THESIS

TECHNICAL EFFICIENCY IN KENYAN'S MAIZE PRODUCTION: AN APPLICATION OF THE STOCHASTIC FRONTIER APPROACH

Submitted by

Betty Wambui Kibaara

Department of Agricultural and Resource Economics

In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Summer 2005

COLORADO STATE UNIVERSITY

July 11, 2005

WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY BETTY WAMBUI KIBAARA ENTITLED TECHNICAL EFFICIENCY IN KENYAN'S MAIZE PRODUCTION: AN APPLICATION OF THE STOCHASTIC FRONTIER APPROACH BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

Committee on Graduate Work

Advisor

Co-Advisor

Chair

ABSTRACT OF THESIS

TECHNICAL EFFICIENCY IN KENYAN'S MAIZE PRODUCTION:
AN APPLICATION OF THE STOCHASTIC FRONTIER APPROACH

The primary objective of this study is to estimate the level of technical efficiency in maize production in Kenya using the Stochastic Frontier Approach. The study will also attempt to determine some socio-economic characteristics and management practices which influence technical efficiency in maize production. Technical efficiency is defined as the ratio of the observed output to the corresponding frontier and is estimated from the composed error term. Previously, technical efficiency was estimated in a two-stage process. This study utilizes the most recent development in the stochastic frontier modeling by using a one-step process in Limdep and primary cross-sectional rural household data for the 2003/2004 main harvest-cropping season provided by Tegemeo Institute of Agricultural Policy and Development in Kenya.

To ensure unbiased results, the model is corrected for heteroscedasticity, by weighing each variable by an estimated variance. In addition, the orthogonality condition that ensures a zero covariance between the independent variables and the error term is imposed. Responsiveness of yield to production inputs is also estimated by computing input elasticities. The marginal value product for fertilizer, labor and seed are also calculated. Finally, the marginal effects of the variables associated with inefficiency are calculated.

Results indicate that the mean technical efficiency of Kenya's maize production is 49 percent; however, this ranges from 8 to 98 percent. There is distinct intra and inter-regional variability in technical efficiency in the maize producing regions. In addition, technical efficiency varies by cropping system; the mono-cropped maize fields have a higher technical efficiency than the intercropped maize fields. The number of years of school the farmer has had in formal education, age of the household head, health of the household head, gender of the household, use or none use of tractors and off-farm income impact on technical efficiency.

The estimated marginal effect shows that, ceteris paribus, the use of purchase hybrid maize seed increase technical efficiency by 36 percent (6.14 bags). Mechanization is also important. Households that used tractors for land preparation increased technical efficiency by 26 percent (4.41 bags). An additional year of school increases technical efficiency by 0.84 percent (0.14 bags). However, technical efficiency increases at a decreasing rate with an increase in the number of years of school. The model also suggests that a maize producer needs only an elementary education (5 years of school) to be technically efficient.

Betty Wambui Kibaara
Department of Agricultural
and Resource Economics
Colorado State University
Fort Collins, Colorado 80523
Summer 2005

ACKNOWLEDGEMENTS

I would like to thank the entire committee Professors, Stephen Davies, Dawn Thilmany and Terutomo Ozawa, for their patience and understanding throughout the completion of this work. Special thanks to my academic advisor, Professor Stephen Davies, for the two years of mentoring, guidance, and kindness. Thanks for the many hours you spent guiding me through the numerous econometric questions that I had. Finally, I would like to thank you for chairing my thesis defense via conference call while in a hospital bed. This was a selfless sacrifice.

I would also like to thank the staff, faculty and students in the Agricultural Economics Departments for their assistance. To Abner Ingosi, thank you for the elder's advice. In addition, I would like to thank the United States Agency for International Development (USAID) Kenya for the financial assistance to study for the Masters degree. I would also like to thank the African American Institute for facilitating my program. Special appreciation to my employer, Tegemeo Institute for providing the data used in this study and in particular, to James Nyoro the Director of Tegemeo Institute, for his encouragement, Francis Karin, Samuel Mburu and Daniel Kariuki for their input. Special thanks to Margaret Beaver (Michigan State University) for the professional assistance in generating syntaxes and data files used in the study. Many thanks to Professor David Hadley (UK) for his input in calculation of the marginal effects.

Sincere thanks to all the American families who have encouraged me and made me feel at home: Sherry and Gregory Smith, Emma Miller, Pat and Ralph Soderberg, Don and Margaret Beaver, Steve and Jeanie Bradley, Mike and Sayeh Sparrs, Lloyd and Martha Denney.

Special appreciation to my loving husband, Sammy, who has stood by me and encouraged me throughout the entire period of my study. Thank you for accepting the double family roles of being a mother and a father to our one-year-old daughter as I pursued higher education. Finally, I would like to thank the Lord for enabling me to go through the program.

DEDICATION

Special dedication to my husband Sammy for his sincere love and commitment. To our daughter Melody for her understanding, beloved daughter, I missed your formative years, but I hope this sacrifice will improve the quality of your life in the years to come. To Aunty Rispha Wainaina, who gave me the inspiration to pursue higher education. To my mother, Rosemary and my father Landan, for their selfless effort in educating me. To my sisters Rispha and Carolyne and my nieces Shiko, Soni, and Joy. Finally, to my nephew Ellis.

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

CHAPTER 2 REVIEW OF LITERATURE

CHAPTER 3 METHODOLOGY

CHAPTER 4 RESULTS AND DISCUSSIONS

CHAPTER 5 CONCLUSION AND IMPLICATIONS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Maize in Kenya

Maize is a very important staple food in Kenya, grown in almost all agro-ecological zones and on two out of every three farms. It accounts for about 40 percent of daily calories (www.fao.org) and has per capita consumption of 98 kilograms; this translates to between 30 and 34 million bags (2.7 to 3.1 million metric tonnes) of annual maize consumption in Kenya. The country produces only 28 million bags[1] and the deficit is bridged by imports from neighboring countries. Over the last 10 years, domestic production has stagnated between 24 and 28 million bags. The quantity of imported maize has increased from 2.9 percent between 1970 and 1991 to an average of 12 percent in the last 10 years (www.fao.org). However, the percentage of imports is highly underestimated because there is massive unreported cross border maize trade from Uganda and Tanzania.

Over 85 percent of the rural population derives its livelihood from agriculture, most of who engage in maize production. Maize is also important in Kenya's crop production patterns, accounting for roughly 20 percent of gross farm output from the small-scale farming sector (Jayne, *et al.,* 2001).

---

[1] A bag weighs 90 kilograms

There was tremendous growth in maize production between 1964 and 1997, fueled by the introduction of hybrid maize and related technologies often dubbed "Kenya's green revolution" (Karanja, *et al.*, 1998). However, there has been a marked decline in yield since 1997. Maize yield have declined from 1.85 metric tonnes per hectare in the period 1985-89 to the current yield of 1.57 metric tonnes per hectare. Shortage of maize in Kenya results in famine among the poor urban and rural households. Since almost all the arable land is under cultivation in Kenya, future increase in maize production will heavily depend on yield improvement rather than expansion in area under production (Karanja and Oketch, 1992)**.**

The Kenyan government policy objective for the maize sub-sector is to encourage increased production so that self-sufficiency and food security can be achieved. However, the production of the crop has fluctuated over the years, partly due to climatic conditions and policy constraints. Some of the main reasons for the dwindling performance in maize production are associated with the following challenges: poor access to credit after the collapse of the Agricultural Finance Corporation and Cooperative Societies that had been mandated to provide inputs on credit, inadequate use of recommended technologies, high costs of inputs, lack of agricultural extension services, poor flow of information from the research stations to farmers, limitations in the development of infrastructure, low prices from the maize market reforms resulting in lower input use, a general decline in performance of the economy, high level of technical and allocative inefficiency.

Lack of credit translates into inadequate working capital, and therefore, farmers are unable to purchase productivity-enhancing inputs such as seeds, fertilizers, pesticides and land preparation. In their study, Nyoro, *et al.*, (2004) concluded that Kenya's ‘breadbasket’ zone incurred higher costs of production than the major maize growing areas of Uganda. In the absence of price supports and open trade between Kenya and Uganda, competition from maize imports from Uganda will negatively affect Kenya’s maize surplus areas. One way of reducing the cost of production is to increase farm output by increasing technical efficiency. In this regard, it is necessary to quantify current levels of technical efficiency so as to estimate losses in production that could be attributed to inefficiencies due to differences in socio-economic characteristics and management practices.

1.2 Objectives

1. The main objective of this study is to contribute to the technical efficiency literature as it relates to developing countries agriculture by applying a stochastic frontier production function to determine levels of technical efficiency among the maize producing farms across Kenya’s high potential, medium potential and low potential agriculture.
2. The second objective is to identify some socio-economic characteristics and management practices that influence technical efficiency in maize production. The assumption used is that the level of technical efficiency can be measured from the error term. Some of the factors that might affect the level of technical efficiency are: access to credit, years of school, age of the household head, off-farm income, gender of the household head, quality of maize seed, and use of machines. The quality of maize seed is a proxy for good management practice.

3. The third objective is to estimate the level of responsiveness of yield to the main factors of production; namely seed, labor and fertilizer, by estimating the supply elasticity of inputs.
4. Lastly the study will suggest appropriate policies given the empirical results.

1.3 Why Maize?

Maize is the main staple food among rural households in Kenya. However, there has been a fluctuating trend in maize production over the last decade, which threatens household food security and income sources.

Secondly, in the last two decades, maize has yielded compelling success stories with the adoption of new technologies that has increased smallholder maize production. The diffusion of new technologies in Africa has been more widespread for maize than for other food crops. This implies that this success can provide lessons for further increasing food production. Finally, maize is a politically important crop because it's the most important staple food crop in Africa.

1.4 Motivation

The main motivation of the study stems from the author's belief that few studies have estimated technical efficiency in Kenya's maize production. A number of studies have been carried out on maize, such as estimation of cost of production and competitiveness between Uganda and Kenya, factors determining yield, impacts of adoption of hybrid maize and maize market liberalization. Although the subject of technical and allocative efficiency is important, few studies have focused on these areas.

Understanding the levels of inefficiency/efficiency can help address productivity gains if there are opportunities to improve socio-economic characteristics and management practices. In addition, use of stochastic frontier production functions is versatile and easy to use following its recent integration in Limdep (Green, 2002), a one-step process as compared to the two-stage process used in previous studies.

1.5 Limitations

Frontier functions assume that all inputs have been taken into consideration. However, in this study as well as others, it is possible to raise questions about whether all inputs have actually been accounted for, since farms that are apparently inefficient may just use less of certain unmeasured inputs.

1.6 Hypotheses

The following hypotheses requires testing with the generalized likelihood ratio test,

$\lambda_{LR} = 2[L(H_1)-L(H_0)]$, where $L(H_1)$ and $L(H_0)$ are the maximum values of the log likelihood functions under the alternative and null hypothesis, respectively. The null hypothesis is rejected when $\lambda_{LR} > \chi_C^2$. The following hypotheses will be tested:

1. $H_0=ß_{ik}=0$, the null hypothesis that identifies an appropriate functional form between the restrictive Cobb-Douglas and the translog production function. It specifies that the cross terms are equivalent to zero.

2. H_0; u=0, the null hypothesis specifies that each farm is operating on the technical efficient frontier and that the asymmetric and random technical efficiency in the inefficiency effects are zero. This is rejected in favor of the presence of inefficiency effects.
3. H_0; $\lambda=\delta_0= \delta_2=\ldots \delta_p=0$, the null hypothesis specifies that the technical inefficiency effects are not present in the model at every level, the joint effect of these variables on technical inefficiency is statistically insignificant.

1.7 Technical Efficiency

The stochastic frontier production function was independently proposed by Aigner, *et al.*, (1977) and Meeusen and Van den Broeck (1977) and is used in the estimation of technical efficiency. The *technical efficiency of an individual farm is defined in terms of the ratio of the observed output to the corresponding frontier output, conditioned on the level of inputs used by the farm.* Technical inefficiency is therefore defined as the amount by which the level of production for the farm is less than the *frontier* output.

Technical efficiency is obtained from the error term (e_i). The e_i is an error term made up of two components: v_i is a random error having a zero mean as (0; σ^2_v) which is associated with random factors such as measurement errors in production and weather, which the farmer does not have control over, u_i is a *non-negative* random variable associated with farm-specific factors which leads to the ith farm not attaining maximum efficiency of production. U_i is associated with technical inefficiency of the farm and ranges between zero and one.

It is important to note that technical inefficiency can only be estimated if the inefficiency effects are stochastic and has a particular distribution specification (Battese and Coelli, 1996). Some of the considered distributions for u_i are the truncated half normal, gamma and exponential distributions. Technical efficiency is estimated using Limdep (Green, 2002). In the specification of the stochastic frontier production function, the model allow for specification of two equations on the right hand side. One equation specifies the main factors of production such as seed, fertilizer and labor and the other equation specifies the variables that are assumed to cause inefficiency such as access to credit and the gender of the household head. This is done in a one-stage process.

Some of the main researchers who have utilized the stochastic frontier approach are: Aigner, *et al.*, (1977); Battese and Coelli (1995); Battese (1996); Abdulai and Huffman (2000); Thiam, *et al.*, (2001); Awudu and Eberlin (2001); Gautam and Alwang (2003); Khairo and Battese (2005). Several studies have been carried out in Kenya, but few have focused on technical or allocative efficiency.

1.8 Preview of Thesis

The remainder of the thesis is organized as follows: Chapter 2 contains a review of literature and includes a detailed discussion of maize in Africa and in Kenya. In addition, related studies and empirical studies are reviewed. Other approaches to the technical efficiency are briefly discussed. Chapter 3 presents the model specification and detailed discussion of the variables and data set utilized in the study. Chapter 4 details the data analysis process, heteroscedasticity and orthogonality condition. In addition, input elasticities, marginal value product and estimation of farm level technical efficiency are discussed. Finally, the conclusions of the major findings and recommendations, and suggestions for further research are discussed in Chapter 5.

CHAPTER 2

REVIEW OF LITERATURE

2.1 African Agriculture

In the beginning of the independence movement (1960s), Africa was self-sufficient in goods and a leading agricultural exporter. In contrast, Asia was the epicenter of the world food crisis. But by the mid 1960s, Asia had launched the green revolution, which at present adds 50 million metric tonnes of grain to the world food supply each year. Although Asia struggles with issues of household food supply, it is Africa, not Asia, which bears the brunt of the world food problem (Byerlee, 1997).

The food balance sheet in Africa has shifted from positive to negative. For example, between 1970 and 1985, food production grew by 1.5 percent while the population growth was 3 percent. This has led to a decline in per capita food consumption, making Sub-Saharan Africa the only region in the world where average calorific intake has declined over time. This problem of stagnation in food production is reflected in growing reliance of food imports, food aid, rising poverty and increasing degradation of the natural resource base. Human population is expected to double to 1.2 billion by 2020, which will further increase demand for food. Africa's food production gap demands fresh thinking and urgent attention by scientists and policy makers.

Two preconditions are essential for alleviating the downward spiral of poverty and malnutrition in Africa. First, in nearly all the African countries, the key to economic growth is growth in agriculture. The bulk of the population depends on agriculture, and increases in agricultural household income generate further rounds of spending that stimulates economic growth by increasing demand for rural non-farm products, as well as urban industrial products. The second precondition is rapid technical change in food production (Byerlee, 1997). However, technology alone will not provide the momentum for a maize revolution. Institutional changes, rural infrastructure and changes in policy are crucial to succeed. Maize is the dominant staple in Eastern and Southern Africa and its importance equals that of rice and wheat in Asia. It was introduced in Africa in the sixteenth century by Portuguese traders on the Eastern and Western Africa coast and slowly moved inland through the incursion of slave traders who valued maize as a storable and easily processed grain (Miracle, 1966).

2.2 An Introduction to Kenya

Kenya is in Eastern Africa and lies along the equator. It covers an area of 582,646 square kilometers (225,000 square miles) and has an estimated population of 30 million people. Neighboring countries are Ethiopia to the North, Somalia to the East, Tanzania to the South, Uganda to the West, and Sudan to the Northwest. Figure 2.1 shows the location of Kenya. Kenya enjoys a tropical climate and there is plenty of sunshine year-round. However, it is usually cold at night and early in the morning. The long rains occur from April to June and short rains from October to December. The rainfall is sometimes heavy and when it does come, it often falls in the afternoons and evenings. The hottest period is from February to March, and the coldest is in July and August.

Source: http://www.appliedlanguage.com/maps_of_the_world/map_of_kenya.shtml

Figure 2.1 Map of Kenya

The main sources of foreign exchange are tourism, tea, coffee, horticultural products and petroleum products. Agriculture is very important for employment creation, foreign exchange earnings and food security. However, agriculture production has erratically fluctuated with a declining trend over the years. The status of the agricultural sector mirrors that of the economy whose growth has been declining (Nyoro, 2002). In order to attain the targeted 6.6 percent economic growth, it is necessary to address growth in agriculture. This is because sustainable industrial development requires sufficient domestic demand, which calls for increasing rural household incomes. The close relationship between agricultural performance and that of the economy imply that agriculture must grow at a higher rate for it to spur economic growth.

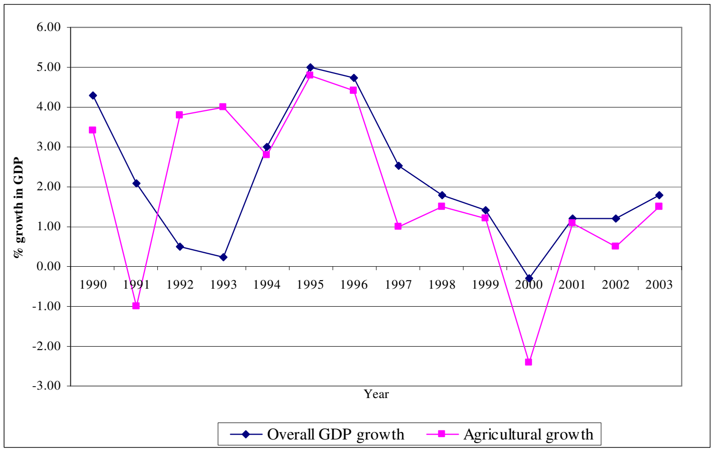
In 2003, the country's GDP was $13.8 billion, 64 percent of which came from services, 19.1 percent from the industrial sector and 16.9 percent from agricultural value added. The contribution of agriculture to GDP has declined from 25 percent in 1999 to 16.9 percent in 2003. Figure 2.2 shows growth in Agriculture and Gross Domestic Product (GDP). The GDP declined between 1995 and 2000, however this trend is reversing. The overall GDP growth rate has increased from 1.5 percent in 2002 to 1.8 percent in 2003. Agriculture mirrors the economic performance and has also grown from 0.8 percent in 2002 to 1.5 percent in 2003. However, the growth in Kenyan agriculture is considered relatively low in comparison to the 4.8 percent growth in 1994 (Economic survey, 2003). Further growth in agriculture could be improved if the following factors were addressed: increased farm productivity, improved access among credit for rural farmers, improvement in market efficiency and farm policies.

For example, in the early 1960's, private commercial banks were required by law to disburse 17 percent of loans to agriculture (Kodhek, 2004). Currently agricultural lending by commercial banks is only 5.35 percent of the lending portfolio. Kenyan farming credit system collapsed in the early 1990's following the wave of liberalization, where farmers who had been given credit sold their produce to new entrants, and thus advanced loans were never recovered. In addition there was a collapse of the Agricultural

Finance Corporation (AFC), the body mandated to provide credit. The main deterrent to borrowing credit is high interest rates with annual percent rate between 12 percent for commercial banks to 65 percent for village banks (Kodhek, 2004).

2.3 The Importance of Maize

Transition of maize to a major crop occurred in Kenya during World War 1, when the colonial government encouraged farmers to plant maize for the war effort. At the same time, a serious disease epidemic in the traditional food crop, millet, led to famine and stocks of millet seed were consumed rather than saved for planting. By providing farmers with seed of a late-maturing white maize variety, the colonial government sped the transition from millet to a maize-based food economy. After the war, the development of export markets encouraged maize production and by 1930s, maize was established as the dominant food crop in much of Kenya and Tanzania (Gerhart, 1975).



Source: Several economic surveys, 2003

Fig. 2.2 Growth in Agriculture and Gross Domestic Product, 1990-2003

As the importance of maize increased, the government intervened more heavily to control production, prices and imports. However, since the 1980s, there has been an advent of structural adjustment programs aimed at removing policy distortions through liberalized trade and reforms of agricultural inputs and product markets.

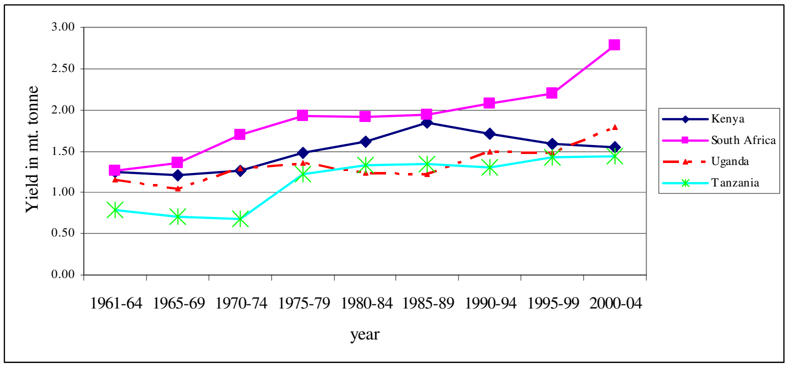
Maize accounts for about 40 percent of daily calories and per capita consumption is 98 kilograms. The poorest households spend 28 percent of the annual household income on maize purchase. Because of this importance, improvement in maize production will be crucial to solving Africa's food security problems and alleviating poverty. Maize is the main staple food for rural households in Kenya. It is associated with household food security such that a low-income household is considered food insecure if it has no maize stock in store, regardless of other foods the household has at its disposal.

Maize also doubles as a main source of income for the producers in the maize surplus regions. Maize is produced in almost all the agro-ecological zones either under mono-crop or an intercrop system. It is grown on 1.5 million hectares and has an annual production of 28 million bags. However, domestic production has stagnated to between 24 and 28 million bags over the last 10 years.

Maize is important in Kenya's crop production patterns, accounting for roughly 20 percent of gross farm output for the small-scale farming sector (Jayne, *et al*., 2001). It is grown for commercial, subsistence or dual purposes. Maize yields during favorable condition ranges from 2.0 to 5.4 metric tonnes per hectare. The annual maize consumption is approximated at 30 to 34 million bags (2.7 to 3.1 million metric tonnes). This outweighs production and the deficit is imported mainly from Uganda, Tanzania, Brazil, South Africa and Mozambique at lower prices than that of domestic production. Over-dependence on imports is likely to displace the only livelihood of the local population.

Though maize is grown in almost all Agro-ecological zones, the highest productivity is in the high potential and central highland zones while the lowest potential for increasing is in the lowland regions. An inter-zonal variation has been attributed to better soils, rainfall, access to agricultural extension services as well as adoption of technologies such as hybrid maize and fertilizers (Karanja, *et al*., 1998).

There was tremendous maize production potential exhibited between 1964-1975, fueled by the introduction of maize hybrids and related technologies often duped "Kenya's green revolution" (Karanja, 1996). However, there has been a marked decline in yield since 1997. Maize yield have declined from 1.85 metric tonnes per hectare in the period 1985-89 to the current yield of 1.57 tonnes per hectare. Figure 2.3 shows 5-year average yields in maize production. The figure paints a gloomy picture for Kenyan maize productivity, while it is clear these countries, and in particular Uganda, Tanzania and South Africa, have continued to increase maize productivity. Among the four countries, Kenya is the only country that has reduced its maize productivity in the last ten years.



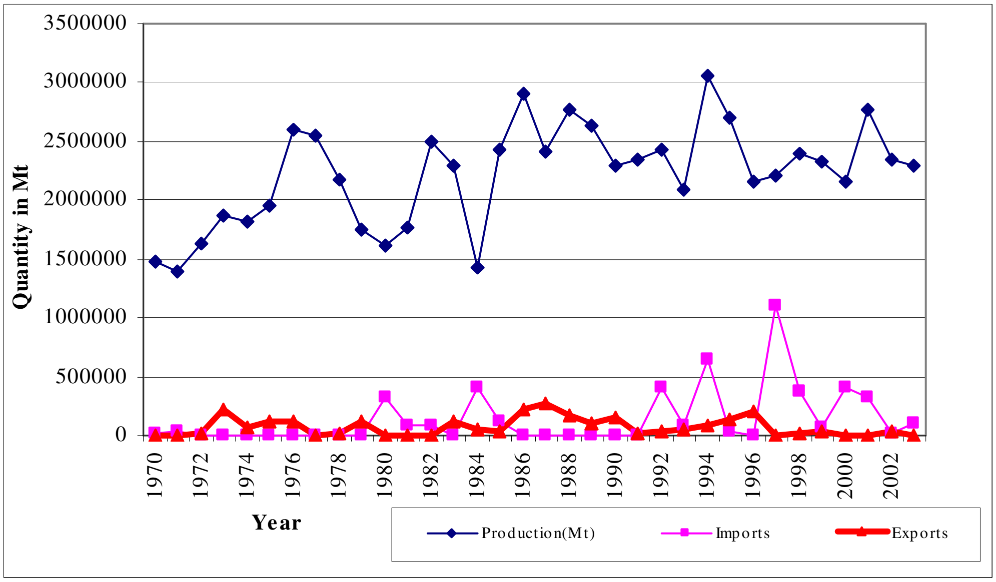
Source http://faostat.fao.org/faostat/

Figure 2.3 Average Maize Yields in Metric Tonnes for Selected Countries, 1961-2004

The quantity of imported maize in relation to total consumption averages 12 percent in the last 10 years as compared to 2.9 percent between 1970 and 1991. It is important to note that this share of imports is likely to be underestimated because there is massive unreported cross border trade maize from Uganda and Tanzania.

Figure 2.4 shows production, imports and exports trends. In the past two decades, the country has shifted from an exporter to an importer as a result of sector reforms since 1992. In addition, other factors such as poor macroeconomic policies, changes in weather patterns, population increasing faster than growth in production, low maize productivity, rising costs of production in relation to neighboring countries such as Uganda, poor research linkages between researchers, extension workers and the farmers as well as low private sector investment in research and development, infrastructure and information technology have all contributed to stagnating domestic production and hence reliance on imports.

Prior to 1992, maize was marketed through the National Cereals and Produce Board (NCPB), a monopsony, government-owned body. The board set seasonal and territorial prices. In 1992, the government liberalized the maize sector by eliminating movement and price controls on maize trading, deregulated maize and maize meal prices and eliminated direct subsidies on maize sold to registered millers. Private traders were allowed to trade and transport maize across districts without barriers. Prior to the policy change, traders were required to acquire movement permits for varying quantities of maize that they transported. However, NCPB still purchases maize for strategic reserves and stabilization of the market when prices go below the marginal cost (Jayne and Kodhek, 1997).



Source http://faostat.fao.org/faostat/

Fig 2.4 Maize Production, Imports and Exports in Metric Tonnes, 1970-2003

The reformed policies were expected to reduce barriers to entry and thus encourage more participants in markets (traders). An uncertain policy environment and frequent government interventions such as trade controls on market imports and exports through use of tariffs and bans also affected the extent of the cereal market reform and the response by the private sector. This emanates from the need to protect producers and consumers from high predatory prices by traders. Liberalization of the maize market has reduced transaction costs in marketing and distribution, increased incentive to traders and marketers and improved access to low maize prices for low income households (Nyoro, *et al*., 2004)

2.4 Related Studies

Cost of production is related to productivity and efficiency of production. High costs could be as a result of poor allocative efficiency or technical inefficiency. Reduction in economic inefficiency can reduce the costs of production. A study carried out by Nyoro, *et al.*, (2004) on costs of production between Kenya and Uganda concluded that the main reason for Kenyan's uncompetitiveness in maize is high costs. Mono-crop systems were found to be more cost effective than intercropped maize. The study also found that those farmers who used more than one land preparation exhibited lower costs of production due to increased productivity. Variations in production costs within production technologies exceeded the variation in production costs across categories. This wide variation in production costs within production categories most likely reflects differences in management practices and husbandly skills in the cultivation of maize. In addition, land rental rates are higher than in the neighboring countries, mainly due to speculation that the government will support maize prices in Kenya. Fertilizer application in mono-crop systems resulted in higher yield; this was found not to be true in intercropping systems. Decomposition of costs of production shows that the largest portion of costs for small-scale farmers is labor, fertilizer and seed costs, while that of large-scale producers is land preparation because of high mechanization.

In another study, Karanja, *et al.*, 1998, used a Tobit model and two stage least squares to model maize productivity and adoption of technologies. They concluded that maize productivity increased with fertilizer use, proximity to navigable roads, education, extension and the presence of a male in the household. Intra-zonal variation was higher than the mean inter-zonal and therefore an indication of great productivity growth, if the level of productivity of the lower half of the farmers could be elevated at least to the mean level within each zone. Maize market reforms have led to a decrease in maize prices and negative effects on maize productivity in almost all agro-regional zones.

This study builds on Karanja's work by estimating the levels of technical efficiency/inefficiency across the high potential, medium and low potential regions in Kenya using a stochastic frontier production function model. The study will go further to identify cross-sectional socio-economic characteristics and management practices that impact maize production efficiency. The regional variable captures the soil and climate differences. Identifying areas of inefficiency will identify the gap between the actual and potential yields.

2.5 Other Approaches to Technical Efficiency

Agriculture is a key pillar in economic development in developing countries. The adoption of new technologies designed to enhance farm output and income has received particular attention as a means of accelerating economic development. However, output growth is not only achieved through technological innovation but also through the efficiency in which such technologies are used. The potential importance of efficiency as a means of fostering production has being recognized by many researchers.

Frontier efficiency has been used extensively in measuring the level of inefficiency/efficiency. Frontier functions can be classified into parametric and non-parametric linear programming approaches. The non-parametric approach is composed of the data envelopment analysis (DEA) and the free disposal hull (FDH). The parametric approach is composed of the stochastic frontier approach (SFA), the thick frontier approach (TFA) and the distribution free approach (DFA). These methods differ mainly in the assumptions made about the functional form, whether or not random errors have been accounted for, and the probability distribution assumed for the inefficiency. Another important distinction is deterministic and stochastic frontiers. *Deterministic* models assume that any deviation from the frontier function is due to inefficiency so they are very sensitive to outliers. On the other hand, the *stochastic* approach allows for statistical noise, (Thiam, *et al*., 2001). However, there is no consensus among researchers as to the best method for measuring efficiency.

This study focuses a stochastic frontier approach (SFA). The model is a linear regression model with a non-normal, asymmetric disturbance term. When measuring technical efficiency, a production function is used. A Meta analysis by Thiam, *et al.,* (2001) on 32 frontier studies using farm level data from 15 different developing countries found that cross-sectional data exhibits significantly lower technical efficiency (TE) estimates than studies that use panel data. According to Green (1993), models relying on panel data are likely to yield more accurate efficiency estimates given that there are repeated observations on each unit. However, no a prior expectations regarding the impact of data type (i.e. cross-sectional versus panel) on the magnitude of efficiency scores have been developed.

2.6 Prior Studies Utilizing the Stochastic Frontier Approach

Stochastic frontier approach has found wide acceptance within the agricultural economics literature because of their consistency with theory, versatility and relative ease of estimation. The measurement of efficiency (technical, allocative and economic) has remained an area of important research both in the developing and developed countries.

This is especially important in developing countries, where resources are meager and opportunities for developing and adopting better technologies are dwindling. Efficiency measures are important because it is a factor for productivity growth. Such studies benefit these economies by determining the extent to which it is possible to raise productivity by improving the neglected source of growth i.e. efficiency, with the existing resource base and available technology.

A study by Battese and Coelli (1995) on paddy rice farms in Aurepalle India used panel data for 10 years and concluded that older farmers were less efficient than the younger ones. Farmers with more years of schooling were also found to be more efficient but declined over the time period.

Battese, *et al.*, (1996) used a single stage stochastic frontier model to estimate technical efficiencies in the production of wheat farmers in four districts of Pakistan ranging between 57 and 79 percent. The older farmers had smaller technical inefficiencies.

Bedassa and Krishnamoorthy (1997) used a two-step approach to estimate technical efficiency in paddy farms of Tamil Nadu in India. They concluded that the mean technical efficiency was 83.3 percent, showing potential for increasing paddy production by 17 percent using present technology. Small and medium-scale-farmers were more efficient than the large-scale farms. In addition, the study concluded that animal power was over utilized and therefore suggested reduction. However, the paddy rice farmers could still benefit by increasing the fertilizer use and expansion of land.

In measuring technical efficiency of maize producers in Eastern Ethiopia for farmers within and outside the Sawakawa–Global 2000 project, Seyoum, *et al.*, 1998 used a translog stochastic production frontier and a Cobb-Douglas production function. Some of the key conclusions from this study were that younger farmers are more technically efficient than the older farmers. In addition, farmers with more years of school tended to be more technically efficient. On the other hand, those that obtained information from extension advisers tended to reduce the technical inefficiency. The mean technical efficiency of farmers within the SG 2000 project was estimated to be 0.937 while the estimate of the farmers outside the project was 0.794. However, this study should have squared the age to address the linear relationship of the age variable.

A study by Wilson, *et al*., (1998) on technical efficiency in UK potato production used a stochastic frontier production function to explain technical efficiency through managerial and farm characteristics. Mean technical efficiency across regions ranged from 33 to 97 percent. There was high correlation between irrigation of the potato crop and technical efficiency. The number of years of experience in potato production and small-scale farming were negatively correlated with technical efficiency.

A study by Liu, *et al*., (2000) on technical efficiency in post-collective Chinese Agriculture concluded that 76 and 48 percent of technical inefficiency in Sichuan and Jiangsu, respectively, could be explained by inefficiency variables. They used a joint estimation of the stochastic frontier model.

Awudu and Huffman (2000) studied economic efficiency of rice farmers in Northern Ghana. Using a normalized stochastic profit function frontier, they concluded that the average measure of inefficiency was 27 percent, which suggested that about 27 percent of potential maximum profits were lost due to inefficiency. This corresponds to a mean loss of 38,555 cedis per hectare. The discrepancy between observed profit and frontier profit was due to both technical and allocative efficiency. Higher levels of education reduced profit inefficiency while engagement in off-farm income earning activities and lack of access to credit experience higher profit inefficiency. The study also found significant differences in inefficiencies across regions.

Awudu and Richard (2001) used a translog stochastic frontier model to examine technical efficiency in maize and beans in Nicaragua. The average efficiency levels were 69.8 and 74.2 percent for maize and beans, respectively. In addition, the level of schooling represented human capital, access to formal credit and farming experience (represented by age) contribute positively to production efficiency, while farmers' participation in off-farm employment tended to reduce production efficiency. Large families appeared to be more efficient than small families. Although a larger family size puts extra pressure on farm income for food and clothing, it does ensure availability of enough family labor for farming operations to be performed on time. Positive correlation between inefficiency and participation in non-farm employment suggests that farmers reallocate time away from farm-related activities, such as adoption of new technologies and gathering of technical information that is essential for enhancing production efficiency. The result indicated that efficiency increased with age until a maximum efficiency was reached when the household head was 38 years old. The age variable probably picks up the effect of physical strength as well as farming experience for the household head.

In a study by Wilson, *et al*, (2001) a translog stochastic frontier and joint estimate technical efficiency approach was used to assess efficiency. The estimated technical efficiency among wheat producers in Eastern England ranged between 62 and 98 percent and found farmers who sought information, and had more years of managerial experiences and had large farm, were associated with higher levels of technical efficiency.

A study by Mochebelele and Winter-Nelson (2002) on smallholder farmers in Lesotho used a stochastic production frontier to compare technical inefficiencies of farmers who sent migrant labor to the South African mines and those who did not. They concluded that farmers who send migrant labor to South African are closer to their production frontier than those who do not.

Belen, *et al*., (2003) made an assessment of technical efficiency of horticultural production in Navarra, Spain. They estimated that tomato producing farms were 80 percent efficient while those that raised asparagus were 90 percent efficient. Therefore, they concluded that there exists a potential for improving farm incomes by improving efficiency.

Gautam and Jeffrey (2003) used a stochastic cost function to measure efficiency among smallholder tobacco cultivators in Malawi. Their study revealed that larger tobacco farms are less cost inefficient. The paper uncovered evidence that access to credit retards the gain in cost efficiency from an increase in tobacco acreage. This suggested that the method of credit disbursement was faulty.

Bravo-Ureta, *et al*., (1994) concluded that Paraguan cotton had 40.1 percent average economic efficiency while cassava producers were 52.3 percent efficient. They concluded that there was room for improvement in productivity for these basic crops. However they did not find a relationship between economic efficiency and socio-economic characteristics. This observation was explained by the possibility of existence of a stage of development threshold below which this type of relationship is not observed. In this case the sampled Paraguan farmers were yet to reach the threshold.

CHAPTER 3

METHODOLOGY

The purpose of this chapter is to develop the general stochastic frontier production function, which will be used in the estimation of technical efficiency for maize producers in Kenya. This begins with a brief discussion of the theory of the production economics. The chapter then lays down the methodological assumptions, describes sources of data and variables used in this study. This section presents the framework of the stochastic frontier model that is estimated in an effort to determine the preferred functional form among the translog, Cobb-Douglas, quadratic and transcendental production functions.

3.1 Production Economics Theory

This is part of microeconomic theory that deals with production of goods using a set of inputs. A production function is a model used to formalize this relationship. Below is a specification of a production function

$$Q = f\{L, S, F\ldots\} \qquad (1)$$

Where Q represent a firms output, L may represent the amount of labor, S represents quantity of seeds used in production of Q while F represent the amount of fertilizers applied. The objective of the producer is to maximize profit either by increasing the quantity of Q produced or by reducing the cost of producing Q. The production function shows the maximum amount of the good that can be produced using alternative combinations of labor (L), seed (S) and fertilizer (F). *Q* is also referred to as the total physical product (TPP). This production relationship can be expressed in several forms such as: linear functional forms, polynomial functional forms and Cobb-Douglas functional form. The later is modified into the transcendental and translog functional forms. The marginal physical product (MPP) of an input is the additional output that can be produced by employing one more unit of that input while holding all other inputs constant.

Example, the MPP of labor, $MP_L = \frac{\partial Q}{\partial L} = f_L$,

This is derived from the first derivative of the production function. However, if labor is employed indefinitely while holding all the other inputs of production indefinitely, this results into diminishing marginal productivity where the rapid increase in use of additional input results to lower productivity. Therefore the second derivative is less than zero:

$$\frac{\partial MP_L}{\partial L} = \frac{\partial^2 q}{\partial L^2} = f_{LL} < 0 \qquad (2)$$

The average physical product (APP) is a measure of efficiency. The APP depends on the level of other inputs employed.

$$AP_L = \frac{Output}{Labor} = \frac{Q}{L} = \frac{f(F, L, S)}{L} \qquad (3)$$

The concept of returns to scale shows how output responds to increase in all inputs together. Returns to scale can either be constant, decreasing or increasing.

The elasticity of supply of an input measures how an output responds to changes in inputs. This is derived by dividing the MPP by the APP (i.e. MPP/ APP). In addition, the total variable product (TVP) is derived by multiplying TPP by the output price (i.e. TPP*output price). Given the output price (P_y), its marginal value product (MVP) can be computed by multiplying (MPP*P_y). Given the above economic concepts from a production function, a profit function can be generated as follows: Profit (π)=TVP-TVC, applying the first order condition (FOC) we get a change in profit with respect to change in input, for example, labor (L) is $\Delta\pi / \partial L$=MVP-MVC=0. Therefore, at profit maximization, MVP (MPP*Py) =MVC=w (unit of input), Ingosi (2005). To determine if the inputs are used at optimum level, the MVP is equated to the unit factor price. It is important to note that in the traditional production function, social economic characteristics and management are not considered as explanatory variables and are thus lumped together in the error term. The stochastic frontier production functions deals with the analysis of socio-economic characteristics of the household that are assumed to be in the composed error term.

3.2 Assumptions

Several assumptions underlie this study. Perhaps the most obvious stems from the very nature of the data. The data is analyzed on the 'largest field[2]' in which a household planted maize during 2003/2004 main harvest cropping season. In this study, the largest field is considered a practical representation of a typical maize farm. By considering the largest field, the study captures 85 percent of the maize area cultivated by the farmers. The second assumption is that the producers have an identical production

---

[2] *A field is defined as piece of land with a uniform crop mixture, e.g. maize alone or maize and beans intercropped in a uniform order. The field may have a boundary such as napier grass or a row of trees or bushes; however, in most cases the field will be defined by the uniformity of the crops dispersed within an area. Some of the field data collected are: acres, land preparation cost, fertilizer information and tenure system. (Tegemeo, 2004)*

function. Additionally, the study assumes that all the production inputs and socio-economic characteristics are included in the specification of the stochastic frontier model.

Finally, the assumption of the composed error term (e_i=u+v) that is symmetric independently distributed as N $(0,\sigma^2_V)$ random variables independent of *u.* Additionally, *u* is assumed to be non-negative truncated half-normal distribution, N $(0, \sigma_u^2)$. Maize yield that weighted less than one bag was considered as an outlier and hence excluded from the study.

3.3 The Proposed Stochastic Frontier Production Function

For a long time, econometricians have estimated average production functions. It is only after the pioneering work of Farrell (1957) that serious considerations have been given to the possibility of estimating the so-called frontier production functions in an effort to bridge the gap between theory and empirical work. (Aigner, Lovell and Schmidt, 1977).

The stochastic frontier production function was independently proposed by Aigner, *et al*., (1977) and Meeusen and Van den Broeck (1977). The stochastic production function is defined by;

$$Y_i = f(x_i; \beta) + e_i \quad where, \quad i=1, 2, \ldots, N \qquad (4)$$

$$e_i = v_i - u_i \qquad (5)$$

Where Y_i represent the output level of the *i*th sample farm; $f(x_i; \beta)$ is a suitable function such as Cobb-Douglas or translog production functions of vector, x_i, of inputs for the *i*th farm and a vector, β, of unknown parameters. e_i is an error term made up of two components: v_i is a random error having zero mean, $N(0; \sigma^2_v,)$ which is associated with random factors such as measurement errors in production and weather which the farmer does not have control over and it is assumed to be symmetric independently distributed as $N(0,\sigma^2_V)$ random variables and independent of u_i.

On the other hand, u_i is a *non-negative* truncated half normal, $N(0, \sigma_u^2)$ random variable associated with farm-specific factors, which leads to the ith firm not attaining maximum efficiency of production; u_i is associated with technical inefficiency of the farm and ranges between zero and one. However, u_i can also have other distributions such as gamma and exponential. N represents the number of firms involved in the cross-sectional survey of the farms.

Technical efficiency[3] of an individual firm is defined in terms of the ratio of the observed output to the corresponding frontier output, conditioned on the level of inputs used by the firm. Technical inefficiency is therefore defined as the amount by which the level of production for the firm is less than the frontier output.

$$\hat{TE}_i = Y_i/Y_i^*, \text{ where } Y_i^* = f(x_i;\beta), \text{ highest predicted value for the ith farm}$$

$$\hat{TE}_i = Exp(-u_i) \tag{6}$$

$$\text{Technical inefficiency} = 1 - \hat{TE}_i$$

In their article Bravo-Ureta, *et al.*, (1993) suggested that the stochastic frontier production function could be established in two ways. First, if no explicit distribution for the efficiency component is made, and then the production frontier could be estimated

---

[3] *The traditional concept of efficiency, as defined by M. J Farrell (1957), has three components: technical, allocative and economic.* ***Technical efficiency*** *is defined as the ability to achieve a higher level of output given similar levels of inputs. '****Allocative efficiency'*** *deals with the extent to which farmers make efficient decisions by using inputs up to the level at which their marginal contribution to production value is equal to the factor costs. Technical and allocative efficiencies are components of* ***economic efficiency.***

using a stochastic the version of corrected ordinary least squares (COLS). However, if an explicit distribution is assumed, such as exponential, half-normal or gamma distribution, then the frontier is estimated by maximum likelihood estimates (MLE). According to Greene (1980), MLE makes use of the specific distribution of the disturbance term and this is more efficient than COLS.

Previously, TE was estimated using a two-stage process. First, was to measure the level of efficiency/inefficiency using a normal production function. Second, was to determine socio-economic characteristics that determine levels of technical efficiency. This was done by using a probit model, with TE as the dependant variable and the socio-economic characteristics as the independent variables. However, since 2000, the stochastic frontier and inefficiency models are jointly estimated using Limdep (Green, 2002) or Frontier computing packages, which apply MLE.

Green (2004) outlines the Log likelihood estimation of the normal-truncated half-normal model.

The log likelihood for the normal-truncated normal model is

$$\log L_i = -\frac{1}{2}\log 2\pi - \log\sigma - \log\Phi\left(\alpha\sqrt{1+\lambda^2}\right) + \log\Phi(\alpha - \varepsilon_i\lambda/\sigma) - \frac{1}{2}(\varepsilon_i/\sigma + \sigma\lambda)^2 \tag{7}$$

Where

$\varepsilon_i = y_i - \beta' x_i$

$\lambda = \sigma_u / \sigma_v$

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

$\sigma = \sqrt{\left(\sigma_u^2 + \sigma_v^2\right)^2}$

$\alpha = \mu/(\lambda\sigma)$

N represents the distribution function of the standard normal random variable.

After optimization, the structural parameter u is recovered from the result $\mu = \alpha\sigma\lambda$. For the model with heterogeneity in the mean,

$$\mu_i = \theta' Z_i \tag{8}$$

3.4 Empirical Model Specification

A number of previous studies specified a Cobb-Douglas production function to represent the frontier function; however, the Cobb-Douglas imposes a severe prior restriction on the farm's technology by restricting the production elasticities to be constant and the elasticities of input substitution to unity (Wilson, *et al.*, 1998). This study specifies the stochastic frontier production function using the flexible translog specification. The model is specified as follows.

$$\ln y_i = \alpha_0 + \sum_{k=1}^{3} \alpha_k \ln x_{ki} + \frac{1}{2} \sum_{k=1}^{3} \sum_{j=1}^{3} \alpha_{kj} \ln x_{ki} \ln x_{ji} + \varepsilon_i \tag{9}$$

$$\varepsilon_i = v_i - u_i$$

Where, Ln denotes natural logarithms, y and x variables are defined in Table 3.1, α's are parameters to be estimated. The inefficiency model is estimated from the equation given below.

$$u_i = \delta_0 + \sum_{m=1}^{12} \delta_m z_i \tag{10}$$

The variables z_i are the variables in the inefficiency variables. Equation 11 shows a joint estimation of a stochastic frontier production function in Limdep (Green, 2002).

$$\begin{aligned}
&\mathit{Lnyield} = f\{\alpha_0 + \alpha_1 \mathit{lnfert} + \alpha_2 \mathit{lnseed} + \alpha_3 \mathit{lnlabor} + \alpha_4 \mathit{lnfert}^2 + \alpha_5 \mathit{lnseed}^2 + \\
&\alpha_6 \mathit{lnlabor}^2 + \alpha_7 \mathit{lnfert} * \alpha_8 \mathit{lnseed} + \alpha_9 \mathit{lnfert} * \mathit{lnlabor} + \alpha_{10} \mathit{lnseed} * \mathit{lnlabor} + \alpha_{12} \mathit{lnmanure} + \\
&\delta_0 + \delta_1 \mathit{purchybr} + \delta_2 \mathit{tractor} + \delta_3 \mathit{schyrs} + \delta_4 \mathit{schsqd} + \delta_5 \mathit{malehead} + \delta_6 \mathit{headill} + \\
&\delta_7 \mathit{agedummy} + \delta_8 \mathit{offinc} + \delta_9 \mathit{offinc} * \mathit{schyrs} + \delta_{10} \mathit{purchybr} * \mathit{credit} + \delta_{11} \mathit{high} + \delta_{12} \mathit{low} + v\}
\end{aligned} \tag{11}$$

The first section is the stochastic frontier production function while the second part captures the inefficiency variables. The model generates variance parameters, (i.e.) Lambda, $\lambda = (\sigma_u/\sigma_V)$; variance of the model (Sigma σ), variance of the stochastic model (σ_v^2) and variance of the inefficiency model (σ_u^2)

3.5 Data and Variables

The production data used in this study are taken from survey information collected by Tegemeo Institute of Agricultural Policy and Development, Nairobi-Kenya. It was collected under the Tegemeo Agricultural Monitoring and Policy Analysis Project (TAMPA), a collaborative effort between the Institute, Michigan State University and United States Agency for International Development. The project is mandated to provide baseline information and subsequent monitoring of smallholder production patterns to assess the impacts of changes in the agricultural policy environment on selected socio-economic and regional groups in Kenya. The study used 2003/2004 main harvest cropping year cross-sectional household data collection. A total of 2017 households were used in this study. The analysis of technical efficiency departs from the Tegemeo classification of the eight ecological zones. For this study, the high potential maize zone is unchanged. However, the central highlands, western highlands, western transition are all merged into one region referred to as the medium potential region. Similarly, the coastal lowlands, eastern lowland and the marginal rain shadow are merged to form the low potential zone. Households with maize yield below one or greater than 40 bags are considered as outliers and hence excluded from this study. Trained graduates with a degree in an agricultural related field gathered data via person-to-person interview under the supervision of experienced researchers from Tegemeo Institute. Stratified random sampling was used. Descriptive statistics are presented in Table 3.1.

The average yield per acre averages 8.27 bags. This is obtained by using: 42 kilograms of fertilizer, 9.11 kilograms of seed and 61 person-days. In addition, 42 percent of the households used manure. 59 percent purchased hybrid seed while the rest used retained hybrid or local seeds recycled for a number of years. Only 23 percent used tractors and this low usage could be related to the high cost of leasing or owning a tractor. In addition, the land terrain may hamper use of tractors.

84 percent of the households are male headed. Only 8 percent of the households reported illness of the head of the household within three months prior to the date of the interview. 40 percent of the household heads are aged below 50 years old. The percentage that received agricultural credit is only 24 percent. Finally, 27 percent of the respondents are in the low potential region, 43 percent in the medium and 29 percent in the high potential region. In addition, 68 percent of the household engaged in an off-farm income earning activity.

Table 3.1 Descriptive Statistics for the Variables

Variable	Description	Units	Mean	Std. Deviation	Min	Max
Yield	Yield in bags per acre	Bag	8.27	6.46	0.95	34
Fert	Fertilizer per acre	Kilograms	42.06	52.45	0.00	420
Seed	Seed per acre	Kilograms	9.11	5.06	0.63	48
Labor	Person-days per acre	Person-days	61.29	45.67	2	372
Manure	Used manure on the maize field	1=yes, 0=no	0.42	0.49	0	1
Purchybr	Purchased hybrid maize seed	1=yes, 0=no	0.59	0.49	0	1
Tractor	Used tractor for land preparation	1=yes, 0=no	0.23	0.42	0	1
Schyrs	Number school years	Years	7.18	4.71	0	19
Malehead	Head if household	1=male, 0=else	0.84	0.36	0	1
Headill	Head of household ill	1=yes, 0=no	0.08	0.26	0	1
Agedummy	Age of household	1=<50, 0=>50 years	0.40	0.49	0	1
Offinc	Off-farm income	1=yes, 0=no	0.68	0.47	0	1
Credit	Obtained credit	1=yes, 0=no	0.24	0.43	0	1
Low	Low potential	1=yes, 0=no	0.27	0.45	0	1
Medium	Medium potential	1=yes, 0=no	0.43	0.50	0	1
High	High potential	1=yes, 0=no	0.29	0.46	0	1

Source:Tegemeo Institute, Kenya, 2004 rural household survey

CHAPTER 4

RESULTS AND DISCUSSIONS

This chapter discusses the results of the estimation of the Stochastic Frontier Approach (SFA). A one step process was used to estimate TE using the maximum Likelihood method in Limdep (Green, 2002). The chapter highlights different the models considered in the analysis. However, the translog production function is discussed most extensively. In addition, the chapter presents results from testing and correction of heteroscedasticity, orthogonality condition, hypotheses testing, input elasticities, and marginal value product. Individual farm level technical efficiency is also estimated.

Appendix 1 shows the estimated models before the data are transformed (corrected for heteroscedasticity and othorgonalised). Most variables are statistically insignificant. However, lambda λ (the variance parameter showing the ratio between the normal error term and half normal positive error term) is statistically significant. This is evidence that there are measurable inefficiencies in maize production probably caused by differences in socio-economic characteristic of the households and their management practices.

4.1 Heteroscedasticity Test

Heteroscedasticity is a violation of one of the requirements of ordinary least squares (OLS) in which the error variance is not constant. The consequences of heteroscedasticity are that the estimated coefficients are unbiased but inefficient. The variances are either too small or too large, leading to Type I[4] or II errors in the presence of heteroscedasticity, OLS is not BLUE (Best Linear Unbiased Estimator). Heteroscedasticity is mainly prevalent in cross-sectional data set such as the one used in this study. Some of the main causes are: variance of dependent variable increase with increase in the level of dependent variable, variance of dependent variables increases or decreases with changes in independent variables and outliers in the data set.

An initial[5] analysis of the heteroscedasticity condition reveals the presence of double heteroscedasticity. This emanates from variance in the normal error term (*v*), represented by heteroscedasticity from *v* (*hfv)* and from variances in the truncated half normal error term (*u*) represented by heteroscedasticity from *u* (*hfu).* Since the t-statistics of the variables in the functions *hfu* and *hfv* are statistically significant, we conclude the presence of heteroscedasticity. However, in order to be sure of the level of heteroscedasticity, the Breusch Pagan test is used.

```
FRONTIER;Lhs=LNYIELD;Rhs=one,LNFERT,LNLABOR,LNSEED,FERTSQ,LABORS
Q,SEEDSQ,FERTLAB,FERTSEED,LABSEED,MANURE;rh2=one,PURCHYBR,SCHY
RS,MALEHEAD,CREDAG,HEADAGE,AGESQ,OTHERINC;HET;hfv=one,lnlabor
,lnseed,laborsq,lnfert;hfu=one, Schyrs, schyrsq$
```

(12)

4.1.1 Breusch Pagan Test for Heteroscedasticity

The Breusch-Pagan heteroscedasticity test is used to detect the presence of heteroscedasticity. This is performed by squaring the error term e_i^2 and dividing each

---

[4] *Type I error, leads to rejection of a true Null Hypothesis, while in Type II error one accepts a false Null Hypothesis.*

error term squared by the mean error term to obtain v_i^2. Then, v_i^2 is regressed against all the dependent variables.

Steps for the test

a) Run an OLS regression ($\ln Yield = ß_0 + ß_1 X_{ik} \ldots + ß_k X_{ik} + e_i$) and obtain e_i

b) Calculate $\tilde{\sigma}^2 = \sum e_i^2 / N$

c) Construct $\hat{V}_i^2 = e_i^2 / \sigma^2$

d) Regress $\hat{V}_i^2$ on Z's (the dependent variables)

e) Obtain R^2

Since this is a large sample, the product of R-squared and the sample size follows a Chi-square distribution. $(N-P)^* R^2 \sim \chi^2_P$, where P is the number of dependent variables in the regression.

The computed chi-square is 295.612 at a 5 percent level of confidence. Since the computed chi-distribution is greater than critical value of 124.561, the null hypothesis of homoscedasticity is rejected and we conclude that there is heteroscedasticity.

4.1.2 Correction for Heteroscedasticity

Some of the methods used to correct for heteroscedasticity are transformation of data into natural logarithms and the generalized least squares (GLS), also known as the weighted least squares (WLS). For this study, the WLS method is used. The weighting function ($1/\sigma_i$) is calculated by obtaining a reciprocal of the variance (σ) i.e. the square root of σ^2_i from equation (d). Then, all the variables in the stochastic frontier model are multiplied by this function, as shown in equation 13.

$$\begin{aligned}\mathit{Lnyield} = {} & \beta_0 + \beta_1 \mathit{lnfert} + \beta_2 \mathit{lnseed} + \beta_3 \mathit{lnlabor} + \beta_4 \mathit{lnfert}^2 + \beta_5 \mathit{lnseed}^2 + \beta_6 \mathit{lnlabor}^2 \\ & + \beta_7 \mathit{lnfert}*\mathit{lnseed} + \beta_8 \mathit{lnfert}*\mathit{lnlabor} + \beta_9 \mathit{lnseed}*\mathit{lnlabor} + \beta_9 \mathit{Manure} + \delta_0 + \delta_1 \mathit{purchybr} \\ & + \delta_2 \mathit{tractor} + \delta_3 \mathit{schyrs} + \delta_4 \mathit{schsqd} + \delta_5 \mathit{malehead} + \delta_6 \mathit{headill} + \delta_7 \mathit{agedummy} + \delta_8 \mathit{offinc} + \\ & \delta_9 \mathit{offinc}*\mathit{schyrs} + \delta_{10} \mathit{purchybr}*\mathit{credit} + \delta_{11} \mathit{high} + \delta_{12} \mathit{low} + v]*\mathbf{1/\sigma} \end{aligned} \tag{13}$$

The transformed variables are then othorgonalised and used in subsequent analysis. Correcting for heteroscedasticity improves precision of the beta coefficients and estimated mean technical efficiency.

4.2 Orthogonality Condition

In ordinary least squares, the covariance between the independent variables and the error term is zero, i.e. $\mathrm{cov}(x_i,e_i)=0$. However, since the estimation of the stochastic frontier production function is based on the distribution of the error term, it is important to ensure that variables measuring inefficiency are independent from the variables in the stochastic frontier. The orthogonality condition requires a linear independent relationship between the independent variables and the error term. If this condition is not met, then the results of the stochastic frontier will be biased. The process is performed by regressing individual efficient measurement variables, such as school years against the natural logarithm of the translog production variables.

$$\begin{aligned}\mathit{Schyrs} = {} & \beta_0 + \beta_1 \mathit{lnfert} + \beta_2 \mathit{lnseed} + \beta_3 \mathit{lnlabor} + \beta_4 \mathit{lnfert}^2 + \beta_5 \mathit{lnseed}^2 + \beta_6 \mathit{lnlabor}^2 \\ & + \beta_7 \mathit{lnfert}*\mathit{lnseed} + \beta_8 \mathit{lnfert}*\mathit{lnlabor} + \beta_9 \mathit{lnseed}*\mathit{lnlabor} + \beta_9 \mathit{Manure} + e_i \end{aligned} \tag{14}$$

A high R-squared is an indication of high dependence between number of school years and variables in the stochastic frontier function.

Table 4.1 is a summary of R-squared values for the efficiency determining variables. The Independent variables: lnfert, lnseed, lnlabor, lnfert^2, lnseed^2, lnlabor^2, lnfert* lnseed+ lnfert*lnlabor, lnseed* lnlabor

Table 4.1 Orthogonality Test

Dependent Variable	R- squared
Purchased Hybrid Maize	0.83
School years	0.68
Male-head households	0.76
Obtained Agric. credit	0.15
Age	0.76
Household head ill	0.01
Used tractor	0.49
Offarm-income	0.30
High potential	0.88
Low potential	0.30
Medium potential	0.24

Source:Tegemeo Institute, Kenya, 2004 rural household survey

From the table, we can conclude that most variables in inefficiency model have a high covariance with the stochastic function model. Therefore, in order to ensure that the independent variable and the error term are not linearly related, the residual (e_i) from the Table 4.1 are then used in the estimation of technical efficiency.

Equation 11 is then estimated after correcting for heteroscedasticity and the orthogonality condition. Data are also analyzed using different functional forms, i.e. the translog, quadratic, transcendental and Cobb-Douglas production functions. Table 4.2 shows results of the stochastic frontier model from the different functional forms.

Table 4.2 Technical Efficiency from Different Production Functional Forms

Variable	Parameters	Translog	Cobb Douglas	Quadratic	Transcendental
Stochastic Frontier					
Intercept	ß0	0.0844	0.7464***	0.0089	0.7284***
LNFERT	ß1	0.0399	0.1433***	-0.0217	0.0335***
LNSEED	ß2	0.6929***	0.4706***	0.9239***	0.7726***
LNLABOR	ß3	0.4255***	0.1476***	0.4019***	0.1719***
LNFERTSQ	ß4	0.0348***		0.0346***	
LLNLABORSQ	ß5	-0.0360**		-0.0349*	
LNSEEDSQ	ß6	-0.1631***		-0.1308***	
LNFERT*LNLABOR	ß7	-0.0414***			
LNFERT*LNSEED	ß8	0.0470***			
LNLABOR*LNSEED	ß9	0.0575*			
MANUREH	ß10	0.0808***	0.0344	0.0712***	0.4820***
FERT	ß11				0.0036***
SEED	ß12				-0.0653***
LABOR	ß13				-0.0013*
FSERT*SEED	ß14				0.000044
FERT*LABOR	ß14				0.000014***
SEED*LABOR	ß15				0.0002***
Inefficiency model					
constant	δ0	0.3413***	0.3168***	0.0712***	0.4820***
Purchased hybrid	δ1	-0.5238***	-0.4909***	0.3474***	-0.2624***
Tractor use	δ2	-0.3628***	-0.3744***	-0.5245***	-0.3429***
School years	δ3	-0.0109*	-0.0064*	-0.3615***	0.0005*
School years squared	δ4	0.0022***	0.0023***	-0.0108*	0.0021***
Male headed	δ5	-0.1206	-0.0982	0.0022***	-0.0306***
Ill head of household	δ6	0.1056	0.0975	-0.1227	0.0594
Age dummy	δ7	-0.0006	-0.0007	0.1010	-0.0004
Off-farm income dummy	δ8	0.0184	0.0151	-0.0007	-0.0214
Off-income*education	δ9	-0.0271***	-0.0292***	0.0166**	-0.0217***
Purchase*credit	δ10	-0.3161***	-0.3485***	-0.0271***	-0.3470***
High potential	δ11	-0.5972***	-0.4886***	-0.3658***	-0.2372***
Low potential	δ12	0.2362***	0.2272***	-0.5978***	0.1348
Variance parameters					
Lambda (σ_u/σ_v)	λ	1.9336***	1.9689***	1.933***	2.0155***
Sigma	σ	0.9351***	0.9682***	0.9424***	0.8692***
Sigma-squared(u)	σ_u^2	0.6899***	0.7451	0.7011	0.6063***
Sigma-squared(v)	σ_v^2	0.1845	0.1922	0.1871	0.1492***
Ln (likelihood)		-2121.0	-2166.00	-2131.00	-2078.00
Gamma, $\sigma_u^2/(\sigma_u^2+\sigma_v^2)$	γ	0.789	0.795	0.789	0.803
Mean technical efficiency		49%	49%	49%	48%

Source:Tegemeo Institute, Kenya, 2004 rural household survey. ***, **.* significance level at 1%, 5% and 10% consecutively

The mean technical efficiency is computed for each model. The estimated mean TE is 49 percent, however, the estimate from the transcendental function is lower by one percent. Because the four functions generate similar results, this study focuses on the result of the translog production function because of its flexibility as compared to the restrictive Cobb-Douglas production function. The quadratic function is not considered because it does not capture the interactive term of inputs; in addition, it is the only functional form that generates contradicting signs in the inefficiency model. Although the transcendental production function captures the three stages of production, it is not considered in this case because of lower TE. The translog production function has been used in stochastic production frontier studies by Wilson, *et al*., (2001), Liu and Zhuang (2000), Awudu and Eberkin (2001), Awudu and Huffman (2000), Wilson, *et al*., (1998). Later, a log likelihood ratio test is carried out to determine if the translog reduces to Cobb-Douglas production function in this case.

4. 3 Input Elasticity

Determination of elasticities is necessary for the estimation of responsiveness of yield to inputs. Most of the inputs on the stochastic frontier are statistically significant and have the expected signs. However, the first-order coefficients of the translog production function are not undertaken, as they are not very informative. Rather, the output elasticities for each of the inputs calculated at the variable means are of interest (Awudu and Eberlin, 2001). Evaluated at the sample mean, the output elasticities with respect to the inputs, X_j, for the translog are computed as follows:

$$Lnyield = \beta_0 + \beta_1 lnfert + \beta_2 lnseed + \beta_3 lnlabor + \beta_4 lnfert^2 + \beta_5 lnseed^2 +$$

$\beta_6 lnlabor^2 + \beta_7 lnfert * lnseed + \beta_8 lnfert * lnlabor + \beta_9 lnseed * lnlabor$ (15)

$$\frac{1}{yield} * \frac{\partial yield}{\partial fert} = \frac{\beta_1}{fert} + \frac{2\beta_4}{fert} + \frac{\beta_7}{fert} + \frac{\beta_8}{fert}$$

The slope is calculated as follows:

$$\frac{\partial yield}{\partial fert} = (\beta_1 + 2\beta_4 + \beta_7 + \beta_8) * yield / fert$$

The equation below shows the calculation of elasticities evaluated at the mean

$$e_{fert} = (\beta_1 + 2\beta_4 + \beta_7 + \beta_8) * \frac{yield}{fert} * \frac{fert}{yield}, \; e_{fert} = \beta_1 + 2\beta_4 + \beta_7 + \beta_8$$

Table 4.3 shows results of the input elasticities for each input in the translog stochastic frontier production function. A one percent increase in the quantity of fertilizer applied increase maize output by 0.17 percent (t=5.7656) ceteris paribus. In addition, a one percent increase in seed rate increased output by 0.63 percent (t= 3.0335). On the other hand, a one percent increase in labor will probably increase maize yield by 0.46 percent (t= 2.0724).

Table 4.3 Input Elasticity

Variable Input	Elasticity
Fertilizer	0.17
Seed	0.63
Labor	0.46

Source:Tegemeo Institute, Kenya, 2004 rural household survey

The study shows that yield has the highest responsiveness to seed, followed by labor and fertilizer. The prior was that yield is more responsive to fertilizer than to labor. The result is surprising and could probably be explained by the following; there is a tendency by some maize farmers in the tea-growing region to use tea fertilizer (such as NPK) on maize. Such fertilizer does not benefit maize plants since the nutritional requirement is different. In addition, incorrect timing of the top dressing fertilizer may reduce the effectiveness of the applied fertilizer. Use of top dressing fertilizer as a basal fertilizer may be another problem. As observed in the above results, all the input elasticities are inelastic; a one percent increase in each input results in a less than one percent increase in yield.

Summation of the partial elasticity of production with respect to every input for a homogeneous function (all resources varied in the same proportion) is 1.26. This represents the returns-to-scale coefficient, also called the function coefficient or total output elasticity. If all factors are varied by the same proportion, the function coefficient indicates the percentage by which output will be increased. In this case, the production function can be used to estimate the magnitude of returns-to-scale. Constant returns-to-scale only holds if the sum of all partial elasticities is equal to one. If this sum is less than one, the function has decreasing returns-to-scale: if more than one, as in this case, an increasing returns-to-scale exists. Therefore, an increase in all inputs by one percent increases maize yield by more than one percent.

4.3.1 Semi-Elasticity for Manure

The calculation of the semi elasticity of manure dummy is different since the regression from a log-lin model, i.e. contains a logarithmic dependent variable and a qualitative dummy variable for use of manure. To obtain the semi elasticity for manure variable, the suggestion by Halvorsen and Palmquist (1980) is used. The antilog (to base e) of the estimated dummy coefficient is taken and a value of 1 is subtracted from it. The difference is then multiplied by 100. In this case, the beta value is 0.08 and the antilog is 1.08. Subtracting one and multiplying by 100 results in a value of 8.4 percent. Thus for the household that used manure, the median yield is higher by 8.4 percent as compared to their counterparts who did not use manure, ceteris paribus.

4.4 Marginal Value Product

In order to assess the condition of a producer's profit maximization, marginal physical product (MPP) [6], marginal value product (MVP)[7] and input prices are also estimated. Table 4.4 the shows MPP, MVP and factor prices. Seed has the highest MPP: therefore an increase in maize seed by one kilogram is estimated to increase output by 0.57 bags (equivalent to 52 kilograms) per acre. An increase in fertilizer application by an additional kilogram is estimated to increase maize yield by 0.03 bags per acre (2.7 kilograms). On the other hand, additional labor (i.e.) a person-day is estimated to increase the maize yield by 0.06 bags (5.4 kilograms) per acre.

Table 4.4 Marginal Value Products and Factor Price

Variable	APP bags per acre	Elasticity	MPP bags per acre	MVP Ksh	Unit factor price Ksh
Fert	0.20	0.17	0.03 (2.7 kg)	39.86	30.00
Seed	0.91	0.63	0.57 (52 kg)	665.23	130.00
Labor	0.13	0.46	0.06 (5.4 kg)	72.42	70.00

Source:Tegemeo Institute, Kenya, 2004 rural household survey

Profit maximizing conditions require the MVP to equal the respective unit factor prices. This necessary condition is only satisfied for labor because MVP is approximately equal to the price of labor (wage rate). Therefore, that additional use of labor will be irrational and will lead to losses. The output price in Kenya Shilling (Ksh) is 1170.

---

[6] MPP= APP*input elasticity

[7] MVP=MPP*output price

However, for fertilizer and seed the MVP is greater than the factor price, an indication that maize production has not reached the optimal use of inputs, and could probably benefit by increasing the quantity of seed and fertilizer used in maize production. The estimated MPP from this study are consistent with results from a study by Ingosi (2005). However, results from this study are probably lower because estimation is by a different function, a translog, while Ingosi used a transcendental production function.

4.5 Hypotheses Testing

To test the first null hypothesis, a nested hypothesis is performed to determine whether the Cobb-Douglas specification is an adequate representation of the frontier production function. This test uses the log Likelihood[8] ratio test. Table 4.5 outlines the results of the null hypothesis. The null hypothesis, $H_0=ß_{ik}= 0$ is rejected in favor of the translog production function.

Table 4.5 Likelihood Ratio Tests

Null hypothesis	Calculated value	df	Pvalue	Decision
$H_0=ß_{ik}=0$	95.73	6	0.0000	Reject Ho
$H_0;u=0$	480.15	1	0.0000	Reject Ho
$H_0; \lambda=\delta_0= \delta_2=\ldots\ldots \delta_p=0$	175.14	13	0.0000	Reject Ho

Source:Tegemeo Institute, Kenya, 2004 rural household survey

The second null hypothesis explores the test that specifies each farm is operating on the technically efficient frontier and that the systematic and random technical efficiency in the inefficiency effects are zero. This is rejected in favor of the presence of inefficiency effects.

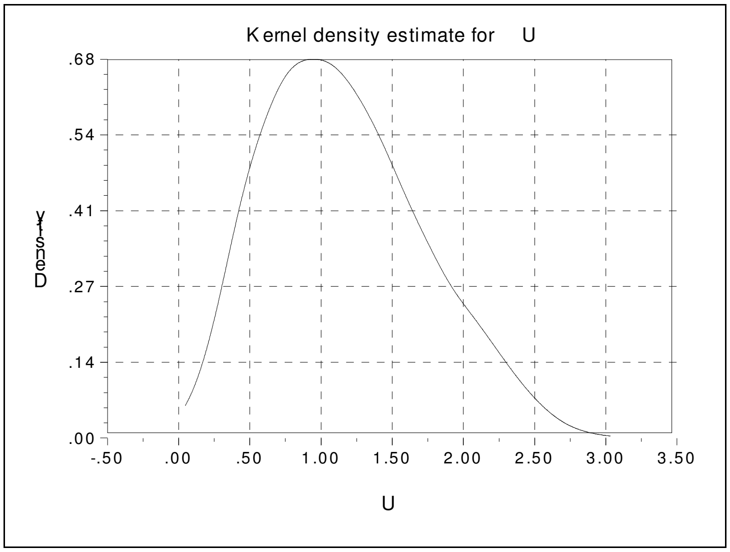
---

[8] *The basic idea behind the LR test is simple: if the priori restriction(s) are valid, then the restricted and unrestricted (log) LF should not be different. In this case Log likelihood test (λ) =0. But if not the case, the two LFs will diverge. And since in a large sample we know that λ follows the chi-square distribution, we can find out if the divergence is statistically significant, say at 1 or 5 percent level of significance. Or else, we can find out the p value of the estimated λ (Gujarati, 2003).*

The final null hypothesis determines whether the variables included in the inefficiency effects model have no effect any effect on the level of technical inefficiency. H_0; $\lambda=\delta_0= \delta_2=\ldots \delta_p=0$, the null hypothesis is rejected confirming that the joint effect of these variables on technical inefficiency is statistically significant.

4.6 Kernel Density

It is important to note that TE can only be estimated if the inefficiency effects are stochastic and has a particular distributional specification (Battese and Coelli, 1996). One of the assumptions made in this study is that the *U* is non-negative truncations of the N $(0, \sigma^2)$ with half normal distribution. In order to confirm the assumed distribution, a kernel density function is plotted in Limdep (Green, 2002). Figure 4.1 shows a truncated half normal distribution of the inefficiency measuring variable. This is an indication that the assumption that u_i is non-negative truncated half normal distribution is probably correct.



Source:Tegemeo Institute, Kenya, 2004 rural household survey

Figure 4.1 Kernel Density Function

4.7 Technical Efficiency

As stated earlier, TE of the ith farm is calculated from the following:

*TE_i=exp (-u_i) *100 (TE is converted into a percent by multiplying this equation by 100)*

Technical efficiency is calculated using the conditional expectation of the above equation, conditioned on the composed error ($e_i=v_i-u_i$), and evaluated using the estimated parameters presented in Table 4.6 from the translog production function.

TE is computed for each farm with the households later disaggregated into three regions, i.e. the high, medium and low potential. Figure 4.2 shows a histogram of predicted technical efficiencies. The minimum estimated efficiency is 8.04 percent, the maximum 98.30 percent and the mean is 49 percent with a standard deviation of 19.71 percent. This is interpreted as follows: in the short run, there is a scope for increasing maize production by 51 percent by adopting technologies and techniques used by the best practice maize farms. This suggests that, on average; about 51.30 percent of maize yield is lost because of inefficiency. However, each region has a different estimated mean technical efficiency.

Most of the variables determining inefficiencies are also statistically significant. It's evident from Table 4.6 that the estimates of λ is 1.9258 and σ is 0.9300 are large and significantly different from zero, indicating a good fit and correctness of the specified distribution assumption. (λ)[9] is the ratio of variance of u (σ_u) over variance of v (σ_v) and is an indication that the one sided error term u dominates the symmetric error v, so variation in actual maize yield comes from differences in farmer's practice rather than random variability.

---

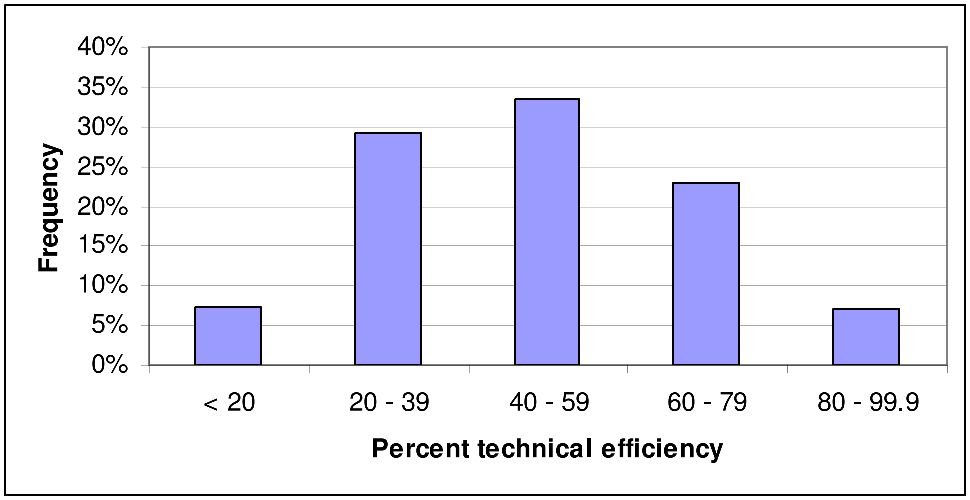
[9] Lambda (λ)=variance of u/variance of v, = 0.825/0.4285=1.9258

Table 4.6 Translog Stochastic Frontier and Inefficiency Model

Variable	Parameters	Translog
Stochastic Frontier		
Constant	ß0	0.0844
Lnfert	ß1	0.0399
Lnseed	ß2	0.6929***
Lnlabor	ß3	0.4255***
Lnfertsq	ß4	0.0348***
Llnlaborsq	ß5	-0.0360**
Lnseedsq	ß6	-0.1631***
Lnfert*lnlabor	ß7	-0.0414***
Lnfert*lnseed	ß8	0.0470***
Lnlabor*lnseed	ß9	0.0575*
Manureh	ß10	0.0808
Inefficiency model		
constant	δ0	0.3413***
Purchased hybrid	δ1	-0.5238***
Tractor use	δ2	-0.3628***
School years	δ3	-0.0109*
School years squared	δ4	0.0022***
Maleheaded	δ5	-0.1206
Ill head of household	δ6	0.1056
Age dummy	δ7	-0.0006
Off-farm income dummy	δ8	0.0184*
Off-income*education	δ9	-0.0271***
Purchase*credit	δ10	-0.3161***
High potential	δ11	-0.5972***
Low potential	δ12	0.2362***
Variance parameters		
Lambda (σu/σv)	λ	1.9336***
Sigma	σ	0.9351***
Sigma-squared (u)	σ_u^2	0.6899***
Sigma-squared (v)	σ_v^2	0.1845
Ln (likelihood)		-2121.0
Gamma, $\sigma_u^2/(\sigma_u^2+\sigma_v^2)$	γ	0.789
Mean technical efficiency		49%

Source:Tegemeo Institute, Kenya, 2004 rural household survey

Gamma, (γ) = $\sigma_u^2/(\sigma_u^2+\sigma_v^2)$ is also a measure of level of the inefficiency in the variance parameter, it ranges between 0 and 1. For the translog model, γ is estimated at 0.789, this is can be interpreted as follows: 78 percent of random variation in maize production is explained by inefficiency.



Source:Tegemeo Institute, Kenya, 2004 rural household survey

Figure 4.2 Frequency Distribution of Predicted Technical Efficiency

4.7.1 Regional Technical Efficiency

The farm-specific technical efficiency is segregated into the three regions. Table 4.7 shows that 22.5 percent of farmers in high potential and 1 percent in the medium potential regions operate at over 80 percent mean technical efficiency, which are considered to be within the technical efficient range. Therefore, this shows that most technically efficient farmers are in the high potential maize zone. On the other hand, 13.1 percent of producers in the low potential, 7.2 percent in the medium potential and 1.7 percent in the high potential, have a mean TE below 20 percent, and thus, are considered technically inefficient. However, analysis of TE of the whole sample indicates that only 7 percent of the farmers are technically efficient, i.e. between 80-98.3 percent.

Further analysis reveals that the high potential region has the highest number of farms with the highest technical efficiency; where 61.8 percent of the producers in the high potential region have mean technical efficiency above 60 percent.

Table 4.7 Range of Technical Efficiency by Region

Range of TE in Percent	Low[a]	Medium[b]	High[c]	Total
Less than 20	13.1	7.2	1.7	7.2
20 - 39	45.9	32.3	9.3	29.3
40 - 59	31.0	39.4	27.1	33.5
60 - 79	10.0	20.1	39.3	23.0
80 - 98.3		1.0	22.5	7.0
Total	100	100	100.0	100

Source:Tegemeo Institute, Kenya, 2004 rural household survey

[a] *Low potential refers to coastal lowlands, Eastern lowlands, Western Lowlands, Marginal rain shadow*

[b] *Medium potential refers to the Central Highlands, Western Transition, Western Highlands*

[c] *High potential region*

For the medium potential region, only 21.1 percent have mean technical efficiency above 60 percent. Finally, the low potential region has the lowest number of farmers with TE above 60 percent. Most maize producers are operating below their estimated level of technical efficiency. This observation is probably due to the comparative advantage that the maize farmers in high potential region have as compared to the medium and low potential maize farmers.

4.7.2 Estimated Potential Yield by Region

Potential yield is calculated for each farm and the results are presented by region and range of technical efficiency. Table 4.8 summarizes the results from the calculation of potential yields.

$$\text{Potential yield} = 100/TE * \text{actual yield} \tag{16}$$

For the low potential maize producers, the actual yield averages 4.29 bags per acre. However, there is a range of between 1.3 and 11.78 bags per acre. This shows that there is intra-variation in yield among farmers in the same region. For example, only

9.98 percent of the producers in the low potential region have a mean technical efficiency of 66 percent.

Table 4.8 Mean Actual and Potential Yield by Range and Region

Region	Categorized technical efficiency	Percent number of farms	Technical efficiency	Yield in bags per acre	Potential yield in bags per acre
Low potential	0 thru 19	13.07	15.95	1.30	8.24
	20 thru 39	45.92	30.32	2.76	8.93
	40 thru 59	31.03	48.90	5.40	10.95
	60 thru 79	9.98	66.01	11.78	17.59
	Overall mean	100	37.77	4.29	10.33
Medium potential	0 thru 19	7.19	16.09	1.79	11.16
	20 thru 39	32.31	31.01	3.88	12.38
	40 thru 59	39.38	49.81	7.80	15.59
	60 thru 79	20.09	67.70	13.73	20.24
	80 thru 98.3	1.03	82.74	16.44	19.93
	Overall mean	100	45.25	7.38	15.21
High potential	0 thru 19	1.69	14.90	1.67	11.12
	20 thru 39	9.32	33.08	5.01	14.94
	40 thru 59	27.12	50.49	8.97	17.70
	60 thru 79	39.32	70.64	14.06	19.86
	80 thru 98.3	22.54	85.43	21.59	25.20
	Overall mean	100	64.06	13.32	19.87
Total	0 thru 19	7.19	15.94	1.54	9.70
	20 thru 39	29.30	30.91	3.51	11.14
	40 thru 59	33.52	49.74	7.47	14.91
	60 thru 79	22.95	68.97	13.66	19.74
	80 thru 98.3	7.04	85.26	21.27	24.87
	Overall mean	100	48.71	8.27	15.24

Source:Tegemeo Institute, Kenya, 2004 rural household survey

The estimated potential yield averages 10.33 bags although this can go up to 17.57 bags among the most efficient farms in the low potential region area.

The medium potential maize region has a higher mean actual average yield of 7.38 bags per acre, although this ranges between 1.79 and 16.78. The mean potential yield averages 15.21 bags, however the most-efficient farmers (with 82.74 percent average TE) have an estimated potential of 19.93 bags.

The high potential maize region has the highest mean technical efficiency of 64.06 percent and mean actual yield of 13.32 bags. The estimated mean potential yield is 19.87 bags, but there exist a higher potential of 25.20 bags for the most-efficient producers (TE greater than 80 percent). This is consistent with Ingosi *ibid* who conclude that the potential yield in the North Rift region of Kenya was 18.8 bags. Although he did not calculate the percent technical efficiency, it can be calculated by dividing the current output of 12 bags by the predicted 18.8 bags. This implies that the producers in the North rift region are 63.8 percent technically efficient. The above analysis shows that there exists unexploited potential of increasing maize yield through improved efficiency.

4.7.3 Input Use and Technical Efficiency

Input use varies across regions and range of technical efficiency. The most efficient producers (technical efficiency greater than 80 percent) use more inputs than producers who are technically less efficient. Table 4.9 details input use across various levels of technical efficiency. The technically efficient producers have the highest average yield of 21.27 bags per acre. They use the following combination of inputs: 65 kilograms of fertilizer per acre, 9.63 kilograms of maize seed per acre and 61 person-days per acre.

Table 4.9 Input Uses and Technical Efficiency

Technical efficiency	Categories of efficiency different groups	N	Yield in bags per acre	Fertilizer in Kilograms per acre	Seed in kilograms per acre	Labor in person-days per acre
0 thru 19	Low potential	72	1.30	4.94	9.09	70.21
	Medium potential	63	1.79	41.04	11.05	66.97
	High potential	10	1.67	42.05	13.29	60.18
	Total	145	1.54	23.18	10.23	68.11
20 thru 39	Low potential	253	2.76	5.20	8.03	56.35
	Medium potential	283	3.88	39.41	9.63	60.88
	High potential	55	5.01	59.62	10.45	50.59
	Total	591	3.51	26.65	9.02	57.98
40 thru 59	Low potential	171	5.40	6.93	7.49	54.77
	Medium potential	345	7.80	50.33	9.01	64.26
	High potential	160	8.97	70.95	10.67	56.55
	Total	676	7.47	44.23	9.02	60.04
60 thru 79	Low potential	55	11.78	17.52	7.41	67.77
	Medium potential	176	13.73	54.44	7.85	77.81
	High potential	232	14.06	68.85	9.96	55.19
	Total	463	13.66	57.28	8.86	65.28
80 thru 98.3	Low potential	-	-	-	-	-
	Medium potential	9	16.44	17.00	6.56	100.88
	High potential	133	21.59	68.75	9.84	58.30
	Total	142	21.27	65.47	9.63	61.00
Total	Low potential	551	4.29	6.93	7.94	58.81
	Medium potential	876	7.38	46.62	9.10	66.46
	High potential	590	13.32	68.08	10.23	55.92
	Total	2017	8.27	42.06	9.11	61.29

Source:Tegemeo Institute, Kenya, 2004 rural household survey

However, though efficient, they still use input below the recommended rates. For example, the amount of fertilizer used by the most efficient farmer is slightly below the recommended rate of 100 kilograms per acre. On the other hand, the quantity of seed used is slightly below the recommended rate of 10 kilograms per acre.

In comparison, the least efficient producer's yield is merely 2 bags per acre, about 10 percent of what is produced by the technically efficient producers. In addition, the least efficient producers use lower levels of fertilizer, i.e. 23 kilograms per acre. This cluster uses the recommended mean seed rate of 10 kilograms per acre. In addition, labor use is 68 person-days per acre. The labor used by this cluster is greater than that of the most efficient producers, an indication of input substitution among the least technically efficient producers.

Further analysis show that there is insignificant difference in the size of the households among the clusters. However, the inefficient cluster source higher proportion, 72 percent of labor from family as compared to the most efficient group that uses only 39 percent of total labor from family. Family labor is therefore cheaper than fertilizer. Another explanation could be due to low access to credit. However, it is insightful to note that there are a few producers in the high potential maize zone who are also classified among the least technically efficient cluster. However, input use of the least efficient producers in the high potential region is relatively higher than their counterparts in the same cluster in the medium and low regions.

4.7.4 Technical Efficiency and Cropping Pattern

In Kenya, maize is planted as either a mono-crop and or intercrop fields. In this study, 93.7 percent of the analyzed maize fields are under maize intercrop while the remaining 6.3 percent are under mono-crop fields. 49.2 percent of the farmers practicing a mono-crop system are in the high potential maize region, probably because of relatively large tracts of land where 31.2 and 19.5 percent are in the low and medium potential regions respectively, where land sizes are relatively smaller.

Table 4.10 shows that across the three maize producing zones, maize produced under the mono-crop system is closer to the frontier function than inter-cropped maize. In the high potential region, the mono-cropped maize has the highest TE of 71.48 percent as compared to 63.18 percent for the intercropped fields. In the medium potential region, the mono-cropped maize and intercropped maize fields have almost identical technical efficiencies of 47 and 45 percent, respectively. Finally in the low potential maize zone, TE in the mono-cropped field is 42 percent as compared to a mean of 37 percent.

Table 4.10 Technical Efficiency and Cropping Pattern

Cropping Pattern	Region	Mean	N	Std. Deviation
Intercrop	Low potential	37.41	511	15.13
	Medium potential	45.18	851	16.71
	High potential	63.18	527	18.37
	Total	48.10	1889	19.49
Mono	Low potential	42.38	40	17.02
	Medium potential	47.34	25	17.95
	High potential	71.48	63	14.09
	Total	57.67	128	20.88
Total	Low potential	37.77	551	15.31
	Medium potential	45.25	876	16.74
	High potential	64.06	590	18.13
	Total	48.71	2017	19.71

Source:Tegemeo Institute, Kenya, 2004 rural household survey

Despite of the benefits of higher efficiency under the mono-crop system, many maize producers continue to intercrop maize with other crops such as bean, peas, pigeon peas and fruit trees, probably because of relatively smaller land sizes and diversification of the investment in crops, to reduce risks of total crop failure.

4.7.5 Technical Efficiency from Region-specific Production Functions

In the previous technical analysis, efficiency was estimated using one stochastic production function on the three regions. The pooling of the regions into one production function is likely to bring about some bias in estimating TE. Therefore, in order to establish the degree of bias, different production functions were regressed for the three different regions. Table 4.11 shows results of the estimation of TE using a separate translog stochastic frontier production function for each region.

Table 4.11 Technical Efficiency from Region-specific Production Functions

Region	Categorized technical efficiency	Percent number of farms	Technical efficiency	Yield in bags per acre	Potential yield in bags per acre
Medium Potential	0 thru 19	3.31	16.65	1.65	10.07
	20 thru 39	23.74	31.04	3.21	10.17
	40 thru 59	35.05	50.18	5.89	11.70
	60 thru 79	33.56	69.16	11.27	16.16
	80 thru 98.3	4.34	83.29	16.53	19.81
	Overall mean	100	52.33	7.38	13.13
High Potential	0 thru 19	2.38	14.87	1.80	12.05
	20 thru 39	10.19	32.60	5.18	15.74
	40 thru 59	27.50	51.00	9.00	17.58
	60 thru 79	39.73	71.40	14.64	20.43
	80 thru 98.3	20.20	84.39	22.04	26.03
	Overall mean	100	63.12	13.32	20.10

Source:Tegemeo Institute, Kenya, 2004 rural household survey

The stochastic frontier failed to run for the low potential area due to the wrong skew of the distribution of the error term, and therefore results from the low potential region are not reported. A comparison of Table 4.11 with Table 4.8 shows that, for the high potential maize zone, the estimated technical efficiency is about the same. However, the estimated technical efficiency in the medium potential region is estimated at 52 percent as compared to the previous 45 percent. However, this difference is not overly large. Although pooling the three regions under-estimates the levels of technical efficiency, the amount of the underestimation are not too significant. Since the estimation of TE for the low potential region does not converge, results reported in this study are mainly based from the calculation of the TE using a single SFPF on the whole data set.

4.7.6 Socio-economic Characteristics and Technical Efficiency

So far, the analysis has only focused on the stochastic frontier part of the model. This section reports on sources of inefficiency also estimated in the model. A negative sign on a parameter inefficiencies means that the variable reduces technical efficiency, while a positive sign increases technical inefficiency. The results on Table 4.12 reveal that purchased hybrid seeds, use of tractors for land preparation, the number of years in school, male headed households, off-farm income, credit, off-farm income and high potential dummy variables have a negative sign, and therefore reduce technical inefficiency (or increase technical efficiency). These results seem plausible. It is important to note that these coefficients should not be directly interpreted and hence marginal effects using the formula recommended by Battese and Coelli (1993) will be calculated later in the chapter (See appendix for details).

A negative sign on the dummy variable for purchasing hybrid seeds indicates that use of certified purchased hybrid seeds for planting maize increases technical efficiency. This variable is statistically significant at one percent. Despite the gains in technical efficiency, only 59 percent of the farmers used certified purchased hybrid seeds. This is probably because of high prices for hybrid seeds, making them unaffordable to most subsistence maize producers. The other maize producers use recycled seeds.

Table 4.12 Technical Efficiency and Socio-economic Characteristics

Variables	Parameter	Coefficient
Inefficiency model		
Constant	δ0	0.3413***
Purchased hybrid	δ1	-0.5238***
Tractor use	δ2	-0.3628***
School years	δ3	-0.0109
School years squared	δ4	0.0022***
Maleheaded	δ5	-0.1206
Ill head of household	δ6	0.1056
Age dummy	δ7	-0.0006
Off-farm income dummy	δ8	0.0184*
Credit*education	δ9	-0.0271***
Purchase*credit	δ10	-0.3161***
High potential	δ11	-0.5972***
Low potential	δ12	0.2362***
Variance parameters		
Lambda (σu/σv)	λ	1.9336***
Sigma	σ	0.9351***
Sigma-squared (u)	$\sigma_u 2$	0.6899***
Sigma-squared (v)	$\sigma_v 2$	0.1845
No. of iterations		40
Mean technical efficiency		49%

*Source:Tegemeo Institute, Kenya, 2004 rural household survey.***, **.* significance level at 1%, 5% and 10% consecutively*

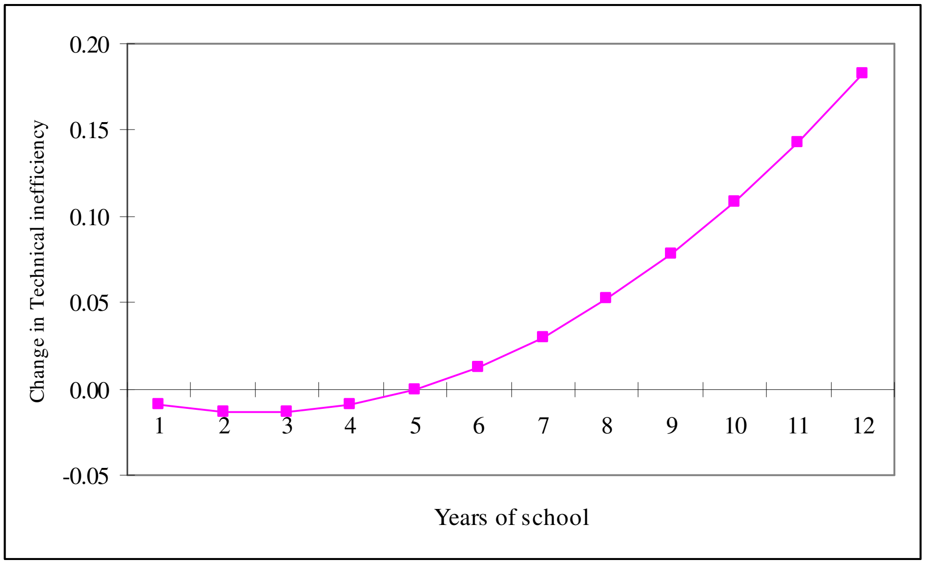
An interactive dummy variable for credit and purchase of hybrid seed has a negative sign, an indication that access to credit reduces technical inefficiency (or increases technical efficiency). This relationship is significant at the one percent level of confidence. Therefore, alleviating credit constraints enables producers to buy hybrid seeds, and thus decrease technical inefficiency.

This finding is consistent with a study by Bravo-Ureta (1994) for the peasant farmers in Eastern Paraguay, where he found evidence that credit had a positive impact on technical efficiency. Other studies consistent with this finding include: Awudu and Eberlin (2001) in Nicaragua; Carter (1989) on peasant productivity in Nicaragua; Awudu and Huffman (2000) on rice farmers in Ghana.

Use of tractors in land preparation reduces technical inefficiency. The variable is statistically significant at one percent. Compared to use of manual labor, use of tractors allows deep tillage of the soil that enhances yield. In addition, tractors use ensures timely land preparation, planting and weeding. This finding is consistent with findings by Awudu and Elberlin (2001).

The negative sign on the years of school variable indicates that an increase in the number of school years decreases technical inefficiency; this relationship is significant at the one percent level. However, when years of schooling are squared (Schsq), the quadratic structure of age is negative implying that farm technical inefficiency increases with an increase in the number of school years of the household head. (See Figure 4.3 on the point of inflection)

The inflection point (the point at which technical inefficiency starts to increase) is after 5 years of school. Therefore this reveals level that a level of education equivalent to elementary school is sufficient for a maize producer to make informed decision and improve production efficiency. This could probably be explained by the fact that very high education (University and college) attenuates the desire for farming and therefore, the farmer probably concentrates on salaried employment instead. This finding is consistent with results from other studies (for example, Awudu, *et al*.,(2001) in their study on technical efficiency during economic reform in Nicaragua found that education increases production efficiency). A study by Seyoum, *et al*., (2000) on technical efficiency and productivity of maize producers in Eastern Ethiopia concluded that farmers with more education respond more readily to new technology and produces closer to the frontier output. This finding is also consistent with results on structural adjustment and economic efficiency of rice farmers in Northern Ghana by Awudu and Huffman (2000).



Source:Tegemeo Institute, Kenya, 2004 rural household survey

Figure 4.3 Point of Inflection of Years of School and Change in Technical Inefficiency

Other studies consistent with this study are: Battese *et al.*, (1996) for wheat farmers in Pakistan, Gautum and Alwang (2003) in Malawian tobacco, Battese and Coelli (1995) on paddy farmers in the Indian village of Aurepalle; Liu and Zhuang (2000) on post-collective Chinese agriculture; Jayashinghe and Takashi (2000) on tea holdings in Sri-Lanka and Khairo and Battese (2005) in Harari region of Ethiopia. From these results, it can be concluded that a maize producer does not need too much education to know the correct amount of fertilizer to be applied, correct seed rate and general management of the farm, but some is useful.

In addition, the coefficient on the interactive dummy on years of school and credit is negative and significant at one percent suggesting that educated farmers without a credit constraint are more efficient than their counterparts who face credit constraints.

Awudu and Huffman (2000) made a similar same conclusion on the efficiency of rice farmers in Northern Ghana.

The coefficient on the male-headed household variable is negative but statistically insignificant. This could probably be explained by the fact that the male-headed households have greater access to credit, probably because of cultural prejudice, and hence men are closer to the frontier. In addition, men are most likely to attend the agricultural extension training seminars. However, the reason for the unexpected insignificance could also be due to an assumption made in this study, that the head of the house is the decision maker in a family's farming practices. Future studies should probably include a variable on the decision maker of the household.

The positive and significant coefficient of the off-farm income variable indicates that farmers engaged in off-farm income earning activities tend to exhibit higher levels of inefficiency. The positive relationship suggests that involvement in non-farm work are accompanied by reallocation of time away from farm related activities, such as adoption of new technologies and gathering of technical information that is essential for enhancing production efficiency. Other researchers that made similar finding are: Huffman (1980); Awudu and Eberlin (2001); Liu and Zhung (2000). However, for the Kenyan maize farmers an interaction between off-farm income and education variables is negative, an indication that educated farmers that generate off-farm income tend to exhibit higher technical efficiency levels in maize production. Such farmers are not financially constrained and can therefore purchase the required inputs for maize production. In addition, they have sufficient education to enable them to make timely decisions on the allocation of farm inputs and general farm management. Educated farmers are better managers; therefore, they produce closer to their production frontier.

The dummy variable for age is also negative, suggesting that younger farmers, who are less than 50 years, are more efficient than the older ones. The reason for this is probably because the age variable picks up the effects of physical strength as well as farming experience of the household head. Although farmers become more skillful as they grow older, the learning by doing effect is attenuated as they approach middle age, as their physical strength starts to decline (Liu and Zhung, 2000). Similar conclusions were made by Awudu and Huffman (2000).

The variable capturing the illness of the household head in the last three month prior to the date of the interview is positive. However, this relationship is not statistically significant, probably because only 8 percent of the households reported an illness of the household head or spouse. The positive sign suggests that illness in a household head or spouse increases the level of technical inefficiency. Kenya is country where diseases such as malaria and acquired immune deficiency syndrome (AIDS) are very prevalent. Although this study cannot justify the existence of either of the above diseases, it is important to note that sickness in the household reduces technical efficiency in maize production. Family illness results to labor shortage thus causing relocation of investment from maize production to medical treatment, which threatens maize production and food security.

Finally, the coefficient on the dummy variable for the high potential maize zone is negative and statistically significant at one percent. This suggests that producers in this region are less inefficient and closer to their production frontier than their counterparts in medium and low maize potential region. Probably, this could be explained by the favorable climate for maize production in the high potential maize zones. On the other hand, the dummy variable for the low potential region is positive, indication that maize producers in the low potential regions are inefficient. In order to avoid the dummy variable trap, the medium potential region is captured by the intercept (constant) variable, in this case the intercept is positive and therefore shows that, technically producers in the medium potential regions are less efficient than those in the high potential.

4.8 Marginal Effects

The estimated parameters on the inefficiency model presented in Table 4.11 only indicates the direction of the effects that the variables have on inefficiency levels (where a negative parameter estimate shows that the variable reduces technical inefficiency). Quantification of the marginal effects of these variables on technical efficiency is possible by partial differentiation of the technical efficiency predictor with respect to each variable in the inefficiency function. In their article, Battese and Coelli (1993) show that for the *i*-th firm in the *t*-th time period, technical efficiency is predicted using the conditional expectation.

$$TE_{it} = E[\exp(-\mu_i)\mathrm{I}E_i = e_i]$$

$$= \exp(-\mu_* + \frac{1}{2}\sigma_*^2)\left(\frac{\Phi[(\mu_*/\sigma_*) - \sigma_*]}{\Phi(\mu_*/\sigma_*}\right) \tag{17}$$

Where

$$\mu_* = (1-\gamma)z_{it}\partial - \gamma\varepsilon_{it}$$

$$\sigma^{2}{}_{*} = \gamma(1-\gamma)\sigma_s^2$$

$$\gamma = \frac{\sigma_u^2}{\sigma_s^2},\ \sigma_s^2 = \sigma_u^2 + \sigma_v^2$$

$\varepsilon_i = v_i - \mu_i$ and Φ represents the distribution of the standard normal random variable. Table 4.13 presents results of partial differentiation of equation (17) with respect to each of the inefficiency variables, evaluated at their mean values or with a value of one for dummy variables and where the residuals e_t are calculated at the mean values of the dependent and independent variables in the stochastic frontier function (Wilson, *et al.*, 2001). Details of the partial differentiation are in the appendix.

Table 4.13 shows the marginal effect of the efficiency measuring variables (this table is interpreted differently, a positive sign indicate an increase in TE). For variables constructed as a dummy variable, the coefficient estimated represents a one-off shift in efficiency rather than a true marginal effect. Producers who use hybrid maize seed are 36 percent more efficient than those that do not, ceteris paribus.

This is equivalent to an increased yield of 6 bags. As seen earlier on from the descriptive statistics, most maize producers use a seed rate close to the recommended 10-kilogram. Therefore, in order to increase the yield, they probably need to improve the quality of maize seeds rather than the quantity of seed. Mechanizing farming operations is a very important step toward increasing production efficiency, in this case, producers that use tractors increase the level of technical efficiency by 26 percent, and this can be converted to approximately 4 bags of maize per acre.

Table 4.13 Marginal Effects of the Efficiency Measuring Variables

Variable	Change in TE	Change in TE in %	Change in bags per acre
PURCHYBR***	0.3632	36.32	6.14
TRACTOR***	0.2612	26.12	4.41
SCHYRS*	0.0084	0.84	0.14
SCHSQD***	-0.0017	-0.17	-0.03
MALEHEAD	0.0918	9.18	1.55
HEADILL	-0.0847	-8.47	-1.43
AGEDUM	0.0005	0.05	0.01
OTHERINC	-0.0145	-1.45	-0.24

Source:Tegemeo Institute, Kenya, 2004 rural household survey

The marginal change (gain in TE) for an additional year of school is 0.84 percent. This translates to 0.14 bags (or 13 kilograms). However, this change in TE increases at a decreasing rate of 0.17 percent. Male-headed households have a marginal effect of 9.18 percent TE. Though illness of the household head was not statistically significant, the marginal effect is 8.47 percent. Younger maize producers (less than 50 years old) are 0.05 percent technically more efficient than the older producers. Finally, participation in off-farm income earning activity reduces technical efficiency by 1.45 percent.

In conclusion, differences in technical efficiency can be explained by differences in use of inputs especially fertilizer. In addition, Table 4.14 shows some of the possible reasons for the differences between the technically efficient and inefficient producers. The least efficient maize producers have the lowest percent use of hybrid maize seed (33%), lowest percent that received credit (17%), highest percent of households involved in off-farm income (69%), lowest number of young household heads (29%) and the highest number of ill head of household (9%).

Table 4.14 Selected Reasons for Differences in Technical Efficiency

TE	Purchased hybrid %	Credit %	Female headed %	Off-farm income %	Ill head %	Intercrop %	Less than 50 years	HH size, number	% of family labor	Annual Income Ksh
0 -19	33	17	27	69	9	96	29	5	72	113,225
20 -39	36	22	19	70	9	96	39	5	75	141,417
40 -59	61	28	16	68	8	95	39	6	66	177,944
60 -79	82	27	11	66	3	91	44	6	59	232,628
>80	99	19	7	68	8	86	43	6	39	374,590

Source:Tegemeo Institute, Kenya, 2004 rural household survey

However, they had the lowest household size (5 persons) although this cluster provided the highest amount of family labor (72 %). In addition, the least efficient producers have the least annual household income of Ksh. 113, 225 or Ksh 62 per day. This is equivalent to less than $1 per day, the value that defines the poverty line in Kenya.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study set out to provide estimates of technical efficiency in Kenyan maize production and to explain variations in technical efficiency among farms through managerial and socio-economic characteristics. Farm specific technical efficiencies are computed using 2003/2004 maize production cross sectional data from the Tegemeo Institute of Agriculture Policy and Development. A stochastic frontier approach is used to generate technical efficiency estimated using Limdep (Green, 2002). Different production functional forms including; translog, Cobb-Douglas, quadratic and transcendental production functions were considered.

Results showed that the mean technical efficiencies generated from the above functions are almost identical. This is consistent with Koop and Smith (1980) and Ahmad and Bravo-Ureta (1996), who concluded that functional form has a discernible, but rather small impact on estimated efficiency. However, the above conclusion contradicts Thiam, *et al.*, (2001) in the Meta analysis of technical efficiency in developing countries. They concluded that the Cobb-Douglas production function generally generates lower technical efficiency, therefore implying that a more restrictive functional form leads to lower average TE.

In order to avoid biased results, the model is corrected for heteroscedasticity. In addition the orthogonality condition (a zero covariance between independent variables and the error term) is imposed. Results show that the overall mean technical efficiency is estimated at 49 percent. Therefore, there is a 51 percent scope for increasing maize production by using the present technology. However, TE ranges between 8 to 98 percent among the maize producers in Kenya.

A significant variation is observed in the mean level of technical efficiency in the three regions. The high potential region achieved the highest TE of 64 percent, for the medium potential a 47 percent TE is achieved, while the low potential maize producers achieve only a 37 percent TE. Further disaggregation of TE shows that farmers practicing maize mono-crop system in the high and low potential regions are more efficient than those that practice maize intercrop. However, there is little difference between maize production systems in the medium potential region. In addition to interregional differences in TE, there exists intra-farm efficiency within a region. This is an indication that the efficient and inefficient maize producers coexist in the same environment in a given region. 22.5 percent of maize producers in the high potential, and 1 percent of the farmers in the medium potential regions exhibit the highest TE of over 80 percent. Maize producers in the low potential region have TE below 80 percent.

One of the marked differences in determining inter-farm difference in TE is input use. From this study, the most efficient farms yield 21 bags of maize per acre. In order to achieve this yield 65 kilograms of fertilizer, 9.63 kilograms of seed and 61 person-days are used. The main difference between the technically efficient and least inefficient (less than 20 percent TE) is the use of input use and yield. The least efficient yield averages

1.5 bags. This is obtained by applying 23 kilograms of fertilizer per acre, 10 kilograms of seed and 68 person-days. Use of more labor by the least efficient producers is an evidence of substitution of labor as a factor of production. Labor is substituted for fertilizer because it is readily available.

Elasticity of inputs is computed. A one percent increase in fertilizer is estimated to increase yield by 0.17 percent. In addition, a one percent increase in seed rate increases yield by 0.63 percent, while an increase in labor by one person-day will probably increase yield by 0.46 percent. A prior expectation was that maize yield is more responsive to fertilizer use than seed rate. The descriptive statistics shows a mean seed rate of 9.11 kilograms, a value that is very close to the recommended 10 kilograms per acre. However, results from the translog production function show that the second derivative of the variable seed is negative, (i.e. seed squared) is an indication that an increase in use of seed will increase yield but at a decreasing rate.

There is lower responsiveness of yield to an increase in fertilizer. One possible explanation is probably because some maize producers, and in particular, those in the tea growing zones use the more readily available tea fertilizer (NPK) as planting and topdressing fertilizer in maize. Therefore, use of the inappropriate fertilizer has negligible effect in raising maize yield. In addition, the issue of poor timing of fertilizer application could be another contributing factor to low responsiveness of yield to fertilizer.

The marginal value product (MVP) and unit factor price are equated to check the optimal use of inputs. Results show that maize farmers are operating at the second stage of production. For the fertilizer and seed inputs the MVP is greater than the unit factor price. This is an indication that the maize producer can still benefit by increasing fertilizer and seed use. However, for labor the MVP almost equals the unit factor price and therefore an additional labor inform of a person-day will not result in production gains. In short, labor is being used optimally.

Household characteristics have been evaluated and the marginal effects estimated. Results show that use of purchased hybrid seed, use of tractors for land preparation, level of education, an interaction of off-farm income and education, purchase of hybrid seed on credit, younger age of the household heads and households in the high potential areas are associated with a higher technical efficiency. Clearly, as noted by Hadley *et al*., (1988), the explanatory variables included here, although indicating the importance of management factors, do not fully capture the extent to which management can explain variation in technical efficiency of maize production. Future studies could probably include variables that address the decision maker in maize production rather than the assumption that the household head is the decision maker in farm decisions. In addition, a quantification of number of visits by an agricultural extension agent and field level soil type could improve the precision of measurement of TE.

The potential yields have been estimated. The most efficient producers in the high potential region have a mean yield potential of 25 bags per acre, within the standard deviation of 6.67 bags per acre. Those in the medium potential region have a mean yield potential of 19.93 bags and standard deviation of 12 bags per acre while the low region has a mean yield potential of 17.57 bags per acre, the standard deviation of 7 bags per acre exists.

Finally, calculation of marginal effects has shown that use of hybrid seed increase technical efficiency by 36 percent from the current 49 percent. In addition, mechanizing maize farms increase TE by 26 percent. In addition, an additional year of school is projected to increase the level of TE by 0.84 percent. However, this increase is quadratic; so the increase in TE reaches a maximum after 5 years of education after which it increases at a decreasing rate. Finally, the technically inefficient producers make the lowest annual income that translates to less than a one US dollar a day; therefore, this is the poorest cluster.

5.2 Recommendations

As noted in the literature review, in the last ten years, Kenya has undergone a transformation from a maize exporting to an importing country. Kenya has lost its competitiveness in maize production to the neighboring regions due to the high cost of maize production (Nyoro, 2004). One of the most important avenues for reducing production cost is to increase yield per unit area by increasing technical efficiency. This study has concluded that increased input use (i.e. seed and fertilizer) and a household's characteristics impact yield across and within regions. Given the empirical findings, the proposed recommendations are:

(1) This study has shown that use of agricultural credit to purchase hybrid seed reduces technical inefficiency and thus shifts the actual production frontier closer to the potential frontier. Credit is necessary to encourage technical innovations, such as use of yield-enhancing inputs, which cost slightly more, but shifts production, transforming the entire input-output relationship. Small farm producers in developing countries appear to be unresponsive to apparently economical justified technical innovations because probably due to risk attitudes

and liquidity constraints. At the subsistence level where sheer survival is at stake, risk-averse producers are likely to prefer the traditional technologies that may promise a higher average yield with lower variance to new technologies that may require a higher average yield but also present the risk of greater variance (Todaro, 1997). The farmers are also risk averse because of uncertainty in repayment and high interest rates.

From this study, one could conclude that only 24 percent of farmers received credit during the 2003/2004 main harvest-cropping season. Most of those who obtained credit were in the medium potential and high potential regions, where credit availability targets producers of industrial tradable crops such as tea, sugarcane, and coffee. As mentioned earlier, in the early 1960's, the private commercial banks were required by law to disburse 17 percent of loans to agriculture (Kodhek, 2004). Currently agricultural lending by commercial banks stands at only 5.35 percent of the total lending portfolio.

The Kenyan farming credit system collapsed in the early 1990's following a wave of liberalization, where farmers who had been given credit sold their produce to new entrants, and thus advanced loans were never recovered. In addition, the collapse of the Agricultural Finance Corporation (AFC), the body mandated to provide credit, damaged access to credit. The main deterrent to borrowing credit is high interest rates as the annual percent rate ranges between 12 to 65 percent for commercial banks and village banks, respectively (Kodhek, 2004).

The government should probably influence borrowing rates on credit and loans so as to spur agricultural development. Currently, commercial banks are trying to incorporate farmers in their clientele base by designing products suitable for agriculture. Barclays Bank has introduced the Structural Commodity Finance product targeting wheat farmers, while the Kenya Commercial Bank has developed a '*Mavuno*' product that advances credit against agricultural produce delivered to reputable buyers.

Another government intervention is to streamline the operation of mushrooming microfinance institutions (MFIs) and village banks. Further analysis of the Tegemeo data set shows that large companies, such as sugar, tobacco and tea companies, provide 51 percent of Kenya's agricultural credit, through inputs. The co-operative societies provide 35 percent of credit, while the informal moneylenders provide 5.3 percent of credit. The MFIs are curving out a niche in the credit market and have a high market share (3.0 percent) compared to the commercial bank's market share (2.7 percent). However, if the government is serious about revitalizing the agricultural sector through credit, it needs to increase the allocated revenue to AFC from a mere Ksh. 1.5 billion (0.003 percent of all total government budget 2006/2007) to an estimated Ksh. 60 billion.

(2) Based on the findings of this study, an effort to emphasize primary schooling will have a positive impact on the TE in maize production, yet schooling is not susceptible to change in the short-run. Since 2003, the Kenyan Government has supported free primary education. If this education policy is sustainable, future maize producers could reap benefits of education in the form of increased maize

production. The Kenyan government has continued to support free education policy. For example in the 2006/2007 financial year, education was allocated the highest amount of Kenya shillings 96.6 billion or 19 percent of all government revenue. However, since the benefits of education are not instantaneous, the government should consider focusing on educating current farmers in best production practices. Non-formal agricultural education, often provided by both public and private extension services, is needed for training of farmers, farm families and workers and for capacity building in a wide range of rural organizations and groups. To meet the challenges of agricultural production and food security facing Kenya today and in the 21st century, the country must be willing to invest in their human capital for development.

Currently, the Kenya Maize Development Program (KMDP) boosts household incomes by raising productivity, improving the effectiveness of smallholder organizations and increasing access to agricultural markets and business support services. Led by ACDI/VOCA, the program involves a diverse consortium of partners within the maize value chain, including the Cereal Growers Association of Kenya, Farm Input Promotions Africa Ltd (FIPS) and the Kenya Agricultural Commodity Exchange. Practical on-farm training on the use of improved varieties of maize seed and fertilizer and practices, such as conservation tillage, through collaboration with the Ministry of Agriculture and other stakeholders. The improvement of a country's human resource capacity for productivity is a pre-requisite for social and economic development. In the agricultural sector, both formal and non-formal education is essential for improving food security and rural employment and reducing poverty. Formal agricultural education is needed for the production of skilled manpower to serve the agricultural sector through extension, research, entrepreneurship and commerce.

(3) The study has shown that male-headed households are more efficient than female-headed households. The FAO estimates that, in Sub-Saharan Africa as a whole, 31 percent of rural households are headed by women, mainly because of the tendency of men to migrate to cities in search of wage labor. Despite this substantial role, women have less access to land than men. When women do own land, the land holding tends to be smaller and located in more marginal areas. Rural women also have less access to credit than men, which limits their ability to purchase seeds, fertilizers and other inputs needed to adopt new farming techniques.

Only 5 percent of the resources provided through extension services in Africa are available to women, although in some cases, particularly in food production, African women handled 80 percent of the work. The Kenyan government should address the concerns and needs of women, with focal points in the ministries of agriculture and other key institutions. Among other things, the government should set a law that stresses the equality of men and women in obtaining land titles.

5.3 Suggestions for Further Research

There are a number of directions in which this study can be extended.

This study only focused on the technical efficiency of the maize in the largest maize fields. An extension could be to analyze all the maize fields of a farm. In addition, the study focused on technical efficiency, but a study on allocative efficiency would probably give more insight to the efficiency studies. It would also be interesting to look at technical efficiency and allocative efficiency using panel data from Tegemeo Institute to see evaluate how technical efficiency has changed over time. In redesigning the above possible studies, variables such as the gender of the decision maker and the number of times a household has received agricultural extension could be considered.

REFERENCES

Ahmed, M. and Bravo-Ureta, B. 1996. "Technical Efficiency Measures for Dairy Farms Using Panel Data: A Comparison of Alternative Model Specification." *Journal of Production Analysis,* 7: 399-416.

Aigner, D.K., C.K.Lovell, and P. Schmidt. 1977. "Formulation and Estimation of Stochastic: Frontier Production Function Models." *Journal of Econometrics,* 6:21-37.

Average Maize Yield in Metric Tonnes for Selected Countries, 1961-2004, www.http://faostat.fao.org/faostat/

Awudu, Abdulai and Richard Eberlin. 2001. "Technical Efficiency during Economic Reform in Nicaragua: Evidence from Farm Household Survey Data." *Economic Systems,* 25: 113-125.

Awudu, Abdulai and Wallace Huffman. 2000. "Structure Adjustment and Economic Efficiency of Rice Farmers in Northern Ghana." *Economic Development and Cultural Change*, 503-519.

Battese, G.E and T.J. Coelli. 1995. "A model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data." *Empirical Economics* 20:325-332.

Battese, G.E , Sohail J. Malik and Manzoor A.Gill. 1996. "An Investigation of Technical Inefficiencies of Production of Wheat Farmers in Four Districts of Pakistan." *Journal of Agricultural Economics*, 47 (1): 37-49.

Bedassa, Tadesse and S. Krishnamoorthy. 1997. "Technical Efficiency in paddy Farms of Tamil Nadu: An Analysis Based on Farm Size and Ecological Zone." *Agricultural Economics,* 16 :185-192.

Belen, Iraizoz, Manuel Rapun and Idoia Zabaleta. 2003. "Assessing the Technical Efficiency of Horticultural Production in Navarra, Spain." *Agricultural Systems,* 78:387-403.

Bravo-Ureta, B. and A. Pinheiro. 1993. "Efficiency Analysis of Developing Country Agriculture: A Review of the Frontier Function Literature." *Agriculture and Resource Economics Review* **22**(1), 88-101.

Bravo-Ureta, B.E.and Robert. E. Evenson. 1994. "Efficiency in Agricultural Production: A Case of Peasant Farms in Eastern Paraguay." *Agricultural Economics,* 10:27-37.

Byerlee, Derek. 1997. *Africa Food Crisis*, Lynee Reinner Publishers Inc, London.

Carter, M.R. 1989. "The Impact of Credit on Peasant Productivity and Differentiation in Nicaragua." *Journal of Development,* 31:13-36.

Economic Survey, 2003. Kenya.

Farrell, M.J. 1957. "The Measurement of Productive Efficiency." *Journal of the Royal Statistical Society* (A, general) 120, pt.3, 253-281.

Gautam, Hazarika and Jeffrey Alwang. 2003. "Access to Credit, Plot Size and Cost Inefficiency among Smallholder Tobacco Cultivators in Malawi." *Agricultural Economics,* 29: 99-109.

Gerhart, J. 1975. *The Diffusion of Hybrid Maize in Western Kenya*. Mexico city. International Maize and Wheat Improvement Center (CIMMYT).

Green, W.H. 2002. *Limdep Version 8.0: Econometric Modeling Guide*. Econometric. Software, Inc, Plainview, New York.

Greene, W.H. 1980. "Maximum Likelihood Estimation of Ecometrics Frontier Functions." *Journal of Econometrics,* 13:27-56.

Greene, W.H. 1993. *The measurements of Productive Efficiency: Techniques and Applications*, Oxford University Press, Oxford, pp 68-119.

Gujarati, D.N. 2003. *Basic Econometrics*, 4th ed. McGraw-Hill, New York.

Halvorsen, Robert and Raymond Palmquist. 1980. "The Interpretation of Dummy Variables in Semi logarithmic Equations." *American Economic Review*, Vol. 70, Issue 3, Pages 474-75.

Ingosi, Abner. 2005. *Economic Evaluation of Factor Influencing Maize Yield in the North Rift Region of Kenya.* Masters of Science Thesis, Colorado State University.

Jayashinghe, J.M.J.K., and Takashi Toyada. 2000. "Technical Efficiency of Organic Tea Smallholdings Sector in Sri-Lanka: A Stochastic Frontier Analysis." *International Journal of Agricultural, Governance and Ecology* Vol 3. No ¾

Jayne, T.S., T. Yamano, J. Nyoro, and T. Awour. 2001. *Do Farmers Really Benefit From High Food Prices Balance Rural Interests in Kenya's Maize Pricing and Marketing Policy*. Working Paper 2b, Tegemeo Institute, Nairobi, Kenya.

Jayne, T.S., and Gem Argwings-Kodhek. 1997. "Consumer Response to Maize Market Liberalization in Urban Kenya." *Food Policy*,Vol.22.No.5.

Karanja, D.D., Thomas S. Jayne, and Paul Strasberg. 1998. *Maize Productivity and Impact of Market Liberalization in Kenya*, Tegemeo Working Paper.

Karanja, D.D. 1996. *An Institutional and Economic Analysis of Maize Research in Kenya.* MSU International Development Working Paper, No.57, East Lansing: Michigan State University.

Karanja, D. D. and A. G. O. Oketch. 1992. *The Impact of Maize Research in Kenya. In Proceedings of a Workshop. Review of the National Maize Research Program. KARI/ISNAR*. Management Training Linkage Project. 100pg.

Khairo, S.A. and G.E. Battese. 2005. "A Study of Technical Inefficiencies of Maize Farmers Within and Outside the New Agricultural Extension Program in the Harari Region of Ethiopia." *South African Journal of Agricultural Extension*, 34.

Kodhek, G.A. 2003. *Feast and Famine: Financial Services for Rural Kenya*, Working Paper, Tegemeo Institute.

Koop, R.J., V.K. Smith. 1980. "Frontier Production Function Estimates for Steam Electric Generations:A Comparative Analysis." *Southern Economic Journal,* 47:1049-1059.

Liu Zinan and Zhuang Juzhong. 2000. "Determinants of Technical Efficiency in Post-Collective Chinese Agriculture: Evidence from Farm-Level Data." *Journal of Comparative Economics,* 28: 545-564.

Map of Kenya, http://www.appliedlanguage.com/maps_of_the_world/map_of_kenya.shtml

Meeusen,W. and J. Van den Broeck. 1977. "Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error." *International Economics Rev*., 18:435-444.

Miracle, M. 1966. *Maize in Tropical Africa*. Madison: University of Wisconsin Press.

Mochebelele, M. T. and A.Winter-Nelson. 2002. "Migrant Labor and Farm Technical Efficiency in Lesothi." *World Development* 18(1):143-53.

Nyoro, J. K., Lillian Kirimi and T.S. Jayne. 2004. *Competitiveness of the Kenyan and Ugandan Maize Production: Challenges for Future*. Tegemeo Working Paper.

Nyoro, J. 2002. *Agriculture and Rural Growth in Kenya*, Tegemeo Working Paper.

Nyoro J. K, Mary W. Kiiru and T.S. Jayne. 1999. *Evolution of Kenya's Maize Marketing Systems in the Post Liberalization Era*. Tegemeo Working Paper.

Seyoum, E.T., G.E. Battese, and E.M. Fleming. 1998. "Technical Efficiency and Productivity of Maize Producers in Eastern Ethiopia: A study of Farmers Within and Outside the Sawakawa–Global 2000 Project." *Agricultural Economics* (19): 341-348.

Tegemeo Agricultural Monitoring and Policy Analysis Project. 2004. *Tampa Household Survey Year 2004 Data Collection Manual*. Tegemeo Institute, Page 17.

Todaro, Michael P. 1997. *Economic Development*. London/New York, Longman.

Thiam, Abdourahmane, B. Bravo-Ureta, E.Rivas and E Teodoro. 2001. "Technical Efficiency in Developing Country Agriculture: A Meta-Analysis". *Agricultural Economics* Volume 25, Issue 2-3, Pages: 235-243.

Wilson, Paul, Dave Hadley, Stephen Ramsden, and Loannis Kaltsas. 1998. "Measuring and Explaining Technical Efficiency in UK Potato Production." *Journal of Agricultural Economics,* 48 (3): 294-305.

Wilson, Paul, David Hadley, and Carol Ashby. 2001. "The Influence of Management Characteristics on the Technical Efficiency of Wheat Farmers in Eastern England." *Agricultural Economics* 24: 329-338.

www.fao.org

APPENDICES

Appendix 1 Original Stochastic Frontier and Inefficiency Model for Maize Farmers

Variable	Parameters	Coeff.	Std.Err.	**t-ratio**	P-value
Stochastic Frontier					
constant	ß$_0$	1.8297	0.3323	**5.5061**	0.0000
LNFERT	ß$_1$	-0.1148	0.0481	**-2.3880**	0.0169
LNLABOR	ß$_2$	-0.0770	0.1461	-0.5271	0.5981
LNSEED	ß$_3$	0.3609	0.1290	**2.7978**	0.0051
FERTSQ	ß$_4$	0.0365	0.0060	**6.0361**	0.0000
LABORSQ	ß$_5$	0.0197	0.0189	1.0406	0.2981
SEEDSQ	ß$_6$	-0.0809	0.0275	**-2.9404**	0.0033
FERTLAB	ß$_7$	-0.0024	0.0096	-0.2513	0.8016
FERTSEED	ß$_8$	0.0213	0.0131	**1.6274**	0.1037
LABSEED	ß$_9$	0.0525	0.0349	1.5046	0.1324
MANURE	ß$_{10}$	0.0765	0.0280	**2.7304**	0.0063
Inefficiency Model					
ONE	δ_0	1.5042	0.1475	**10.1997**	0.0000
PURCHYBR	δ_1	-0.3627	0.0660	**-5.4946**	0.0000
TRACTOR	δ_2	-0.3655	0.0918	**-3.9823**	0.0001
SCHYRS	δ_3	-0.0202	0.0133	-1.5236	0.1276
SCHSQD	δ_4	0.0594	0.0798	0.7446	0.4565
MALEHEAD	δ_5	-0.0832	0.0507	**-1.6409**	0.1008
HEADILL	δ_6	0.0662	0.0689	0.9607	0.3367
AGEDUM	δ_7	-0.0003	0.0270	-0.0129	0.9897
OTHERINC	δ_8	0.0515	0.0649	0.7932	0.4276
PCRED	δ_9	0.0987	0.0900	1.0961	0.2730
OFFEDUC	δ_{10}	-0.0066	0.0089	-0.7333	0.4634
CREDAG	δ_{11}	-0.1444	0.0744	**-1.9405**	0.0523
HIGH	δ_{12}	-0.5709	0.1184	**-4.8235**	0.0000
LOW	δ_{13}	0.1768	0.0488	**3.6252**	0.0003
Variance Parameters					
Lambda (σ_u/σ_V)	λ	2.0456	0.2687	**7.6124**	0.0000
Sigma	σ	0.6561	0.0173	**38.0212**	0.0000
σu^2		0.3472			
σv^2		0.0830			
ln (likelihood)		-1733.4000			
Gamma, $\sigma_u2/(\sigma_u2+ \sigma_v2)$	γ	0.807			
TE		**36%**			

Source:Tegemeo Institute, Kenya, 2004 rural household survey

Appendix 2 Calculation of Marginal Effects

For the i-th firm, technical efficiency is predicted using the conditional expectation:

$$\mathrm{TE}_i = E[\exp(-U_i) \mid E_i = e_i]$$

$$= \left\{\exp(-\mu_* + 0.5\sigma_*^2)\right\}\left\{\Phi[(\mu_*/\sigma_*) - \sigma_*]\right\} / \left\{\Phi(\mu_*/\sigma_*)\right\}$$

$$= A(B/C) = AD,$$

where

$$\mu_* = (1-\gamma)z_i\delta - \gamma e_i,$$

$$\sigma_*^2 = \gamma(1-\gamma)\sigma_s^2,$$

$$A = \left\{\exp(-\mu_* + 0.5\sigma_*^2)\right\},$$

$$B = \left\{\Phi[(\mu_*/\sigma_*) - \sigma_*]\right\},$$

$$C = \left\{\Phi(\mu_*/\sigma_*)\right\},$$

and

$$D = \left\{\Phi[(\mu_*/\sigma_*) - \sigma_*]\right\} / \left\{\Phi(\mu_*/\sigma_*)\right\}.$$

We wish to obtain the partial derivative of the technical efficiency measure with respect to the j-th element of the z vector. Now, by the chain rule we have:[10]

$$\frac{\partial \mathrm{TE}}{\partial z_j} = \frac{\partial \mathrm{TE}}{\partial \mu_*}\frac{\partial \mu_*}{\partial z_j}. \tag{1}$$

Furthermore, we have:

$$\frac{\partial \mu_*}{\partial z_j} = (1-\gamma)\delta_j, \tag{2}$$

$$\frac{\partial C}{\partial \mu_*} = \frac{1}{\sigma_*}\phi(\mu_*/\sigma_*) = C',$$

$$\frac{\partial B}{\partial \mu_*} = \frac{1}{\sigma_*}\phi\left[(\mu_*/\sigma_*) - \sigma_*\right] = B',$$

$$\frac{\partial D}{\partial \mu_*} = \frac{CB' - BC'}{C^2} = D',$$

and

---

[10] From this point forward the firm subscript will be dropped.

$$\frac{\partial A}{\partial \mu_*} = -A = A'.$$

Using these results we obtain:

$$\frac{\partial TE}{\partial \mu_*} = AD' + DA' = A(D' - D)$$

$$= A\left\{\left[\frac{CB' - BC'}{C^2}\right] - \frac{B}{C}\right\}$$

$$= \frac{A}{C^2}(CB' - BC' - CB)$$

Thus, using this result and equations (1) and (2) we obtain:

$$\frac{\partial TE}{\partial z_j} = \frac{A}{C^2}(CB' - BC' - CB)(1-\gamma)\delta_j.$$ (Tim Coelli, 2001[11])

---

[11] An adjusted version of the cost function case by Scott .W. Frame and Tim.J.Coelli, .2001. “U.S. Financial Services Consolidation: The Case of Corporate Credit Unions”, *Review of Industrial Organization* **18:** 229–242, 2001.