not identify the various sources of technical efficiency among matoke-producing farmers.

Seyoum et al. (1998) investigate the technical efficiency and productivity of maize producers in Ethiopia and compare the performance of farmers within and outside the program of technology demonstration. Using Cobb-Douglas stochastic production functions, their empirical results show that farmers that participate in the program are more technically efficient with mean technical efficiency equal to 94 percent compared with those outside the project with mean efficiency equal to 79 percent. Townsend et al. (1998) using data envelopment analysis investigate the relationship between farm size, returns to scale and productivity among wine producers in South Africa and find that most farmers operate under constant returns to scale, but the inverse relationship between farm size and productivity is weak.

Weir (1999) investigates the effects of education on farmer productivity of cereal crops in rural Ethiopia using average and stochastic production functions. This study finds substantial internal benefits of schooling for farmer productivity in terms of efficiency gains but finds a threshold effect that implies that at least four years of schooling are required to lead to significant effects on farm level technical efficiency. Using different specifications, average technical efficiencies range between 0.44 and 0.56, and raising education from zero to four years in the household leads to a 15 percent increase in technical efficiency. Moreover, the study finds evidence that average schooling in the villages (external benefits of schooling) improves technical efficiency.

Weir and Knight (2000) analyse the impact of education externalities on production and technical efficiency of farmers in rural Ethiopia, and find evidence that the source of externalities to schooling is in the adoption and spread of innovations which shift out the production frontier. Mean technical efficiencies of cereal crop farmers are 0.55 and a unit increase in years of schooling increases technical efficiency by 2.1 percentage points. Nonetheless, one limitation of the Wier (1999) and Wier and Knight (2000) is that they only investigate the levels of schooling as the only source of technical efficiency.

Mochebelele and Winter-Nelson (2000) investigate the impact of labour migration on the technical efficiency performance of farms in the rural economy of Lesotho. Using the

stochastic production function (translog and Cobb-Douglas), the study finds that households that send migrant labour to South African mines are more efficient than households that do not send migrant labour with mean inefficiencies of 0.36 and 0.24, respectively. In addition, there is no statistical evidence that the size of the farm or the gender of the household head affects the efficiency of farmers. Mochebelele and Winter-Nelson (2000) conclude that remittances facilitate agricultural production, rather than substitute for it. This study, does not consider the many other household characteristics that may affect technical efficiency such as education, farmers' experience, access to credit facilities (capital) and advisory services, and the extent to which households that export labour receive remittances. The authors' interpretation that it is remittances that explain differences in technical efficiencies are based on the presumption that migrant labourers remit to their exporting households, and not on some measure of the extent of remittances.

Most of the empirical studies show that socio-economic characteristics and farm characteristics are important source of technical efficiency among farmers. Nonetheless, these studies assume that the farming household behaves as if it were an individual farmer, hence ignoring plot level characteristics and the intra-household resource allocation of the household. In this study, we adapt the approach by Udry (1996) and Udry et al. (1995) by focusing on plot level analysis of technical efficiency among smallholder maize farmers.

3. Methodology and data

The econometric models

We use the stochastic production frontier approach in estimating the production function and the determinants of technical efficiency among smallholder maize farmers in Malawi. Given the potential estimation biases of the two-step procedure for estimating technical efficiency scores and analysing their determinants, we use the one-stage procedure following Battese and Coelli (1995). The following translog production function is estimated

$$\ln y_j = \alpha + \sum_{i=1}^m \beta_i \ln x_{ij} + \frac{1}{2} \sum_{i=1}^m \sum_{k=1}^m \gamma_{ik} \ln x_{ij} \times \ln x_{kj} + v_j - u_j \quad (6)$$

where for plot j , y is the total quantity or value of maize produced, x is the quantity or value of input i used in the production process including labour, land, capital and material, v_j is the two-sided error term and u_j is the one-sided error term (technical inefficiency effects). Output is measured as the total value of maize, land is measured as the total plot area cultivated in hectares, labour is estimated as person days worked, capital is estimated as the total value of farm implements, and material are other inputs measured as the value of other inputs including fertilizers, manure, seeds, and pesticides.

The one-sided error term (the technical inefficiency effect) u_j is specified as

$$u_j = f(z) \quad (7)$$

where z is a vector of socio-economic characteristics of the farmer and the plot. We define

the farmer as the household member who controls production activities on each plot used mainly for the production of maize. The socio-economic and plot level characteristics modelled in the inefficiency effect include gender, education, farmer's experience, plot size, distance of the plot to the main access road, use of hired labour, application of fertilizer, use of hybrid seeds and membership to a farmers club.

Data

The data used in this study were collected through a smallholder farmer questionnaire administered to 156 households with information collected at household member level. The data collected include plot level output of maize and other food crops produced, the inputs used in the production process (land, capital, labour and other inputs) on each plot and the socio-economic and plot-specific characteristics.

The sample of smallholder farmers was drawn from one of the eight Agricultural Development Divisions (ADDs). We purposively selected Machinga ADD in southern Malawi as one of ADDs that devote a large percentage of cultivatable land to maize production. Mataya et al. (1999) note that nearly 48 percent and 45 percent of cultivatable smallholder land is allocated to maize production in Kasungu and Lilongwe ADDs, respectively - and followed by Machinga and Blantyre ADDs. In the selected ADD, we selected one Rural Development Programmes (RDPs) or districts - Machinga - based on the cultivatable land devoted to maize production. The selected RDP or district was stratified into Traditional Authorities (TAs) with each TA being further stratified into Enumeration Areas (EAs). We randomly selected two Traditional Authorities in the selected district and two EAs in each TA. In each selected EA, we randomly select at least 37 households, after a simple household listing. In each of the selected household, we interviewed the household head or a person with information about the farming activities of other household members, and individual members where necessary. The 156 households interviewed had a total of 444 plots used for the production of various crops with 206 plots used for maize production. Of the total 206 plots on which maize was the main crop, only 50 plots from 37 households were used purely for maize production. Since the output and input data was only collected with respect to the main crop grown on the plot, we use data from 50 plots on which maize is monocropped.

4. Empirical results

Descriptive statistics

Table 1 presents the definition of variables and descriptive statistics. About 44 percent of the plots are controlled by women. The level of education among maize farmers is low as revealed by the mean years of schooling of 3.7 years. Most of the plots on which maize is grown are small with the mean plot size of 0.52 hectares. This implies that most of the farmers interviewed were net food buyers. With the famine in the previous season, 2000/2001, many households ate most of the maize while green to meet the food deficits in the pre-harvest season. The average distance from the plot to the main access road is less than one kilometre. Most labour used in the cultivation of maize is from family members while hired labour was only used in nearly 12 percent of the maize plots. Fertilizers were applied only to 50 percent while hybrid maize was the main crop in 48 percent of the plots. Only 6

percent of farmers come from households in which at least a member has membership to a club or association.

Table 1: Definition of variables and descriptive statistics

Variable	Description	Mean	SD
<i>Production function</i>			
<i>ln maize</i>	Natural log of the quantity of maize cultivated (kilograms)	4.3941	1.1087
<i>ln land</i>	Natural log of the land under maize cultivation (hectares)	-1.0638	0.8834
<i>ln capital</i>	Natural log of the value of capital at current cost used on the plot	5.8494	0.8159
<i>ln labour</i>	Natural log of family and hired labour used (man-days)	3.4412	1.1968
<i>ln material</i>	Natural log of the value of other inputs (Malawi Kwacha)	5.7328	1.2494
<i>Inefficiency model</i>			
<i>female</i>	Dummy: 1 if the farmer in control of the plot is female	0.3800	0.4903
<i>experience</i>	Number of years of experience in farming	12.600	11.685
<i>experience squared</i>	Squared number of years of experience in farming	292.56	447.78
<i>education</i>	Number of years of schooling for the farmer	3.6800	3.4252
<i>plotsize</i>	Size of the plot under maize cultivation (hectares)	0.5180	0.5658
<i>distance</i>	Distance of the plot from the main access road (kilometres)	1.0382	1.7411
<i>hiredlabor</i>	Dummy: 1 if hired labour was used in crop production	0.1200	0.3283
<i>fertilizer</i>	Dummy: 1 if the farmer used fertilizer on the plot	0.5000	0.5051
<i>hybrid</i>	Dummy: 1 if the main type of maize on the plot is hybrid	0.4800	0.5047
<i>club</i>	Dummy: 1 if any of the members of the household belongs to a club or association	0.0600	0.2399

Source: Computed by author based on *Smallholder Farmer Survey 2002*

Stochastic production function and sources of technical efficiency

The estimation of the translog stochastic production function in equation (6) simultaneously with the technical inefficiency effects in equation (7) generates results in Table 2. The production function shows that many of the interaction terms are statistically significant at the conventional significance levels, implying the suitability of the translog function. The parameter $\gamma = \sigma_u^2 / \sigma^2$, lies between 0 and 1; with a value equal to 0 implying that technical inefficiency is not present and the ordinary least square estimation would be an adequate representation and a value close or equal to 1 implying that the frontier model is appropriate (Piesse and Thirtle, 2000). The value of $\gamma = 1.000$ and is statistically significant which implies that all of the residual variations is due to the inefficiency effect. The one-sided generalized likelihood ratio tests of $\gamma = 0$ provided a statistic of 70.6 distributed as χ^2 with one degree of freedom, which is statistically significant at 1 percent level, indicating that the average production function is not a suitable specification of maize production and technical efficiency effects are not random errors.

Table 2: Maximum likelihood estimation of the production frontier with inefficiency model (dependent variable: *ln maize*)

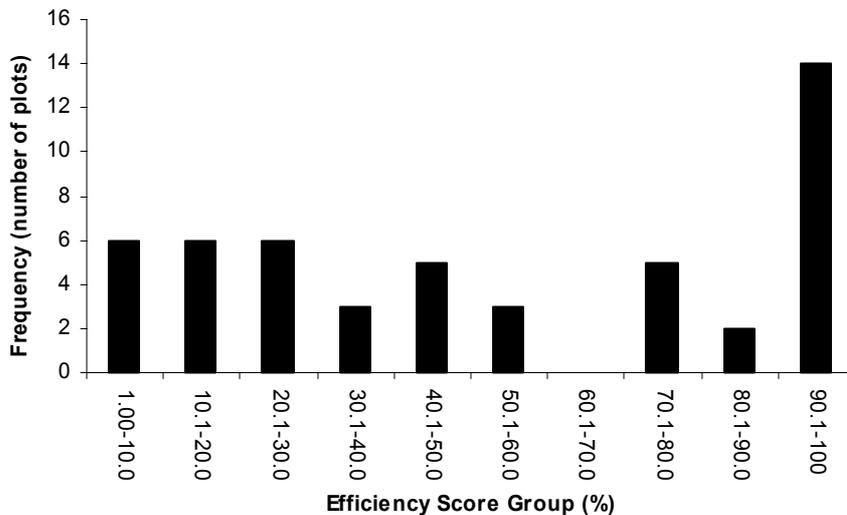
Variables	coefficient	t-ratio	t-prob	elasticities
<i>Production function</i>				
constant	0.5420	0.6042	0.551	-
<i>ln land</i>	-2.5378	-4.1137	0.000	1.6671
<i>ln capital</i>	2.5779	9.8173	0.000	1.3491
<i>ln labour</i>	-1.9299	-2.8490	0.008	0.7307
<i>ln material</i>	-0.8576	-1.6004	0.122	2.0194
<i>ln land</i> × <i>ln land</i>	-1.2024	-11.6941	0.000	-
<i>ln capital</i> × <i>ln capital</i>	-0.4982	-7.0498	0.000	-
<i>ln labour</i> × <i>ln labour</i>	0.4268	3.2803	0.003	-
<i>ln material</i> × <i>ln material</i>	-0.1600	-4.4768	0.000	-
<i>ln land</i> × <i>ln capital</i>	0.0704	0.3497	0.729	-
<i>ln land</i> × <i>ln labour</i>	-0.4839	-2.8937	0.008	-
<i>ln land</i> × <i>ln material</i>	0.7290	6.6558	0.000	-
<i>ln capital</i> × <i>ln labour</i>	-0.3372	-0.9565	0.348	-
<i>ln capital</i> × <i>ln material</i>	0.5094	4.1418	0.000	-
<i>ln labour</i> × <i>ln material</i>	0.4621	6.8856	0.000	-
$\sigma^2 = \sigma_u^2 + \sigma_v^2$	0.9571	5.6174	0.000	-
$\gamma = \sigma_u^2 / \sigma^2$	1.0000	5.3E+07	0.000	-
Log Likelihood	-23.337	-	-	-
Returns to Scale (RTS)	-	-	-	5.7663
N	50	-	-	-
<i>Inefficiency model</i>				
constant	3.0629	4.1945	0.000	
<i>female</i>	-0.4903	-0.9423	0.355	
<i>experience</i>	-0.0256	-0.2779	0.783	
<i>experience squared</i>	0.0004	0.1771	0.861	
<i>education</i>	0.1250	1.3988	0.174	
<i>plotsize</i>	-1.7066	-3.6350	0.001	
<i>distance</i>	-0.0103	-0.0624	0.951	
<i>hiredlabor</i>	-3.1663	-2.3053	0.029	
<i>fertilizer</i>	-0.9231	-1.5766	0.127	
<i>hybrid</i>	-1.5785	-1.8679	0.073	
<i>hybrid*education</i>	-0.5247	-2.8170	0.009	
<i>club</i>	-4.4940	-3.7382	0.001	

The production function shows that the smallholder farmers in the sample are producing maize combining inputs in the uneconomic region. Most of the coefficients particularly land and the interaction variables with land are negatively related to maize output. The negative relationship between output and land in production processes has also been observed in other African studies. For instance, Udry et al. (1995) using data from Burkina Faso find output per hectare strongly declining with the size of the plot and attribute this to lower yields on larger plots within a household. Owens (2003) in a study of maize production in Malawi using a national survey data finds a negative relationship between local maize yield and land holdings but a positive relationship in a hybrid maize model. Others factors that may lead to such negative relationship between land and output include plot area measurement errors,

fixed transport costs to the plot and unobservable variations in plot quality. Nonetheless, the output elasticities at the means show positive response of output to changes in inputs and with all having positive values and most of the values are above unity. Materials have the largest elasticity of 2.02, followed by land with an elasticity of 1.67 and capital with an elasticity of 1.35. However, output is inelastic with respect to labour, with a computed elasticity of 0.33. The returns to scale, the sum of the output elasticities, equal to 5.78 shows that production on average is done under increasing returns to scale suggesting that size may matter in the efficiency of smallholder farmers.

The mean technical efficiency level among smallholder maize farmers is 53.11 with a standard deviation of 35.3 percent, and range from 3.26 to 99.98 percent. Figure 2 presents the distribution of the technical efficiency levels. The modal group is the efficiency level between 90.1 and 100 percent, and 42 percent of the pure maize plots have technical efficiency scores of more than 70 percent. The mean levels of efficiency are low but comparable to those from other African countries. For instance, Seyoum et al. (1998) find the mean technical efficiency of maize producers in Ethiopia to be 79 percent, Wier (1999) and Wier and Knight (2000) find mean efficiency levels of about 55 percent among cereal crop producers while Mochebelele and Winter-Nelson (2000) find average technical efficiencies of between 64 percent and 76 percent in Lesotho.

Figure 2: The distribution of efficiency indices among smallholder maize farmers



Source: Computed by author based on *Smallholder Farmer Survey 2002*

The technical inefficiency model shows that five of the eleven variables are statistically significant at least at the 10 percent level. The sex of the farmer, farmer’s experience, farmer’s education and use of fertilizer are not statistically associated with levels of technical efficiency in maize production. The insignificance of the sex of the farmer, although suggesting that female controlled maize plots are more efficient, shows that gender is not important factor in explaining efficiency. This in contrast to Udry (1996) and Udry et al. (1995) who find support for the inefficiency of female controlled plots.

The dummy representing adoption of fertilizers is statistically insignificant, given that almost half of the smallholder farmers in the sample adopted technology. It is quite possible that although some farmers adopted fertilizer technology, given the low level of education among most farmers and the small land holdings, such technologies may be applied inappropriately. Dzimadzi et al. (2001) in the case of a targeted input safety net programme find that problems of literacy and numeracy led farmers to use the inputs inappropriately. In some cases, inputs were used on larger areas than the technical specifications that were contained in the leaflets and in other cases the instructions conflicted with the traditional farming systems. Sibale et al. (2001) find that only 50 percent of the targeted inputs recipients followed the targeted inputs programme instructions for planting maize.

The variable, *plotsize*, is included to capture efficiency advantages and disadvantages associated with the size of the plot. In our sample, most of the plots are small and the variation in plot sizes is small. The coefficient of *plotsize* is negatively associated with technical inefficiency and it is statistically significant at the 1 percent level. The significant negative relationship implies better optimal combination of factors of production is achieved on larger plots than on smaller plots. Given that land ownership on most plots is non-market based, particularly through subdivisions from the traditional leaders and subdivision/inheritance from family, the increasing population pressure will continue to magnify the problem of land fragmentation with implications on efficient production and maximization of maize production.

The dummy variable representing the use of hired labour on maize plots to control for variations in efficiency due to contract enforcement. In cases where contract enforcement is strong, we would expect hired labour to work more efficiently especially when performance is output-oriented. The results in this study point to the fact that plots on which hired labour is used to supplement family labour tend to produce maize less inefficient than those that exclusively use family labour. The coefficient of the dummy variable for use of hired labour is statistically significant at the 5 percent level. However, this case may just reflect the economic use of hired labour resources for farm households that are constrained in terms of family labour.

The coefficient of the dummy representing use of hybrid seeds is statistically significant at the 10 percent level. Plots with hybrid maize seeds are more efficient than plots using local seeds. In order to test the hypothesis that the more educated farmers are likely to embrace the Green Revolution, we included an interaction variable between years of education and the dummy for use of hybrid seeds. The coefficient of the interaction variable is statistically significant at the 1 percent level, confirming that educated farmers utilize the Green Revolution more efficiently.

The role of social capital or networks in explaining levels of efficiency is captured by the dummy representing membership to a farmers' club or association. The role of social capital in providing incentives for efficient maize production in this study is revealed by the negative and statistically significant relationship between club membership of a household member and technical inefficiency at the 1 percent level. The sharing of information on crop husbandry at club or association level tend to filter to other members of the households that are not members or through demonstration effects of farming practices on club or association member's plots. Thus club membership has some external effects on family members that are not members of the farming clubs.

The relative low levels of technical efficiency among smallholder maize farmers in southern Malawi point to the need to pursue policies that enhance the organisation of farming systems in Malawi. One of the main constraints facing agriculture in Malawi is the small land holdings among smallholder farmers that are becoming smaller and smaller through subdivision to family members. The average plot size of 0.5 hectare in an economy with agricultural labour surplus leads to uneconomic combination of factors of production leading to technically inefficient production levels. Given that maize is the main staple food in Malawi, efficient food production and food security can be enhanced through policies that increase the land size holdings such as resettlement schemes or land redistribution programme. Our results also suggest the critical role of social capital plays in enhancing the technical efficiency of farmers either through demonstration effects or mere exchange of best-practice farming ideas. For a long time, from independence to 1992, smallholder agriculture was largely organized around farmers' clubs for effective delivery extension services and agricultural credit. The farmer club system collapsed in 1992 following the collapse of the agricultural credit scheme that worked through the club system and only a few farmers today belong to farmers club or association. The significance of the club membership dummy variable in this study, points to the need for the revival of the farmer club system or the development of farming co-operatives in Malawi.

5. Concluding Remarks

This study set out to estimate levels of technical efficiency in maize production among smallholder farmers in Malawi. Since maize is the main staple food in Malawi, high productivity and efficiency in production are therefore critical for food security in the country. Although the government has been investing in agricultural development since independence in 1964, most households remain food insecure and aggregate maize production indices do not show sustainable patterns in food production. We used the stochastic production function approach to estimate technical efficiency scores at plot level while simultaneously determining the factors that are associated with efficiency using maize production data on monocropped plots from southern Malawi.

Our econometric results based on the stochastic production function shows that maize production is done under increasing returns to scale. Many smallholder maize farmers are technically inefficient, with mean technical efficiency scores of 53.11 percent and technical scores as low as 3.26 percent. The modal efficiency class is 90.1-100 percent and about 58 percent of maize plots have efficiency levels of below 60.1 percent. The mean efficiency levels are lower but comparable to those that obtain in other African countries whose mean range from 55 to 79 percent. The results, however, support the hypotheses that technical efficiency increases with larger plot size, use of hired labour, use of hybrid seeds, farmer education interacted with use of hybrid seeds and club membership. Surprisingly, one of the variables that are capturing adoption of technology shows that plots in which of fertilizers were applied do not explain the variations in technical inefficiency. This may imply that most farmers using these technologies use them inappropriately on the small land holdings.

Despite a long history of government investment in the agriculture sector through extension services and promotion of technology, smallholder maize farming remains uneconomic and technically inefficient. Two main policy issues emerge from the results of this study. First, there is need to re-organize the land size holdings to make smallholder farming more economic through a programme of land redistribution or resettlement. Secondly, there is need

to enhance social capital in smallholder farming through the revival of farmers clubs or through the creation of agricultural cooperatives. Our results are based on a small sample of smallholder farmers in one of the districts in southern Malawi and may not be very representative of the smallholder sector with varying land holding sizes in different ecological zones. Furthermore, it was not possible to control for differences in the family life cycle and the natural abilities of farmers through fixed effects modelling due to the limited number of plots cultivated by the farmers or households.

References

- Aigner, D.J., Lovell, C.A.K. and Schmidt, P. (1977) Formulation and Estimation of Stochastic Frontier Production Function Models, **Journal of Econometrics**, **6**, 21-37
- Alwang, J. and Siegel, P.B. (1999) Labour Shortages on Small Land Holdings in Malawi: Implications for Policy Reforms, **World Development**, **27 (8)**, 1461-1475
- Battese, G.E. (1992) Frontier Production Functions and Technical Efficiency: A Survey of Empirical Applications in Agricultural Economics, **Agricultural Economics**, **7**, 185-208
- Battese, G.E. and Coelli, T. (1988) Prediction of Firm-Level Technical Efficiencies with a Generalised Frontier Production Function and Panel Data, **Journal of Econometrics**, **38**, 387-399
- Battese, G.E. and Coelli, T. (1995) A Model of Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data, **Empirical Economics**, **20**, 325-332
- Battese, G.E. and Corra, G.S. (1977) Estimation of a Production Frontier Model: With Application to Pastoral Zone of Eastern Australia, **Australian Journal of Agriculture Economics**, **21**, 169-179
- Browning, M. and Chiappori, P. (1994) Efficient Intra-Household Allocations: A General Characterisation and Empirical Tests, McMaster University Department of Economics Working Paper 94-07
- Chen, Z. and Woolley, F. (2001) A Cournot-Nash Model of Family Decision Making, **Economic Journal**, **111 (October)**, 722-748
- Chiappori, P. -A. (1992) Collective Labour Supply and Welfare, **Journal of Political Economy**, **100**, 437-467
- Chilowa, W. (2000) The Impact of Agricultural Liberalisation on Food Security in Malawi, **Food Policy**, **23 (6)**, 553-569
- Chirwa, E.W. (2000) Liberalization of Food Marketing and Market Integration in Malawi, Draft Final Report presented at the African Economic Research Consortium Biannual Research Workshop held in Nairobi, Kenya: May
- Chirwa, E.W. (1998) Fostering Private Food Marketing and Food Policies after Liberalisation in Sub-Saharan Africa - The Case of Malawi, in P. Seppala (ed.) **Liberalized and Neglected? Food Marketing Policies in Eastern Africa**, World Development Studies 12, Helsinki: UNU/WIDER
- Coelli, T.J. (1995) Recent Developments in Frontier Modelling and Efficiency Measurement, **Australian Journal of Agricultural Economics**, **39 (3)**, 219-245
- Coelli, T. (1996) A Guide to FRONTIER Version 4.1: A Computer Program for Stochastic Frontier Production and Cost Function Estimation, CEPA Working Paper 96/07, University of New England, Armidale, Australia
- Coelli, T. and Battese, G. (1996) Identification of Factors which Influence the Technical Inefficiency of Indian Farmers, **Australian Journal of Agricultural Economics**, **40 (2)**, 103-128

- Coelli, T., Prasada, R. and Battese, G. (1998) **An Introduction to Efficiency and Productivity Analysis**, Boston: Kluwer Academic Press
- Dorward, A. (1999) Farm Size and Productivity in Malawian Smallholder Agriculture, **Journal of Development Studies**, **35 (5)**, 141-161
- Dzimadzi, C., Chinsinga, B., Chaweza, R. and Kambewa, P. (2001) Targeted Inputs Programme (TIP) 2000/01: Agricultural Communications, Final Report on an evaluation commissioned by Ministry of Agriculture and Irrigation (Malawi) and the Department for International Development (DfID - UK).
- Farrell, M.J. (1957) The Measurement of Productive Efficiency, **Journal of Royal Statistical Society Series A** 120, part 3, 253-281
- Forsund, F.R., Lovell, C.A.K. and Schmidt, P. (1980) A Survey of Frontier Production Functions and of Their Relationship to Efficiency Measurement, **Journal of Econometrics**, **13**, 5-25
- Goletti, F. and Babu, S. (1994) Market Liberalization and Integration of Maize Markets in Malawi, **Agricultural Economics**, **11**, 311-324
- Greene, W.H. (1980) Maximum Likelihood Estimation of Econometric Frontier Functions, **Journal of Econometrics**, **13**, 27-56
- Harrigan, J. (1988) Malawi: the Impact of Pricing Policy on Smallholder Agriculture 1971-1988, **Development Policy Review**, **6**, 415-433
- Heshmati, A. and Mulugeta, Y. (1996) Technical Efficiency of the Ugandan Matoke Farms, **Applied Economic Letters**, **3**, 491-494
- Jondrow, J., Lovell, C.A.K., Materov, I.S. and Schmidt, P. (1982) On the Estimation of Technical Inefficiency in the Stochastic Frontier Production Function Model, **Journal of Econometrics**, **19**, 233-238
- Kaluwa, B.M. (1992) Malawi Food Marketing: Private Trader Operation and state Intervention, in J. B. Wyckoff and M. Rukuni (eds) **Food Security Research in Southern Africa: Policy Implications**, proceedings of the Sixth Annual Conference on Food Security Research in Southern Africa, University of Zimbabwe/ Michigan state University Food Security Research Project.
- Kaluwa, B.M. and Chilowa, W.R. (1991) Malawi: Food Marketing Liberalisation and Household Food Security - Preliminary Results from Baseline Surveys, in Rikuni M and Wyckoff J B (eds) **Market Reforms, Research Policies and SADCC Food Security**, proceedings of the Sixth Annual Conference on Food Security Research in Southern Africa, University of Zimbabwe/ Michigan state University Food Security Research Project.
- Kydd, J. and Christiansen, R. (1982) Structural Change in Malawi since Independence: Consequences of a Development Strategy Based on Large-Scale Agriculture, **World Development**, **10 (5)**, 355-375
- Lee, L.F. and Tyler, W.G. (1978) The Stochastic Production Function and Average Efficiency: An Empirical Analysis, **Journal of Econometrics**, **7**, 385-389
- Lele, U. (1989) Sources of Growth in East African Agriculture, **World Bank Economic Review**, **3 (1)**, 119-144
- Malawi Government (1971) **Statement of Development policies 1971-1980**, Zomba: Government Printer
- Malawi Government (1987) **Statement of Development policies 1987-1996**, Zomba: Government Printer
- Mataya, C., Chulu, O. and Chilima, E. (1999) Socio-Economic Effects of Structural Adjustment Policies on Malawi's Rural and Urban Households, Report prepared for the Poverty and Social Policy Division, National Economic Council
- Meeusen, W. and Broeck, J. van den. (1977) Efficiency Estimation from Cobb-Douglas

- Production Function with Composed Error, **International Economic Review**, **18**, 435-444
- Mkwezalamba, M. (1989) The Impact of Liberalisation of Smallholder Agricultural Produce Pricing and Marketing in Malawi, Report submitted to Ministry of Agriculture, Lilongwe
- Mochebelele, M.T. and Winter-Nelson, A. (2000) Migrant Labor and Farm Technical Efficiency in Lesotho, **World Development**, **28 (1)**, 143-153
- Owens, J. (2003) How Important is Access to ADMARC markets in Malawi? Washington: World Bank (mimeo)
- Owens, T., Hoddinott, J. and Kinsey, B. (2001) The Impact of Agricultural Extension on Farm Production in Resettlement Areas of Zimbabwe, Working Paper CSAE WPS/2001-6, Centre for the Study of African Economies, University of Oxford
- Page, J.M. (1980) Technical Efficiency and Economic Performance: Some Evidence from Ghana, **Oxford Economic Papers**, **32**, 319-339
- Parikh, A., Ali, F. and Shah, M.K. (1995) Measurement of Economic Efficiency in Pakistani Agriculture, **American Journal Agricultural Economics**, **77 (August)**, 675-685
- Piesse, J. and Thirtle, C. (2000) A Stochastic Frontier Approach to Firm Level Efficiency, Technological Change, and Productivity during the Early Transition in Hungary, **Journal of Comparative Economics**, **28**, 473-501
- Sahn, D.E. and Arulpragasam, J. (1991) The Stagnation of Smallholder Agriculture in Malawi: A Decade of Structural Adjustment, **Food Policy**, **16 (3)**, 219-234
- Scarborough, V. (1990) Domestic Food marketing Liberalisation in Malawi: A Preliminary Assessment, ADU Occasional Paper 13, Wye College, University of London
- Seyoum, E.T., Battese, G.E. and Fleming, E.M. (1998) Technical Efficiency and Productivity of Maize Producers in Eastern Ethiopia: A Study of Farmers Within and Outside the Sasakawa-Global 2000 Project, **Agricultural Economics**, **19**, 341-348
- Sibale, P.K., Chiremba, A.M., Saka, A.R. and Lungu, V. O. (2001) Targeted Inputs Programme (TIP) 2000/01: Food Production and Security, Final Report on an evaluation commissioned by Ministry of Agriculture and Irrigation (Malawi) and the Department for International Development (DfID - UK).
- Smale, M. (1995) "Maize is Life": Malawi's Delayed Green Revolution, **World Development**, **23 (5)**, 819-831
- Smale, M., Heisey, P.W. and Leathers, H.D. (1995) Maize of the Ancestors and Modern Varieties: The Microeconomics of High-Yielding Variety Adoption in Malawi, **Economic Development and Cultural Change**, **43 (2)**, 351-368
- Stevenson, R. E. (1980) Likelihood Functions for Generalized Stochastic Frontier Estimation, **Journal of Econometrics**, **13**, 57-66
- Tadesse, B. and Krishnamoorthy, S. (1997) Technical Efficiency in Paddy Farms of Tamil Nadu: An Analysis based on Farm Size and Ecological Zone, **Agricultural Economics**, **16**, 185-192
- Townsend, R.F., Kirsten, J. and Vink, N. (1998) Farm Size, Productivity and Returns to Scale in Agriculture Revisited: A Case Study of Wine Producers in South Africa, **Agricultural Economics**, **19**, 175-180
- Udry, C. (1996) Gender, Agricultural Production, and the Theory of the Household, **Journal of Political Economy**, **104 (5)**, 1010-1046
- Udry, C., Haddinott, J., Alderman, H. and Haddad, L. (1995) Gender Differentials in Farm Productivity: Implications for Household Efficiency and Agricultural Policy, **Food Policy**, **20 (5)**, 407-423
- Wadud, A. and White, B. (2000) Farm Household Efficiency in Bangladesh: A Comparison of Stochastic Frontier and DEA Methods, **Applied Economics**, **32**, 1665-1673

- Wang, J., Cramer, G.L. and Wailes, E.J. (1996) Productive Efficiency of Chinese Agriculture: Evidence from Rural Household Survey Data, **Agricultural Economics**, **15**, 17-28
- Weir, S. (1999) The Effects of Education on Farmer Productivity in Rural Ethiopia, Working Paper CSAE WPS99-7, Centre for the Study of African Economies, University of Oxford
- Weir, S. and Knight, J. (2000) Education Externalities in Rural Ethiopia: Evidence from Average and Stochastic Frontier Production Functions, Working Paper CSAE WPS/2000.4, Centre for the Study of African Economies, University of Oxford
- Zeller, M., Diagne, A. and Mataya, C. (1998) Market Access by Smallholder Farmers in Malawi: Implications for Technology Adoption, Agricultural Productivity and Crop Income, **Agricultural Economics**, **19**, 219-229