ANALYSIS OF PRODUCTION EFFICIENCY IN IRISH POTATO PRODUCTION IN KENYA: THE CASE OF NYANDARUA NORTH DISTRICT

By

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DECLARATION AND RECOMMENDATION

DECLARATION

I declare that this thesis is my original work and has not been presented for the award of any degree in any university.

Signed:……………………………….

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Date………………………………….

RECOMMENDATION

This thesis has been submitted with our approval as university supervisors.

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DEDICATION

Dedicated to my loving mother and father.

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ABSTRACT

During the past two decades, agricultural scientists in Kenya in collaboration with International Potato Centre have released numerous new varieties, developed improved Irish potato management practices, and actively worked with government agencies, NGOs and farmer groups to ensure that these improved technologies are widely available to farmers. However data on national Irish potato production in Kenya fail to demonstrate that these efforts have had an impact on national mean yields. Trends in national Irish production show that in the last twenty years there has been no significant increase in average national yields and hence productivity. Using farm-level data collected from 127 farmers through multi-stage sampling technique, this study employed a stochastic parametric decomposition and neoclassical duality model to estimate the technical, allocative and economic efficiency of a sample of Irish potato producers in Nyandarua North district. To elicit information on these aspects, a Cobb-Douglas production frontier was specified and estimated by using Maximum Likelihood techniques. The estimated production frontier was used to derive the dual cost frontier. These two frontiers were used to derive farm-level efficiency measures. In addition a two-limit Tobit analysis was used to determine socio-economic and institutional factors that influence economic efficiency of Irish potato producers in the study area. Results reveal that smallholder Irish potato farmers are inefficient; the average efficiency scores are 66.7 percent, 57.3 percent and 38.1 percent for technical, allocative and economic efficiency respectively. The two-limit Tobit results indicate that education level of the household head (number of years of formal schooling), contact with extension, use of credit in Irish potato production, and membership in a farmers' association are significant factors for improving the level of efficiency. There is need to expand farmer education complimented by quality and effective extension service on improved agronomic and management practices. Innovative ways need to be devised that will ensure that farmers are enabled to access credit at a reasonable cost.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AE	Allocative Efficiency
ADC	Agricultural Development Corporation
CD	Cobb-Douglas
CEE	Cost of Economically Efficient input vectors
COB	Cost of Observed inputs
COLS	Corrected Ordinary Least Squares
CTE	Cost of Technically efficient inputs
CIP	International Potato Centre
CMAAE	Collaborative Masters in Agricultural and Applied Economics
DEA	Data Envelopment Analysis
EE	Economic Efficiency
FAO	Food and Agriculture Organization
FFS	Farmer Field School
GDP	Gross Domestic Product
GOK	Government of Kenya
KARI	Kenya Agricultural Research Institute
KENAPOFA	Kenya National Association of Potato Farmers
Ksh	Kenya shillings
LLF	Log-likelihood Function
LLR	Log-likelihood Ratio
ML	Maximum Likelihood
MoA	Ministry of Agriculture
MoNPD	Ministry of National Planning and Development
NGO	Non-Governmental Organization
OLS	Ordinary Least Squares
SSA	Sub-Saharan Africa
TE	Technical Efficiency
Translog	Translogarithmic Function

CHAPTER ONE

INTRODUCTION

1.1 Background

Meeting the ever-growing demand for food remains a major challenge for world agriculture (Bhasin, 2002). Sub-Saharan Africa (SSA) is the only region of the world where per capita food production has steadily declined over the past two decades and where agricultural output has grown annually by an average of less than 1.5%, with food production increasing at a slower rate than the population growth (FAO, 2000). This greatly undermines the food security situation of the sub-region.

To address the world food challenges the adoption of new technologies designed to enhance farm output and income has continued to receive particular attention as a means to accelerating economic development (Hayami and Rutan, 1985). The focus of researchers and policy makers has mainly been on the impact of adoption of new technologies on farm productivity and income. However, output growth is not only determined by technological innovations alone but also by efficiency with which available technologies are used. In the last decade major technological gains have been largely reduced across the developing world and specifically in Africa because of lack of complementary inputs such as fertilizers, irrigation and pesticides (Bagaba, 2007). This suggests attention to productivity gains arising from efficient use of existing technologies is justified.

The need to increase agricultural productivity and employment in sub-Saharan African countries has received widespread attention in the literature on economic development and poverty alleviation (Abdulai and Huffman, 2000). An effective economic development strategy depends critically on promoting productivity and output growth in the agricultural sector, particularly in the smallholder subsector (Bravo-Ureta and Pinheiro, 1997). With persistent population growth, a dwindling supply of arable land per capita, and the relatively high income elasticity for food demand in developing countries, there is a growing need for food supply increases that originate from growth in productivity rather than expansion in inputs (Alauddin et al., 2005). According to Bhasin (2002) expected increases in agricultural demand associated with population growth and rising per capita incomes will require continuing increases in agricultural productivity. Moreover if farmers are not making efficient use of the existing technology then efforts designed to improve efficiency would be more cost effective than introducing new technologies as a means of increasing agricultural output (Belbase and Grabowski, 1985). This implies that increased productivity would require the effective use of available technology.

Obwona (2000) observes that the importance of the efficient use of available technology is seldom realized by policy makers as they erroneously assume that farm-owners can operate the existing technology efficiently, but cannot make a rational choice among the various technologies. Thus unless the potential of an existing technology is completely exploited, benefits from new technologies may not be fully realized. The thrust of most agricultural development agents has been in trying to identify and suggest ways to eliminate the constraints on the adoption of new technologies. From a long-run policy viewpoint, it is imperative to examine how effectively and efficiently farmers, given the current technology, apply the technology at farm level.

Efficiency in production may be defined as how effectively a firm uses variable resources for the purpose of profit maximization given the best production technology available. The efficiency of a firm or production unit can be measured in terms of technical and allocative efficiency. Technical efficiency refers to the maximum attainable level of output for a given level of production inputs while, allocative efficiency refers to the ability of a farm to use inputs in optimal proportions given their respective prices (Battese, 1992).

Agriculture remains an important sector for the Kenyan economy. The primary agricultural sector generates approximately 75% of rural employment, accounts for 25% of total GDP and represents 60% of the value of the country's exports (MoA, 2007). Furthermore, agriculture and its related economic activities are particularly critical for the development of Kenya's rural economy. Agriculture contributes to the achievement of national food security; about 80% of the Kenyan population live in the rural areas and derive their daily livelihoods largely from agricultural related activities (Alila and Atieno, 2006).

During the 1963-1983 period, the agricultural sector grew steadily recording some of the most impressive growth rates in Sub-Saharan Africa (SSA) at an average growth rate of 6% per annum (MoA, 2004). However over the 1996-2000 period, the performance of the agricultural sector registered a declining trend with growth declining from 4.4% in 1996, to 1.5% in 1999 and to an all time low of negative 2.4% in 2000 (MoA, 2006). Agriculture, which is the driver of the economy grew significantly from negative 3% in 2003 to 5.4% in 2006 (GoK, 2008).

According to the *Strategy for Revitalizing Agriculture* (SRA) (MoA, 2004), declining performance of the sector in terms of growth has been one of the major concerns facing policy makers. As a sector that engages about 75% of the country's labour force, such a decline implies lower levels of employment, incomes and more importantly food security for a vast majority of rural Kenyans. It is recognized that low land productivity, is among the main sources of high unit production costs in agriculture in Kenya (Alila and Atieno, 2006). The overriding goal of SRA is to achieve a progressive reduction in unemployment and poverty, the two major challenges that Kenya continues to face (MoA, 2006). The role of Irish potato sub-sector in the matrix of challenges cannot be overemphasized.

Irish potato is the second most important food crop after maize because of its ability to grow in high altitude areas where maize does not do well and its high nutritive value. Being labour intensive, the crop generates employment in production, marketing and processing sectors (Gildemacher et al., 2006; MoA, 2004). In addition, it is an important food crop for many Kenyan smallholder farmers; it plays a major role in national food security and its demand has continued to increase over the years especially by urban consumers (MoA, 2007). The crop is therefore important to agricultural policy decisions, food security, and overall development of the agricultural sector and the economy.

Irish potatoes in Kenya are cultivated in intensive, small-scale agriculture in the highlands of the country, which are characterized by cool temperatures with high rainfall of at least 800mm per annum at altitudes ranging between 1500 and 3500mm above sea level (Kinyae et al., 1996). These areas include the slopes of Mt. Kenya (Meru , Embu, Kirinyaga, parts of Laikipia, Nyeri); both sides of the Aberdare range covering parts of Nyeri, Murang'a, Maragua, Thika, Kiambu and Nyandarua North and South districts; the Mau Escarpment (Narok, Nakuru, Molo, Bomet, Uasin Gishu, Koibatek districts); Nandi South and North districts; and parts of Trans Nzoia, Mt Elgon, Keiyo and Marakwet districts. Small acreages are cultivated in Kericho, Kisii and Taita Taveta districts (MoA, 2004). In some of these areas Irish potato ensures food security and provides income to many households through sales.

There are approximately 500,000 growers cultivating over 100,000 hectares with an annual production of about 1 million tonnes in two growing seasons (MoA, 2006). The Irish potato sector indirectly employs about 2.5 million people as transporters, processors, vendors and retailers (MoA, 2004). Per capita consumption is at 40kg/person (Lung'aho et al., 2006).

Over the years, Irish potato production in Central province has averaged 412,700 tonnes per year from an average of 57,650 hectares. It is the leading producer both in acreage and volume in the country and it accounts for about 51.5% of national Irish potato production in Kenya. Rift Valley province follows with an annual average production of 228,230 tonnes from 27,138 hectares while average production from Eastern province is 160,725 tonnes from 22,315 hectares (MoA, 2004).

Kenya produces 0.3% of the world's total production and 6.5% of Africa's production (MoA, 2004). Trends in production and area planted to Irish potatoes in Kenya are shown in Figure 1. The area and total production has been increasing over the year but no significant increase in Irish potato yield over the 1961-2005 period was realized.

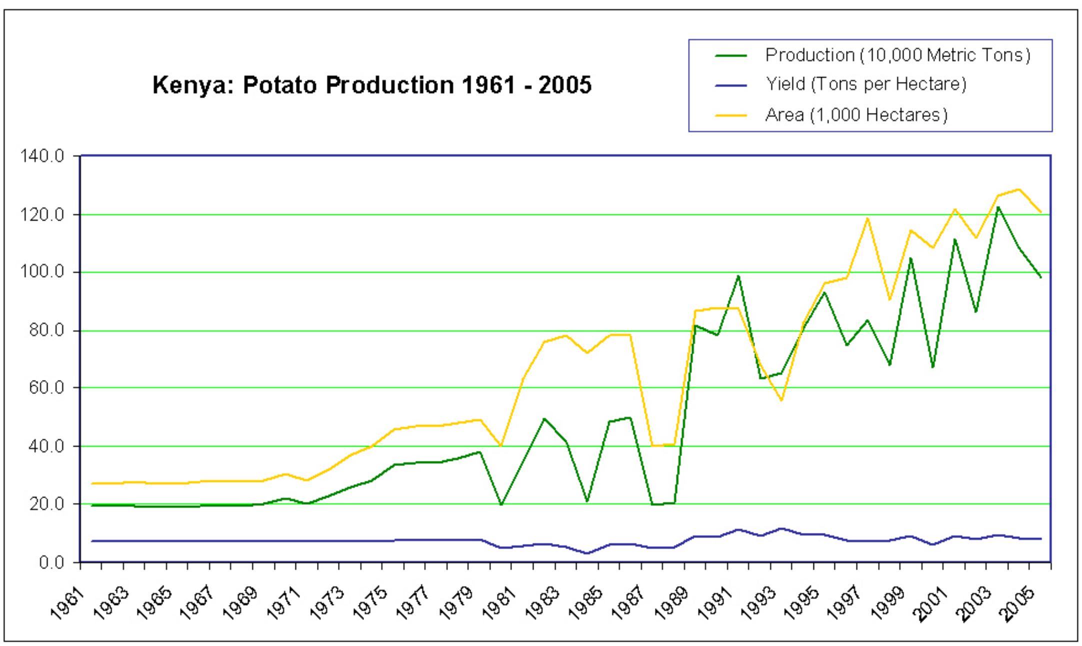

Figure 1: Irish Potato Production Trend in Kenya (1961-2005)

Source: www.research.cip.cgiar.org/confluence/display/wpa/country+maps

Irish potato production has risen substantially over the past three decades (Figure 1). Annual production in 2002-2007 averaged about 1million tonnes compared to an average of about 245,000 metric tonnes (mt) in the 1960s. Although Irish potato production has risen over the years, practically all this increase has been due to expansion in area planted, rather than increase in yields. This implies that the tremendous growth in Irish potato production in Kenya is attributed to the expansion of the area under Irish potato cultivation (MoA, 2006). Due to increase in population size, there is currently little scope for expanding agricultural production in general and area planted to Irish potatoes in particular through expansion in cultivated land (KARI, 2005). In order to keep pace with the population growth rate a significant increase in the productivity and production of Irish potatoes is needed.

1.2 Statement of the Problem

Statistics of Irish potato production (MoA, 2006; CIP, 2006) show that the area under Irish potato production in Kenya has increased from around 22,210 hectares in 1963 to about 107,907 hectares in 2006, with a corresponding increase in annual production from 245,000 to about 784,506 metric tonnes. This implies that average Irish potato yields during the 1963-2006 period declined from about 11.03 to 7.3 metric tonnes per hectare. This farm level yield is several times lower than the expected 25-35 metric tonnes per hectare at agricultural research stations. To address this challenge, the Government of Kenya and other stakeholders have undertaken a number of Irish potato development programmes such as varietal improvement, seed development, multiplications and distribution to boost production and improve farm incomes. The National Potato Research and Development Programme has developed and introduced several technologies which have been passed to farmers through the extension service over the years (Kinyae et al., 1996).

Despite substantial effort and resources devoted to the development and transfer of new technologies, average Irish potato output has not been increasing at farm level. Trends in national Irish potato production show that during the past 20 years there has been no significant increase in productivity and the average national yield is less than 10 metric tonnes per hectare compared to a potential of 25-35 metric tonnes per hectare on research station and an expected 14.5-20 metric tonnes per hectare under farm-level conditions (KARI, 2005; MoA, 2006). Although there has been a marked improvement in total production of Irish potatoes in Kenya over the years, the contribution of efficiency strategies and the associated economic efficiency in achieving these levels is not known.

1.3 Objectives of the Study

The main objective of this study was to characterize the Irish potato production system, examine the economic efficiency and determine socio-economic and institutional factors influencing the observed variability in efficiency levels among Irish potato producers in Nyandarua North district.

To meet the broad objective the specific objectives of the study were:-

1) To characterize the Irish potato production system in Nyandarua North district.
2) To estimate the Irish potato frontier production and cost functions for Nyandarua North district in order to determine the level of responsiveness of output to the factors of production.
3) To estimate the level of technical, allocative, and economic efficiency for Irish potato producers in Nyandarua North district in order to determine the potential for productivity gains and cost savings through optimal resource use.
4) To determine socio-economic and institutional factors that influence the observed variability of production efficiency levels for Irish potato producers in Nyandarua North district in order to draw policy implications.

1.4 Hypotheses of the Study

In order to achieve the objectives, the following hypotheses were postulated for testing:

1) Irish potato producers in Nyandarua North district operate on production and cost function frontiers.
2) There are constant returns to scale in Irish potato production in Nyandarua North district.
3) Socio-economic factors do not influence the observed level of technical, allocative, and economic efficiency of Irish potato producers in Nyandarua North district.
4) Institutional factors do not influence the observed level of technical, allocative, and economic efficiency of Irish potato producers in Nyandarua North district.

1.5 Justification of the Study

Irish potatoes being the second most important food crop in Kenya after maize, the crop plays a major role in food security and alleviation of poverty through income generation. It is a source of livelihood for an estimated 500,000 small-scale farmers and employs approximately

2.5 million people (MoA, 2004). Demand for Irish potatoes has continued to rise over the years especially by urban consumers.

Comparatively low average yields achieved at farm level implies that Irish potato producers are not getting maximum returns from resources committed to the enterprise. Thus given the importance of Irish potato to smallholder farmers, a better understanding of the efficiency levels is needed to assess the potential productivity gains and identify appropriate policy recommendations to increase Irish potato production in Kenya. Improved efficiency may translate into higher productivity, raise farmer incomes and ultimately reduce poverty.

Several studies have revealed widespread inefficiencies in agricultural production (e.g. Bhasin, 2002; Binam et al., 2004). Others have studied the impact of specific constraints on efficiency like extension services (Seyoum et al., 1998) and financial services (Battese et al., 2005). Given the similarity in the developing nature of the regions where these studies have been conducted, this study aims at providing information on economic efficiency of Irish potato production in Kenya.

The study of efficiency of resource use in Irish potato production is important to policy makers, researchers and extension as a basis for policy initiatives, especially for institutions dealing with inputs, credit and extension. By establishing a better understanding of the level of and the factors influencing production efficiency in Irish potato production, policy makers can better implement measures that contribute to enhancing agricultural efficiency and productivity.

1.6 Scope and Limitations of the Study

The study focuses on economic efficiency for Irish potato producers at farm level. The input supply, marketing and consumer stages are not investigated. However, this does not mean that their role in Irish potato production and marketing is less significant. Because of limited resources available only aspects of economic efficiency of Irish potato producers in Nyandarua North district were investigated.

Nyandarua North district was selected for the study due to the importance of the district in national Irish potato production. Therefore the results of this study are based on a small sample of smallholder farmers in one district and may not necessarily be representative of the entire smallholder farmers with varying land holding sizes in different ecological zones.

In Nyandarua North many Irish potato producers do not keep records of the inputs and outputs. This study suffers from weaknesses associated with the survey interviews when data accuracy depends heavily on the respondent's ability to recall past information and to answer the survey question accurately. Such effects were minimized by re-interviewing the farmers in case of inconsistencies. However, some errors and discrepancies are unavoidable in this kind of study despite every caution.

1.7 Definition of Terms

This section provides the operational definitions of the terms as used in this study.

Technical Efficiency: With an input orientation refers to the ability to minimize physical input use for a given output level.

Allocative Efficiency: Given a level of production, a firm is said to be allocatively efficient if inputs are used in those proportions which minimizes the cost of production given input prices.

Economic Efficiency: Relates to the situation where a firm produces a given quantity of outputs at minimum possible cost given the existing state of technology.

Production frontier: Is defined in terms of the maximum output that can be achieved from a set of inputs given the technology available to the farm.

Returns to scale: A way of classifying the relationship between output and inputs as the scale of production changes. Returns can be increasing, constant or decreasing.ether

Plot: Means a piece of land planted with a uniform crop. The plot may have a marked boundary e.g by nappier grass or a row of trees. In this study the plot is defined by the uniformity of the Irish potato crop in a given land area.

Household: A farm household comprises the head of the household, the spouse (s), children, and all other relatives and individuals of a common decision making unit, usually within one residence, that are sharing income and other pooled resources. They rely on the same plot of land and common sources of income. Workers are included as members of the household only if resident at least twelve months in the household prior to the date of the interview.

Child: A child in this study is a member of the household aged 15 years and below. No distinction was made between a male and female.

1.8 Outline of the Thesis

This thesis is divided into 5 chapters including this chapter on introduction. The remainder of this thesis is organized as follows. Chapter 2 is devoted to the literature review where empirical literature and theoretical framework are presented. A brief review of the input-oriented frontier production function methodology is also provided.

Chapter 3 gives the description of the study area including location, physical environment and demographic characteristics. The agricultural system in the area is described with special emphasis on Irish potato production. The method of data collection, survey and sampling procedures and empirical models are presented.

Chapter 4 is devoted to presentation and discussion of results. The main characteristics of the sample households are outlined and discussed. Estimated coefficients of the ordinary least squares and maximum likelihood estimates and cost frontier together with the estimated efficiency indices are presented. Results of the two-limit Tobit model and sources of efficiency are presented and discussed. Based on the results and discussion, Chapter 5 winds up the study by drawing conclusions and policy implications.

CHAPTER TWO

LITERATURE REVIEW

2.1 Irish Potato Productivity in Kenya

The Irish potato is one of the most important food crop in Kenya that plays a major role in national food security. Irish potato production is an important agricultural activity and is estimated that about 120,000 hectares are harvested and about 1 million metric tons are produced on an annual basis (Lung'aho et al., 2006). Production estimates over the years, indicate that from 1964 to 2007 area under Irish potato production increased by over 270% (i.e. from 27,000 to about 100,000 hectares). Despite this expansion, total production did not increase over the same period at the same pace and average production by small scale farmers is approximated at less than 10 metric tons per hectare (Lung'aho et al., 2006; Walingo et al., 2002).

Available studies on Irish potato in Kenya, have shown little improvement in productivity. Kabira et al. (1998) noted that in Kenya, Irish potatoes were produced on a small scale basis on an average plot size of less than 0.51 hectares. The national Irish potato yields of less than 2 metric tons per hectare achieved by farmers were low compared with potential yields and production costs were high.

A survey by Kinyae et al. (1996) on adoption of Irish potato production technologies in Nyandarua district, found that yields in 1996 in the district were generally low at 1.43 metric tons per hectare. This is about 29.2 percent of the yields attained at research stations. Of the farmers interviewed, 86 percent obtained less than 12.24 bags/ha (equivalent to 1.3 metric tons per hectare) while only 2 percent obtained yields above 36.73 bags/ha.

In another study of Irish potato farmers in Kinangop division of Nyandarua district, Odero (1997) found that farmers obtained a mean yield of about 13.45 bags/ha. Improvement of road quality and increase in market accessibility was found to have a significant effect on fertilizer use. Similarly, fertilizer use was found to have a strong and significant effect on Irish potato yield and hence productivity.

Although several production technologies have been developed over the years, national yields are still low at less than 10 metric tons per hectare (mt/ha) (MoA, 2007). This low national average yields which is about 33% of potential yields attainable at research stations, gave rise to the concerns by the government over low productivity in the sub-sector. Consequently the National Potato Policy was formulated in 2004 (MoA, 2004). In particular, one of the objectives of the National Potato Policy is to raise productivity of the Irish potato industry through provision of appropriate technology and services. This is in line with the overall policy objective of the Strategy for Revitalizing Agriculture to provide a policy and institutional environment that is conducive to increasing agricultural productivity.

A number of studies on Irish potato production have been conducted in Kenya. However, most studies have focused on agronomic aspects of Irish potato production, pest and diseases, and marketing (Durr and Lorenzl, 1980; Crissman, 1989; Walingo et al., 2002). Other studies have described adoption levels (e.g., Kaguongo et al., 2007; Kinyae et al., 1996). While these studies have mainly addressed the problems of Irish potato production and marketing little attempts have been made to assess the levels of efficiency of resource use in the Irish potato sub-sector. Ogola et al. (2002) for example note that most Irish potato farmers are small-scale, owning an average land size of about 2 hectares and with these small land sizes, the only option to enhance production lies in increased productivity.

2.2 Review of Studies on Efficiency of Resource Use

Studies conducted in Kenya and elsewhere have identified several factors affecting the efficiency of resource use by farmers. Some of these studies are reviewed in this section. Abedullah and Khuda (2006) used a stochastic Cobb-Douglas production function to estimate the technical efficiency of a sample of potato farmers in Punjab, Pakistan. The authors found a mean technical efficiency of 0.80 which implies a 20% potential gains in potato production. Extension services was found to be one of the most important factors explaining variation in technical efficiency levels.

In a study of the technical efficiency of a sample of UK potato producers, Wilson and Hadley (1998) estimated a stochastic frontier production function for the 1992 crop year. The range of technical efficiency index across production regions ranged between 0.33 to 0.97. Irrigation of the potato crop and storage of potatoes after harvest were found to positively influence technical efficiency. Number of years of experience of growing potatoes and chitting of seed potatoes were found to be negatively correlated with technical inefficiency.

Using a stochastic efficiency decomposition technique, Binam et al. (2006) derived the technical, allocative, and economic efficiency levels for a sample of 450 farmers in

Cameroon. The analysis revealed average levels of technical, allocative and economic efficiency equal to 77 percent, 58 percent, and 44 percent, respectively. In a second step two-limit Tobit regression, the authors regressed the technical (*TE*), allocative (*AE*) and economic (*EE*) indices on several farm-specific socio-economic variables. The results indicated that the efficiency differences were explained significantly by the years of schooling, credit, social capital, distance of the plot from the main access road, and access to extension services.

Bravo-Ureta and Pinheiro (1997) estimated a Cobb-Douglas production frontier by maximum likelihood method to measure the technical, allocative and economic efficiency for a sample of 66 farmers in the Dominican Republic. Analysis revealed average technical, allocative, and economic efficiency equal to 70 percent, 44 percent and 33 percent respectively. In a second step regression, using a two-limit Tobit model, various farm/farmer characteristics were examined. Results of the two-limit Tobit regression of technical (*TE*), allocative (*AE*) and economic (*EE*) indices and farm/farmer characteristics indicated that important explanatory variables were contract farming, farm size, and being an agrarian farm beneficiary.

Chirwa (2007) estimated technical efficiency levels for smallholder maize farmers in Malawi. He found that smallholder maize farmers in Malawi are inefficient with an average efficiency score of 46.23%. About 79% of the plots were found to have efficiency scores below 70%. Results of the study revealed that inefficiency declines on plots planted with hybrid seeds and for those controlled by farmers who belong to households with membership in a farmers' association.

Seyoum et al. (1998) estimated a Cobb-Douglas production frontier by maximum likelihood to measure the technical efficiency for a sample of 40 farmers each within and outside the Sasakawa-Global 2000 project in two districts of Ethiopia. Farmers within the Sasakawa-Global 2000 project were found to be more technically efficient with a mean technical efficiency (*TE*) of 93.7% than those outside the project who had a mean technical efficiency (*TE*) of 79.4% relative to their respective technologies. The technical inefficiency effects were found to be negatively related to the hours of extension (i.e. positively related with efficiency) advice implying the program should be expanded. The study suggested that adoption of new technologies could materially improve output and income of the farmers.

Bozoglu and Ceyhan (2007) used a stochastic frontier analysis to measure technical efficiency of 75 vegetable farms in Samsun province of Turkey. The authors found the mean technical efficiency of vegetable farms to be 82%. The variables of schooling, experience, credit use, participation by women, and information score negatively affected technical inefficiency.

2.3 Theoretical Framework

This study is based on the neoclassical theory of production. The neoclassical production theory provides a framework for modeling production functions in which it is assumed that the firm is operating on the frontier. In neo-classical theory of production, the primal production function defines the maximum possible output for combinations of inputs and technology.

Production is the process of transforming inputs into outputs in the form of either input for another production process or final consumer goods. This involves the use of resources (inputs) aggregated into land, labour, capital and entrepreneurship in agriculture to obtain output. The neo-classical production theory therefore provides a basis for analyzing the factors that help explain the changes in output level.

A production function indicates a relation between quantity of output and the quantities of inputs. In microeconomic theory a production function is defined as the maximum output that can be produced from a specified set of inputs, given the existing technology available to the firms (Battese and Tessema, 1992). It is expressed as a mathematical relationship which describes the way in which the quantity of an output depends on the quantity of inputs used. This relationship is expressed as

$$Y_i = f(X_{1i}, X_{2i}, ...X_{ni} \mid X_{ki}) \tag{1}$$

where Y_i is output of the ith firm and X_{ni} is a matrix of variable inputs; X_{ki} is a matrix of fixed inputs for a given period.

Presentations of production functions is done using either the primal or the dual approach. The primal approach uses production functions which are based on a technical assumption of output-maximization given a set of inputs. It involves a direct estimation of the production function. Use of traditional production or primal frontiers in measuring productive efficiency is quite limited in that the production frontiers yield information only on technical efficiency but not on allocative or scale inefficiency.

Kopp and Diewert (1982) proposed methods of decomposing cost inefficiency into technical and allocatve inefficiency using numerical methods. Their method permits flexible forms using duality models, to derive a system of stochastic frontiers and subsequently to estimate total inefficiency and its technical and allocative components. The method developed by Kopp and Diewert (1982) was extended by Bravo-Ureta and Rieger (1991) by estimating a Cobb-Douglas stochastic production frontier analytically. This method permits a corresponding cost frontier to be derived using duality theory and subsequent estimation of technical, allocative and economic efficiency indices.

For illustration the multi-input and single-output constant returns-to-scale case is shown in Figure 2 as adopted from Bravo-Ureta and Pinheiro (1997).

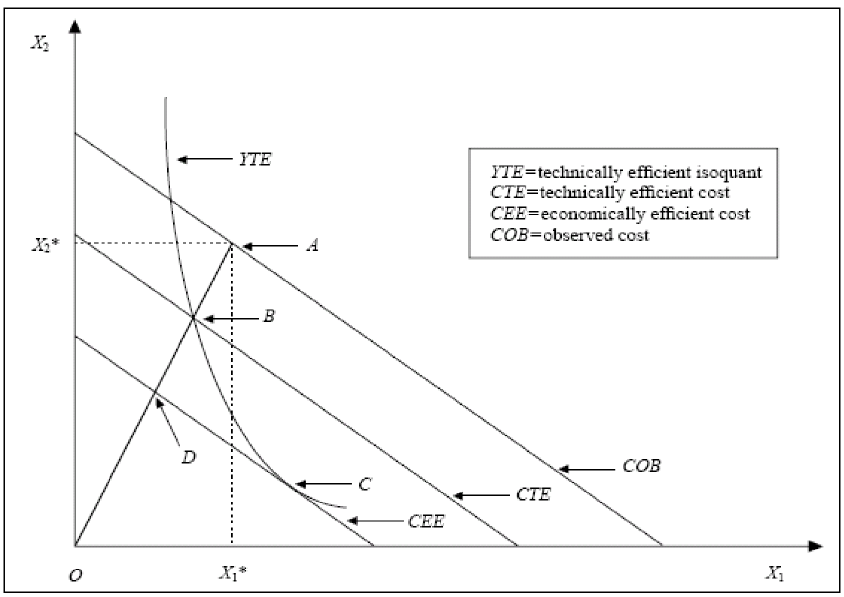

Figure 2: Observed, Technically and Economically Efficient Cost Measures
Source: Adopted from Bravo-Ureta and Pinheiro (1997).

Suppose the level of output represented by isoquant *YTE,* is Y^0. The isoquant (*YTE*) represents a number of combinations of inputs (X_1 and X_2) used to produce this given level of output, Y^0. All points on this isoquant reflect technically efficient production. In this figure, suppose a firm is operating at point *A*, with the combination of actual levels of inputs X_1 and X_2 (i.e., X_1^* and X_2^*), at this point (*A*), the particular firm produces the same level of output

(Y^0) as produced on isoquant *YTE*. Inputs are not being used efficiently by operating at point *A*, that is, the firm is actually using more inputs (*OA*) than actually needed (*OB*) to produce output Y^0.

To define the technical efficiency of the firm, a line is drawn from the origin to the point *A*. The line crosses the isoquant at the point *B*. In the case of a technically efficient firm, the same amount of output (Y^0) is produced using input levels of X_1 and X_2 defined by the point *B*. Technical efficiency of the firm is defined as the ratio of the distance from the origin to the point *B* over the distance from the origin to point *A* (i.e $TE=OB/OA$). Therefore OB/OA is the proportional reduction of all inputs that could theoretically be achieved without any reduction in output (Bravo-Ureta and Pinheiro, 1997).

Given input prices, an isocost line (i.e., *CEE*) reflecting the economically efficient cost level is drawn tangent to the isoquant at point *C*. The line *CEE* represents the input price ratio or isocost line, which gives the minimum expenditure for which a firm intending to maximize profit should adopt. This isocost line (*CEE*) intersects the line *OA* at the point *D*. The economically efficient production is at point *C* where the firm produces at minimum cost. Allocative efficiency is in this case defined as the distance *OD* from the origin over the distance *OB* from the origin (i.e $AE = OD/OB$). At this point (*B*), distance *DB* represents the potential reduction in production costs if the farm using the combination of input (X_1 and X_2) was to produce at any point on *CEE*. Economic efficiency is the product of technical and allocative efficiency (i.e., $EE = TE*AE$).

In the duality approach, firms are assumed to seek to minimize the cost of producing their desired output subject to a stochastic production frontier constraint. The stochastic production frontier is derived using the maximum likelihood estimates. The estimated stochastic production frontier is used to compute the technically efficient input vectors as well as to derive the dual cost frontier. By using Shephard's lemma (Shephard, 1970), the cost frontier is then used to obtain the minimum cost factor demand equations, which in turn become the basis for calculating the economically efficient input levels.

In the context of the duality approach illustrated in Figure 2, technical inefficiency is related to deviations from the frontier isoquant while allocative inefficiency reflects deviations from the minimum cost input ratios.

CHAPTER THREE

METHODOLOGY

3.1 Description of the Study Area

The study area covers Nyandarua North district in Central province. Nyandarua North district is one of the ten (10) districts of Central province of Kenya situated in the central part of the country (Figure 3).

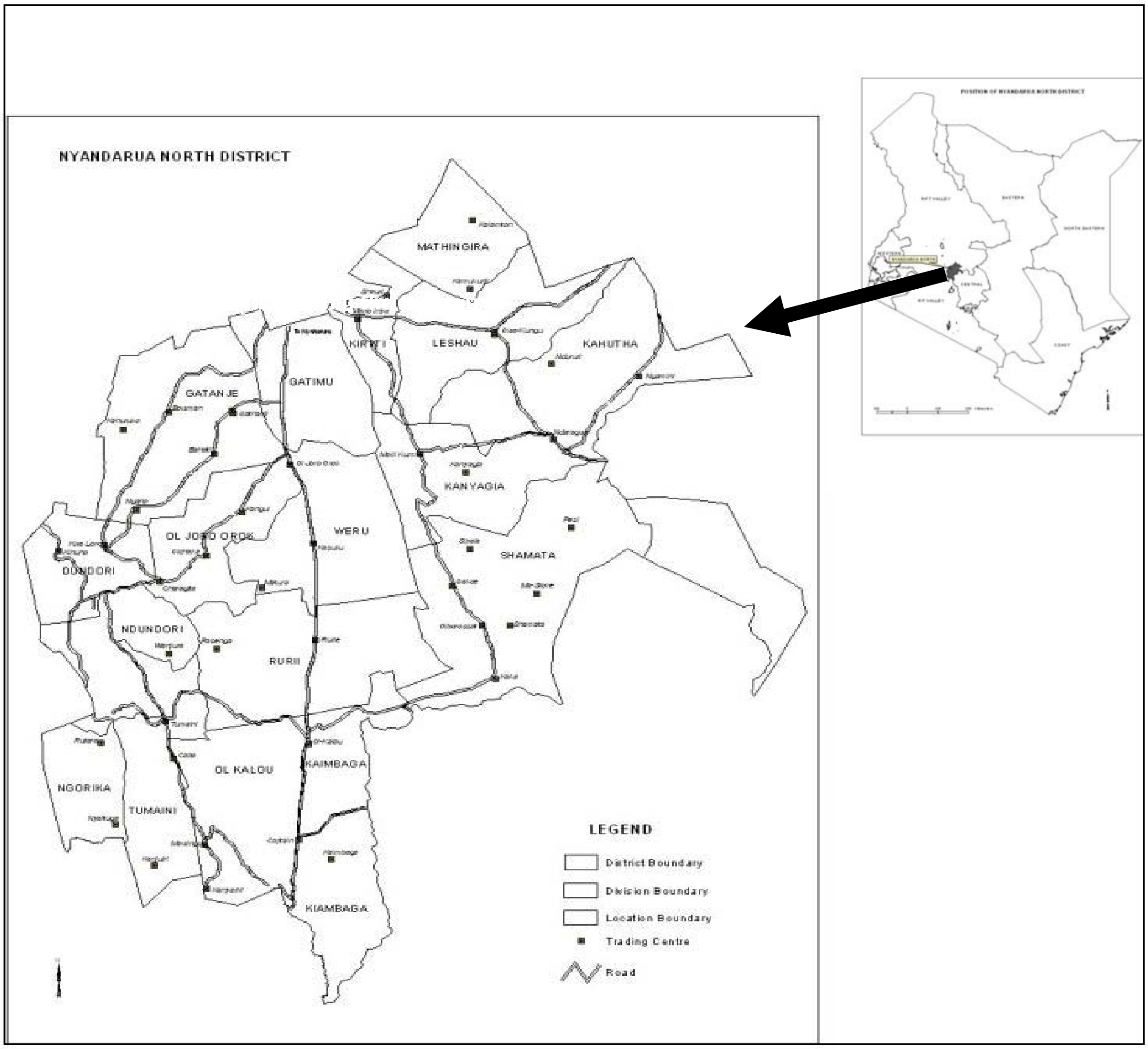

Figure 3: Map of Kenya Showing the Study Area

The district covers an area of approximately 1,657.7 km^2. Administratively, the district is divided into 3 divisions- Ndaragwa, Ol joro orok and Ol Kalou divisions. It is noteworthy that Nyandarua district was recently divided to form Nyandarua North and South districts.

The district falls within the Central highlands of Kenya with a range in altitude of between 2350 to 3000 metres above sea level.

Nyandarua North district was chosen for the study because of its importance in national Irish potato production. Based on statistics, of the approximately 100,000 ha of land annually under Irish potato cultivation in Kenya, approximately 17500 ha (17.5%) are located in Nyandarua North district (MoA, 2007; Kirumba et al., 2004).

The highest part of the district along the Aberdare ranges has dark clay and peaty soils of moderate to high fertility. Soils are humic andosols of high to moderate fertility. In some parts of Ol Kalou salient there are poorly drained clay to clay loam soils. Most of Ndaragwa division, northern parts of Ol joro orok and Ol Kalou divisions have well drained deep friable clay loams.

There are two major agro-climatic zones in the district: Upper Highland UH2 and UH3. The mean annual rainfall is 1000 mm distributed in a bimodal pattern which permits two rain-fed cropping seasons: the first, from March to August and the second, from October to December. Mean maximum temperatures is 22^{o}C and the mean minimum temperature ranges between 10 to 16^{o}C. The climate is conducive to rich and varied agricultural production (Jaetzold et al., 2006).

The estimated population of Nyandarua North district is about 249,280 persons (1999 census) with about 122,584 male and 126,696 female. The population is 90% rural based consisting of 55,228 households with a mean household size of 4 persons (Jaetzold et al., 2006).

Land ownership is predominantly freehold. The majority of the farms in the area are small-scale. The land size per household varies across the divisions but on average it is 2 hectares (Jaetzold et al., 2006).

Agriculture is the main activity in the district with Dairy production as the dominant farming activity followed by Irish potato production. The district has two planting seasons: the long and short rain seasons. The dominant annual crop in both seasons is Irish potatoes (Jaetzold et al., 2006). The major cash crops grown in the district include wheat, pyrethrum and horticultural crops such as cabbages, garden peas and carrots.

3.2 Survey and Sampling Procedure

Data used in this study were obtained from a cross sectional survey of Irish potato farmers in Nyandarua North district, Kenya. The survey was conducted during the months of May and June 2008. Table 1 presents the administrative units covered in the survey.

Table 1: Administrative Units Sampled for the Study

Division	Location	Sub-locations	
		Sub-location 1	Sub-location 2
Ol Kalou	Ol Kalou	- Mawingo	- Munyeki
	Tumaini	- Kanjuiri	- Upper Gilgil
	Kaimbaga	- Gichungo	- Kandutura
	Rurii	- Rurii	- Matura
	Ngorika	- Ngorika	-
	Ndundori	- Melangine	- Matindiri
Ol joro orok	Gatimu	- Gatimu	- Gikingi
	Gathanje	- Gathanje	- Ngano
	Ol joro orok	- Oraimutia	- Nyairoko
	Weru	- Weru	- Kirimangai
Ndaragwa	Kahutha	- Kianjogu	- Uruku
	Shamata	- Shamata	- Simbara
	Leshau	- Karagoini	- Munyu
	Kiriita	- Shauri	- Mairo Inya
	Mathigira	- Ndivai	- Mathigira
	Kanyagia	- Kanyagia	- Kihara

Source: Survey data, 2008.

A multistage sampling technique was used to select a sample of farmers for the study. First, the number of administrative Locations in each of the three divisions of Nyandarua North district were determined and then for each Location two Sub-locations were randomly selected. Secondly, all the villages in the selected Sub-locations were listed and a simple random selection was used to select two villages per Sub-location. The villages that formed the sampling frame are those that are used by Kenya National Bureau of standards for their statistical reporting. The list was obtained from the local administrative leaders.

Finally, visits were made to all the selected villages a complete list of all the Irish potato producing households in the selected villages were compiled with the help of the local extension staff and administrative leaders. This was supplemented by information from the local Kenya National Potato Farmers Association (KENAPOFA) officials. The list prepared in each selected village served as a sampling frame and households were randomly selected after a simple household listing.

A total sample of 130 Irish potato-producing households was selected. The sample size of Irish potato producers was computed according to the following formula developed by Kothari (2004):

$$n = \frac{z^2.p.q}{e^2} \qquad (2)$$

where n is the sample size, z is the confidence interval (Z-value), p is the expected proportion and e is the acceptable margin of error. In this study, a 95% confidence interval was assumed, with an expected proportion of 0.5 and an expected margin of error of 10%. Therefore the sample size was calculated as

$$n = \frac{(1.96)^2(0.5)(0.5)}{(0.10)^2} = 96.04 \approx 96 \text{ households} \qquad (3)$$

giving a minimum sample size of 96 adjusted to 130 households.

3.3 Data Collection

Data collection was conducted using a structured questionnaire (see Appendix 1). The questionnaire was designed and pre-tested on 10 non-sample households. The objective of pretesting was to enable a correction of mistakes, evaluate the relevance of a given question, add relevant information, exclude irrelevant information and make overall improvement on the standard of the questionnaire in line with the objectives of the survey. After the pretest, the questionnaire was modified and used in face-to-face interviews in 130 households.

Information was collected regarding Irish potato production in the second season of 2007/08 cropping year. All households selected using random sampling from the selected villages were visited and face to face interviews carried out. In each of the selected Irish potato producing households, the household head or any adult who had lived with the household for at least two previous crop production seasons and was conversant with the farming activities of the other household members was interviewed.

Each of the 130 sampled households was surveyed with respect to output and input use in Irish potato production as well as socio-economic characteristics. The output was measured as the quantity of Irish potato harvested. Gross production was calculated as sales plus farm household consumption in 110-kg bags equivalent. Data were also collected for five production inputs: land (Irish potato plot size), labour, seed, fertilizer, and fungicides.

Measurement of the land (plot size) input was by area planted to Irish potato expressed in hectares.

Concerning labour input, data were collected for family and hired labour in terms of hours used in each activity in the production process. Calculations were made by choosing the man-day as the base unit and weighting it according to the Food and Agriculture Organization (FAO) method. For women, working hours were multiplied by 0.75 and for children the coefficient is 0.5 (Nchare, 2007; Battese et al., 1992). Finally, working hours were converted to man-days by dividing actual working hours by eight. Therefore, labour input is expressed in man-days with each man-day equivalent to 8 hours of adult male labour.

Fertilizer input was obtained as the total amount of fertilizer (in kg) used in the potato plot in the same season. Quantity of seed was recorded as the quantity of Irish potato seed in kilograms planted. The quantity of fungicide used was collected in terms grams of product applied in the Irish potato plot. In addition to input and output quantities, prices for input and output were collected as well. The cost of land was calculated on the basis of its rental value.

Socio-economic data relating to the household heads were also collected. These included age, gender, level of education, and farming experience of the household head. Other socio-economic information collected regards family size, farm size, and sources of income. In addition, access to extension services and access to credit was also obtained. Agricultural extension agents contact with the farmers recorded was the number of visits paid to the Irish potato farmers during the year 2007. These data are important in the analysis to identify important characteristics influencing efficiency levels of Irish potato production.

Three of the questionnaires had incomplete information and therefore only data from 127 of the questionnaires were used in the final analysis.

3.4 Techniques for Efficiency Measurement

Empirical studies of productive efficiency have used a variety of approaches in modeling frontier production functions. Examples of such approaches include: parametric versus nonparametric; and deterministic versus stochastic methods (Xu and Jeffrey, 1997). Each of these techniques is briefly discussed in the sections that follow.

3.4.1 Parametric Versus Non-parametric Frontiers

Broadly, the two quantitative approaches developed for measurement of production efficiency are parametric and non-parametric. Parametric and non-parametric approaches differ on the basis of two criteria. First, the two approaches differ on the assumption of the error term that represents inefficiency. The parametric approach distinguishes the effects of random shocks from the effects of inefficiency as it takes into account measurement errors and other noise in the data. The non-parametric assumes any deviation from the frontier is due to inefficiency (Iraizoz et al., 2003). This however, introduces a severe bias in efficiency measurement when production is subject to random shocks (noise) outside the firm's control.

Secondly, they differ in the way the frontier function is imposed on the data. Parametric methods consider frontier production as a parametric function of the inputs and start from a particular function (e.g. Cobb-Douglas, CES, Translog). In the estimation of non-parametric functions, no previously defined form is imposed on the production function. Non-parametric estimation uses linear programming with no assumptions being made on the stochastic properties of the data (Apezteguia and Garate, 1997).

The distributional forms of the error term must also be specified in a parametric specification whereas in the non-parametric methods they are not. The parametric approach allows one to perform hypothesis tests regarding the existence of inefficiency and the structure of production technology. The non-parametric approach imposes less restrictive assumptions about production technology.

3.4.2 Deterministic Versus Stochastic Frontiers

Parametric frontiers can be further specified as deterministic or stochastic. In deterministic models it is assumed that any deviation from the frontier is due to inefficiency (Bravo-Ureta and Antonio, 1993). According to Battese (1992) the basic structure of the deterministic model is specified as:

$$Y_i = f(X_i;\beta)\exp^{-\mu_i} \quad (4)$$

where Y_i represents the potential production level of the ith farm; $f(X_i;\beta)$ is a suitable function (e.g., Cobb-Douglas or Translog); X_i is a vector of inputs of the ith farm; β is a vector of parameters to be estimated; and μ_i is a non-random error term associated with the farm-specific factors which contribute to the ith farm not attaining maximum efficiency. One important limitation of the deterministic approach is that it does not allow for random errors. This implies that all the residuals are considered as inefficiency.

Stochastic frontiers have their origin in trying to solve the limitation of deterministic functions. In the stochastic model the error term is assumed to have two additive components: a symmetric component accounting for pure random factors and a one-sided component that captures the effects of inefficiency relative to stochastic frontier. The basic structure of the stochastic frontier is given as

$$Y_i = f(X_i;\beta)\exp^{(\nu_i-\mu_i)} \quad (5)$$

where Y_i is the observed output of the ith farm; $f(X_i;\beta)$, is a suitable function (e.g., Cobb-Douglas); X_i and β are as defined above.

The essential difference of the stochastic frontiers from the conventional (average) production function is that its disturbance term has two components: one to account for technical inefficiency and the other accounts for random events that affect production. The error term, ε_i, is defined as:

$$\varepsilon_i = \nu_i - \mu_i \quad (6)$$

where ν_i is a two-sided $(-\infty < \nu > \infty)$ normally distributed random error ($\nu \sim N[0,\sigma_\nu^2]$). The symmetric error term (ν_i) captures the stochastic effects outside the farmer's control (e.g., weather, natural disasters, e.t.c.), measurement errors and other statistical noise. The error term μ_i is a one sided $(\mu_i \geq 0)$ efficiency component that captures technical inefficiency. The one-sided error can follow such distributions as half-normal, exponential and gamma (Aigner et al., 1977). The two components ν_i and μ_i are also assumed to be independent of each other (Khai et al., 2007). In this study it's assumed that μ_i follows a half-normal distribution $(\mu_i \sim N[0,\sigma_\mu^2])$.

The frontier production function model is estimated using Maximum likelihood procedures. The maximum likelihood estimation of equation (5) yields consistent estimators for β, λ and σ^2 where $\lambda = \sigma_\mu / \sigma_\nu$ and $\sigma^2 = \sigma_\nu^2 + \sigma_\mu^2$.

In order to empirically measure technical efficiency, the deviations from the frontier must be separated into the random component (ν) and inefficiency component (μ). Given the distributional assumptions for ν and μ, the Maximum likelihood estimation provides sufficient information to calculate a conditional mean for μ. Jondrow et al. (1982) have shown that inferences about the technical inefficiency of individual firms can be made by considering the conditional distribution of μ_i given the fitted values of ε_i and the respective parameters. In other words, given the distribution assumed for ν_i and μ_i and assuming that these two components are independent of each other, the conditional mean of μ_i given ε_i is defined by:

$$E(\mu_i \mid \varepsilon_i) = \sigma_* \left[\frac{f^*(\lambda\varepsilon_i/\sigma)}{1 - F^*(\lambda\varepsilon_i/\sigma)} - \frac{\lambda\varepsilon_i}{\sigma} \right], \qquad (7)$$

where $\sigma_* = \sigma_\nu \sigma_\mu / \sigma$, f^* is the standard normal density function and F^* is the cumulative normal distribution function both functions being evaluated at $\lambda\varepsilon/\sigma$. From this calculation, estimates of ν and μ can be determined.

The stochastic frontier model has particular advantages over other approaches: it introduces a disturbance term which captures random or measurement error and exogenous shocks beyond the control of the production unit; and this approach provides the basis for statistical tests on the results. However, this model imposes considerable structure on the farm technology by requiring the production technology to be defined before estimation (e.g., Cobb-Douglas, Translog, e.t.c). In addition, the distribution of the one-sided error term must be specified (e.g., as half-normal, exponential, truncated normal e.t.c.) when the model is estimated and this imposes additional structure on the distribution of technical inefficiency. Finally the stochastic frontier production function cannot handle multiple output cases.

3.6 Empirical Models and Data Analysis

3.6.1 Descriptive Statistics

To get some insight about the characteristics of the sampled farm households, descriptive statistics were used. Descriptive statistical analysis were employed to analyze the survey data using measures of dispersion such as percentage, frequency and measures of central tendency such as mean, variance, and standard deviation. The t-test was used to determine any statistically significant differences.

3.6.2 Cobb-Douglas Stochastic Frontier Model

Several functional forms have been developed to measure the physical relationship between inputs and outputs. The most common are the Cobb-Douglas (CD) and the transcendental logarithmic (translog) function. The CD is the simpler but less flexible form, is very parsimonious with respect to degrees of freedom (Leavy et al., 1999) and it meets the requirement of being self-dual which allows the examination of allocative and economic efficiency.

However, one of the drawbacks of the CD is that it is less flexible as it imposes severe priori restriction on the farm's technology by restricting the production elasticities to be constant and elasticities of input substitution to unity (Wilson and Hadley, 1998).

The translog production function on the other hand is a more flexible functional form than the CD which takes account of interactions between variables and allows for non-linearity in the parameters. However, the translog suffers some drawbacks. First, it does not yield coefficients of a plausible sign and magnitude due to the degrees of freedom and secondly, when estimating the translog production function, multicollinearity among explanatory variables is usually present (Leavy et al., 1999).

Inspite of its restrictive properties, the CD functional form was used in this study because its coefficients directly represent the elasticity of production. Secondly the analytical method used requires that the production function be self-dual. Finally, the CD has been widely used in many empirical studies particularly those related to developing countries for farm efficiency analysis (Bravo-Ureta and Pinheiro, 1997).

The stochastic parametric method requires that a functional form of the frontier production function be specified. The model chosen for efficiency analysis is expressed in a general form as:

$$\mathrm{Y} = f\,(Psize, Lab, Seed, Fert, Agchem), \tag{8}$$

where Y is the Irish output produced in bags[1]. The variable *Psize* represents land area planted to Irish potatoes, *Lab* means family and hired labour measured in man-days, *Seed* represents the quantity of seed in kilograms, *Fert* corresponds to fertilizer measured in kilograms and *Agchem* is the quantity of fungicides applied in grams.

[1] A bag is the standard measure of Irish potatoes in the study area equivalent to 110kg.

Using a linear representation the empirical function to be estimated is written as:

$$\begin{aligned} \ln(Output)_i &= \beta_{0i} + \beta_{1i}\ln Psize_i + \beta_{2i}\ln Lab_i + \beta_{3i}\ln Seed_i \\ &= \beta_{4i}\ln Fert_i + \beta_{5i}\ln Agchem_i + \nu_i - \mu_i \end{aligned} \quad (9)$$

where the subscript i, indicates the ith household in the sample (i=1,…….,127); ln is the natural logarithm (i.e. logarithm to base e); β_k are parameters to be estimated (k= 1,….,5). The parameters ν and μ represent the stochastic and inefficiency components of the error term respectively; and the other variables is as defined above. In this study, the half-normal distribution is assumed for the asymmetric technical inefficiency parameter.

In the Cobb-Douglas functional form the parameters to be estimated, β_k, represent the elasticity of output with respect to each ith input, that is the percentage change in output from a 1% change in the ith input. Table 2 below summarizes the variables in the stochastic production frontier together with their hypothesized signs.

Table 2: Variables Included in the Cobb-Douglas Model and Hypothesized Signs

Variable	Description	Hypothesized sign
Output	The physical amount of Irish potato harvested (bags)	Dependent
Psize	The land area cultivated to Irish potato (hectares)	+
Lab	Amount of family and hired labour used (man-days)	+
Seed	Quantity of seed planted (kilograms)	+
Fert	Quantity of chemical fertilizer used (kilograms)	+
Agchem	Quantity of fungicide applied (grams)	+

The maximum likelihood estimates for the parameters of the stochastic frontier are obtained by using the FRONTIER 4.1 (Coelli, 1996) computer programme, in which the variance parameters are expressed in terms of

$$\sigma^2 = \sigma_\nu^2 + \sigma_\mu^2 \text{ and} \quad (10)$$

$$\gamma = \sigma_\mu^2 / \left(\sigma_\nu^2 + \sigma_\mu^2\right), \quad (11)$$

where σ^2 is the total variance of the model and the term γ represents the ratio of the variance of inefficiency's error term to the total variance of the two error terms defined above. The value of variance parameter, γ, ranges between 0 and 1.

The likelihood-ratio (LR) statistic is used to test the significance of the γ-parameter. This procedure is briefly discussed in the section that follows.

3.6.3 Likelihood- ratio (LR) Statistic

The reliability of empirical results depends on whether or not the models that are being estimated satisfy certain criteria. Specifically, the models have to be correctly specified, and the assumptions or restrictions made must hold. Incorrect functional specifications and violations of the assumptions can lead to incorrect conclusions and recommendations (Gujarati, 2003).

In this study the gamma and the generalized likelihood ratio (LR) statistic are used to test for inefficiency and the appropriateness of the frontier production function (which includes two error terms) compared to the ordinary least squares (OLS) production function (which includes one error term). The gamma parameter is defined as the ratio of the variance of the one sided error term μ, to the total variance of the model, $(\gamma = \sigma_{\mu}^{2}/\sigma^{2})$, and the parameter is bounded between 0 and 1. If the null hypothesis that γ equals zero is accepted, this would indicate that σ_{μ}^{2} is zero meaning that inefficiency effects are absent from the model. This implies that the μ_i term should be removed from the model, leaving a specification with parameters that can be consistently estimated using ordinary least squares.

The LR statistic was employed in this study to establish whether the stochastic frontier production function is preferred to the ordinary least squares (OLS) production function as one that best represents the data generation process. The LR statistic is calculated as follows:

$$LR = -2\ln[L(H_0)/L(H_1)] = -2[\ln L(H_0) - \ln L(H_1)], \qquad (12)$$

where $L(H_0)$ and $L(H_1)$ denotes the values of the likelihood function for the restricted and the unrestricted frontier model respectively.

The LR statistic has approximately a Chi-square distribution with degrees of freedom equal to the number of restrictions imposed (i.e., difference between the number of parameters estimated under H_0 and H_1 respectively). The null hypothesis is rejected if the computed value of LR exceeds its critical value. A significant LR statistic implies that the frontier production function fits the data better than the ordinary least squares (OLS) production function and estimates for the farm-specific efficiencies are obtained (Bhasin, 2002).

3.6.4 Dual Cost Frontier Model

The dual cost frontier of the production function in equation (9) can be derived analytically. The general form of the dual cost frontier is presented as:

$$C = h(P, Y^{*}; \alpha), \qquad (13)$$

where C is the minimum cost; P is a vector of average prices for the production inputs; Y^{*} is the output adjusted for statistical noise; and α is a vector of parameters to be estimated. The empirical model is defined as:

$$\ln C_i = \alpha_{0i} + \alpha_{1i}\ln P_R + \alpha_{2i}\ln P_L + \alpha_{3i}\ln P_{SD} + \alpha_{4i}\ln P_{CF} + \alpha_{5i}\ln P_{AC} + \alpha_{6i}\ln Y_i^{*} \qquad (14)$$

where the subscript i, indicates the ith household in the sample (i=1,….,127); ln represents the natural logarithm (i.e., logarithm to base e); C_i is the minimum cost of Irish potato production for the ith farm; $\alpha_{0i}, \alpha_{1i}.....,\alpha_{6i}$ are parameters to be estimated. P_R is the seasonal rent of an acre of land in the study area (in Kshs); P_L is the daily wage rate per man-day (in Kshs); P_{SD} is the price of seed per kilogram (in Kshs); P_{CF} is the price of chemical fertilizer per kilogram (in Kshs); P_{AC} is the average price of fungicides; and Y_i^{*} is as defined above.

3.6.5 Determinants of Productive Efficiency

Table 3 presents the description and expected signs of the variables included in the two-limit Tobit model. Several farm/farmer characteristics were hypothesized to explain variations in technical, allocative and economic efficiency levels across the sample farms. Some of the socio-economic factors which were postulated to have some influence on the efficiency levels in this study are age, gender, educational level, and experience of the household head. Institutional factors such as access to extension, credit and membership in a farmers' association were also postulated to influence Irish potato production efficiency.

The age (*Age*) variable was included to test the hypothesis that younger farmers are more receptive to innovations and therefore more efficient. The effect of age of the household head in explaining efficiency is somewhat controversial in the literature. Older farmers are less likely to have contacts with extension workers; are less willing to adopt new practices and inputs; reflects a reduction in physical strength, thereby increasing inefficiency (Binam et al., 2005). On the other hand, older household heads may have more experience with farming, higher accumulated capital therefore better preferred by credit institutions and therefore expected to be more efficient. The effect of age of household head on efficiency was anticipated to be either positive or negative.

Table 3: Variables Included in the Tobit Model and their Description

Variable	Description	Hypothesized sign
Age	Age of household head in number of years	+/-
Gend	Dummy variable with value 1 if household head is male and 0 otherwise	+
Educ	Number of years of schooling for the household head	+
Exp	Experience measured by number of years producer has cultivated Irish potatoes	+
Ext	Number of visits by extension agents	+
Credit	Dummy variable with a value of 1 if producer had received credit and 0 otherwise	+
Assoc	Dummy variable with a value of 1 if the producer is a member of a farmers' association and 0 otherwise	+

In the model the gender (*Gend*) variable is a dummy (1: male; 0: female) that was included to estimate the differences of efficiency levels between male and female headed households. Male headed households are likely to have better access to information and services and therefore farms managed by men are expected to attain higher efficiency than those managed by women. For this reason the expected sign for this variable in the model was positive.

The education (*Educ*) variable was used as a proxy for managerial input. The education level of the household head was measured by the number of years of formal schooling. Education represents the human capital of the household head. The assumption was that the household head whether male or female, is also the primary decision maker in the family farm. More educated producers are assumed to be more efficient in their acquisition and processing of technical knowledge. This may lead to better assessment of the importance of good farming decisions including efficient use of inputs. It was postulated that more years of schooling of the household head would lead to higher production efficiency.

Experience (*Exp*) of the household head, was measured by the number of years the household head had cultivated Irish potatoes. It was hypothesized that more years spent on Irish potato farming predisposes farmers to better farming techniques through learning by doing. Increased farming experience may also lead to good farm decision making including the efficient use of inputs. Experience is an important positive determinant of a farmer's level of efficiency Experience was therefore postulated to be positively influence technical, allocative and economic efficiency.

The extension (*Ext*) variable represents the number of visits to the farm by extension workers. Contact with extension was recorded as the number of visits paid to the Irish potato farm during the year 2007 by extension workers. Access to information or extension messages is one of the institutional characteristics hypothesized to influence a farmer's decision to adopt a new technology. Extension workers also provide information on new technologies, on markets, farm inputs and sale of produce. Access to extension is assumed to expose farmers to more knowledge on improved production methods. Regular contacts with the extension workers are expected to facilitate practical use of modern techniques and adoption of improved agronomic practices. This variable was therefore expected to have a positive impact on efficiency.

The association (*Assoc*) variable is a dummy (1=farmer is a member; 0=otherwise). Farmers usually belong to various farmers' associations dealing with Irish potato production and marketing. It is expected that farmers who are members of associations are in a privileged position with respect to other farmers in terms of access to information. Membership in a farmers' association implies that farmers meet regularly and allow discussions on potato production. Associations may also provide mechanisms for mutual support among members by securing labour, skills and as well as access to financial institutions prepared to lend credit to farmers only when they are in an association or group, in addition to lending among themselves e.g. in merry-go-rounds or table banking. Being a member of a farmers' association was hypothesized to be positively associated with production efficiency.

Credit (*Credit*) is a dummy variable indicating if farmer had received and used credit in Irish potato production (1: yes, 0: otherwise) and is used to capture the effect of credit on the production efficiency level of farmers. The availability of credit will loosen the constraints of production therefore facilitating the acquisition of inputs on a timely basis and hence is supposed to increase the level of efficiency of the farmers. Farmers who receive credit are assumed to overcome liquidity constraints, purchase more production inputs or a new technological package such as high yielding seeds since this can be regarded as access to funds. The expected sign of the estimated coefficient for credit is positive.

For the investigation of socio-economic and institutional factors affecting efficiency levels the following model was estimated:

$$\begin{aligned} EFF_i = \delta_0 + \delta_{1i}\ln(Age_i) + \delta_{2i}(Gend_i) + \delta_{3i}\ln(Educ_i) \\ + \delta_{4i}\ln(Exp_i) + \delta_{5i}\ln(Ext_i) + \delta_{6i}(Credit_i) + \delta_{7i}(Assoc_i) \end{aligned} \quad (15)$$

where EFF is the natural logarithm of technical (*TE*), economic (*EE*) and allocative (*AE*) efficiency indices respectively. The subscript i, indicates the ith household in the sample (i=1,…..,127); ln represents the natural logarithm (i.e., logarithm to base e); $\delta_{0i}, \delta_{1i}, \ldots\ldots\delta_{7i}$ are parameters to be estimated. *Age* represents the age of the household head (in years); *Gend* represents the gender dummy which has the value of 1 for male and 0 otherwise; *Educ* refers to the number of years of formal schooling of the household head; *Exp* represents the experience of the household head, measured by the number of years the farmer has grown Irish potatoes; *Ext* represents access to extension services, measured by the number of extension visits by extension agents; *Credit* represents the credit dummy which has the value 1 if household had received credit, 0 otherwise; *Assoc* represents a dummy for membership in a farmers' association, which has the value 1 if the farmer is a member of a farmers' organization and 0 otherwise.

The empirical model in equation 15 was estimated using a censored regression model. Therefore given that the dependent variable (*EFF*) is censored: the efficiency indices are scaled from a lower limit of 0 to an upper limit of 1 and cannot fall outside of this range, a censored regression model is appropriate for estimation of this equation. Using ordinary least squares (OLS) regression analysis for such data will yield biased and inconsistent parameter estimates and therefore a maximum likelihood estimation procedure is more appropriate.

The most common censored regression model is the Tobit model which expresses the observed level in terms of an underlying latent variable. A Tobit is a censored regression model in which the dependent variable is observed only if it is above or below some cut off level. A two-limit Tobit model is a censored normal regression model where the dependent variable is continuous but its range is constrained both from above and below by cut-off points. In equation 15, the dependent variable, *EFF* lies in a double bounded range (i.e., between zero and one). Three separate equations - for determinants of technical, allocative, and economic efficiency - were estimated using a two-limit Tobit model with the dependent variable, *EFF*, as the technical, allocative and economic efficiency indices respectively.

In the two-limit Tobit model, the observed level of the dependent variable (i.e., *EFF*) is expressed in terms of an underlying latent variable Y^*. Following Binam et al. (2005), the functional form of the two-limit Tobit model is given as:

$$\begin{aligned}
EFF_i^* &= X_i b + \mu_i \\
EFF &= L_{1i}, \text{if } EFF_i^* \leq L_{1i} \\
&= EFF_i^*, \text{if } L_{1i} < EFF_i^* < L_{2i} \\
&= L_{2i}, \text{if } EFF^* \geq L_{2i}
\end{aligned} \quad (16)$$

where EFF_i^* is the non-observable efficiency latent variable; X is the nxk matrix of explanatory variables; b is a kx1 vector of parameters to be estimated; L_{1i} is the lower limit (i.e. zero); L_{2i} is the upper limit (i.e. 1); and μ_i is an independently and normally distributed error term with zero mean and constant variance σ^2. The ε_i is identically and independently distributed (iid) as $\varepsilon_i \sim N(0, \sigma^2)$.

The threshold values in the above model is zero and one because the efficiency scores lie between the two values. The two-limit Tobit model was estimated using STATA computer programme.

3.7 Empirical Estimation Procedure

In this study a parametric stochastic efficiency decomposition approach (Bravo-Ureta and Pinheiro, 1997) is used to measure the production efficiency in Irish potato production. This is an extension of Kopp and Diewert's (1982) cost decomposition and efficiency estimation procedure. The stochastic frontier production function model is specified as follows:

$$Y_i = f(X_i; \beta) + \varepsilon_i \quad (17)$$

where Y_i measures the quantity of output; X is a nxk matrix of the input quantities; β is a kx1 vector of parameters to be estimated; $f(X_i; \beta)$ is a frontier production function; and ε_i is a composite error term (Aigner at al., 1977). Following Aigner et al. (1977) the composite error term is given as:

$$\varepsilon_i = \nu_i - \mu_i \quad (18)$$

where ν_i is assumed to be independently and identically distributed as $\nu \sim N(0, \sigma_v^2)$ random error and represents random variability in production that cannot be influenced by producers,

μ_i is a non-negative random variable associated with technical inefficiency in production and is independently and identically distributed as half-normal, $\mu \sim N(0, \sigma_\mu^2)$. The frontier production function $f(X_i;\beta)$ measures the maximum potential output for a given input vector, X_i. Both ν_i and μ_i cause actual production to deviate from the frontier.

In the empirical estimation, first a Cobb-Douglas function was specified and used to model Irish potato production technology. The frontier production function in equation (17) was then estimated using maximum likelihood estimation procedures which provided estimators for β and variance parameters, $\sigma^2 = \sigma_v^2 + \sigma_\mu^2$ and $\gamma = \sigma_\mu^2/\sigma^2$.

To empirically measure efficiency, deviations from the frontier were separated into a random (ν) and an inefficiency component (μ). Following Jondrow et al. (1982) and given the distribution and independence assumptions on ν_i and μ_i in addition to the fitted values of ε_i the conditional mean of μ_i was estimated as:

$$E(\mu_i \mid \varepsilon_i) = \sigma_* \left[\frac{f^*(\lambda\varepsilon_i/\sigma)}{1 - F^*(\lambda\varepsilon_i/\sigma)} - \frac{\lambda\varepsilon_i}{\sigma} \right] \qquad (19)$$

where $\sigma_*^2 = \sigma_\mu^2\sigma_v^2/\sigma^2$, f^* is the standard normal density function and F^* is the distribution function both functions being evaluated at $\lambda\varepsilon/\sigma$. From this calculation, estimates of ν and μ were determined.

According to Bravo-Ureta and Pinheiro (1997) the efficiency of the ith firm is measured using adjusted output. Adjusted output was derived by subtracting the random error ν_i from both sides of equation (17) thus:

$$Y_i^* = f(X_i;\beta) - \mu_i = Y_i - \nu_i \qquad (20)$$

where Y_i^* is ith firm's observed output adjusted for the statistical noise captured by ν_i, $f(X_i;\beta)$ is the deterministic frontier output, and ν_i and μ_i are respectively, the random and inefficiency components of overall deviations from the frontier.

Adjusted output Y_i^* was used to derive the ith firm technically efficient input vector X_{it} by simultaneously solving equation (20) and the observed input ratios $X_1/X_i = k_i$ ($\forall i>1$), where k_i is equal to the observed ratio of the two inputs in the production of Y_i^*.

Given the assumption of Cobb-Douglas technology the frontier production function is assumed to be self-dual (Xu and Jeffrey, 1998). The dual cost frontier can be derived analytically from the production function in equation (9) and written in a general form as follows:

$$C_i = h(P, Y^*; \Phi) \quad (21)$$

where C_i is the minimum cost of the ith firm associated with output Y^*; P is a vector of average input prices; and Φ is a vector of parameters to be estimated.

The economically efficient input vector for ith firm, X_{ie}, was derived by applying Shephard's Lemma (Shephard, 1970) and substituting the average input prices and adjusted output levels into the derived system of input demand equations given by:

$$\partial C / \partial P_i = X_{ie}(P_i, Y_i; \Phi), \quad (22)$$

where Φ is a vector of estimated parameters.

The observed, technically efficient and economically efficient costs of production of the ith firm are equal to $\Sigma X_i P_i$, $\Sigma X_{it} P_i$ and $\Sigma X_{ie} P_i$ respectively. These cost measures were used to compute the technical (*TE*), allocative (*AE*) and economic (*EE*) efficiency indexes for ith firm as follows:

$$TE_i = \Sigma X_{it} P_i / \Sigma X_i P_i \quad (23)$$

$$EE_i = \Sigma X_{ie} P_i / \Sigma X_i P_i \quad (24)$$

Following Farrel (1957), the allocative efficiency (*AE*) index was then derived from equations (23) and (24) as follows:

$$AE_i = EE_i / TE_i = \Sigma X_{ie} P_i / \Sigma X_{it} P_i \quad (25)$$

where $\Sigma X_{it} P_i$ and $\Sigma X_{ie} P_i$ are, respectively, the technically and economically efficient cost of production. $\Sigma X_i P_i$ is the observed (or actual) cost of production for any farm's observed level of output.

Following the quantification of technical, allocative and economic efficiency indices, a second stage analysis involving a regression of theses indices on the hypothesized socio-economic and institutional factors affecting efficiency of farmers using a two-limit Tobit was carried out.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Characteristics of Irish Potato Production System

Table 4 presents a summary statistics of the socio-economic characteristics of the farm households. The mean age of the household heads in the sample was 47 years old with 10.64 years standard deviation. The minimum age of the household heads was 26 years and the maximum was 70.

Table 4: Socio-economic Characteristics of Irish Potato Producers

Characteristic	Unit	Mean	Std. Dev	Min.	Max.
Age of household head	Years	47.06	10.643	26	70
Education level	Years	9.59	3.003	0	18
Experience of producer	Years	14.13	8.232	2	35
Contact with extension	No. of visits	1.09	1.362	0	6
Family size	Persons	4.82	1.706	1	10
Farm size (acres)	Hectares	2.46	3.057	0.51	24.49

Source: Computed from Field Survey Data

The average level of education (years of formal schooling) of the household head was 9 years with a range of 0 to 18 years. The mean years of education suggest that on average the level of education attained by sample farmers is a secondary school level of education.

Experience was measured by the number of years household head had spent producing Irish potatoes. The overall mean number of years of experience was 14 years with the highest being 35 and lowest 2 years. Table 4 shows that, on average, extension workers made one visit to each sample farm household in 2007, which undoubtedly will hamper technology transfer. The number of extension workers visits to the farm households recorded ranges between 0 and 6. This

Family size defined as the total number of people living in the household at least 12 months prior to the interview averaged 5 persons, ranging from 1 and 10 persons. The farm sizes ranged between 0.51 to 24.49 hectares. The results show that the average farm size was 2.46 hectares with a standard deviation of 3.057 hectares. As population increases land per capita will decline and there is therefore need to improve the productivity and efficiency of farmers.

Table 5 presents characteristics with respect to gender, access to credit and membership in a farmers' association of the sample Irish potato producers. In terms of gender, of the 127 randomly selected households, 38 (30%) were female headed while 89 (70%) were male headed.

Table 5: Gender, Access to Credit, and Membership in Farmers' Association

Characteristic	Number of farmers	Percent of farmers
Gender of household head		
Male	38	30
Female	89	70
Received credit		
Yes	44	35
No	83	65
Member in farmers' association		
Yes	53	42
No	74	58

Source: Computed from Field Survey Data

On average only 35% of the sample households used credit in which indicates that opportunities for accessing credit appear to be limited in the study area. Only 53(42%) of the farmers were members of a farmers' association while the rest 74(58%) were not. Irish potato producers identified the benefits of being a member in a farmers' association as being enabled to access extension services, mutual support and in some cases acquiring credit.

Table 6 shows the frequency distribution of the age, educational level and years of experience of the household heads. Of the respondents, 33.1% were between 36 and 45 years old, 29.1% were between 46 and 55 years of age, and only 23.6% were older than 55 years of age.

Education level of the household head is an important variable likely to have a positive influence of efficiency. With respect to the education level of the household head, 87 (68.5%) household heads had 8 to 14 years of formal schooling, 34 (26.8%) had 1 to 7 years of formal schooling while 5 (3.9%) of household heads had above 15 years of formal schooling. Therefore majority of the household heads had attained a secondary school education.

Majority of the sample households (65.3%) had grown Irish potatoes for over 10 years while 34.6 % had grown Irish potatoes for less than 10 years. Experience is one of the socio-economic variables that was hypothesized to positively influence production efficiency of the farmers, through learning by doing.

Table 6: Frequency Distribution of Age, Educational level, and Experience of Household Heads

Characteristic of household head	Number of household heads	Percentage of total number of household heads
Age (years):		
25-35	18	14.2
36-45	42	33.1
46-55	37	29.1
55+	30	23.6
Education level (years):		
0	1	0.008
1-7	34	26.8
8-14	87	68.5
15+	5	3.9
Experience (years):		
≤10	44	34.6
11-20	61	48.0
21-30	20	15.7
31+	2	1.6

Source: Computed from Field Survey Data

Table 7 presents results of sample Irish potato producers' contact with extension workers by division. Of the sample households, on average, only 49.8 % were visited by extension workers which imply that the majority of the farmers (50.2%) had no contact with extension agents.

Table 7: Sample Farmers' Access to Extension by Division

Division	Mean number of visits per year	Percentage of farmers receiving extension
Ndaragwa	1.27	57.5
Ol joro orok	0.98	45.5
Ol kalou	1.02	46.5
Mean	1.09	49.8

Source: Computed from Field Survey Data

Given such a low farmer-extension worker contact, then the intended objective of facilitating farmers access to production technology and hence productivity in the Irish potato sector might be hard to achieve. In recent years, the numbers of government extension workers have been going down due to natural attrition and retrenchment while the number of farmers have been increasing. This indicates the need for more innovative approaches of farmer training in order to enhance technology transfer.

The sources of credit obtained by the sample farmers are presented in Table 8. Credit access by Irish potato farmers was poor. Of those who received credit, majority obtained credit from relatives and/or friends accounting for 48.8% of credit sources while rotating savings and credit associations (ROSCAS) accounted for 34.1%. Other sources were savings and credit societies (10.5%), input traders (3.8%) and others (2.8%). It can be concluded that informal sources constituted the greatest source of credit for those who accessed. This may be due the ease with which credit from these sources can be accessed with minimal transaction costs and without collateral.

Table 8: Sources of Credit for Irish Potato Producers

Source of credit	Percentage of farmers receiving credit
Savings and credit societies (SACCO)	10.5
Relatives and friends	48.8
Rotating savings and credit associations (ROSCAS)	34.1
Input traders	3.8
Others	2.8

Source: Computed from Field Survey Data

A summary statistics of the variables which are defined in the production function empirical model in equation 9 are presented in Table 9. The mean yield of Irish potatoes obtained by farmers was approximately 97.55 bags per hectare with a standard deviation of 39.16 bags. Irish potato yields was highly variable, ranging from 62.05 to 185 bags/ha. The yield gap between the average and the lowest was 35.5 bags and between the average and the highest was 87.45 bags/ha. These results suggest that there is considerable room for improving average Irish potato yields in the study area.

The mean plot size over the sampled farms was 0.34 hectares with a range of about 0.082 to 1.22 hectares. This implies that most of the farmers grew Irish potatoes on a small-scale given than on average the national Irish potato acreage ranges between 0.5 to 5 hectares (Lung'aho et al., 2006).

Table 9: Summary Statistics of Variables in the Production Function

Variable	Unit	Mean	Std. Dev	Min.	Max.
Output	Bags[a]/ha	97.55	39.16	62.05	185
Plot size	Hectares	0.34	0.215	0.082	1.22
Labour	Man-days/ha	154.19	53.90	95.08	345.45
Seed	Kgs/ha	1592.10	639.22	1326.67	2975.38
Fertilizer	Kgs/ha	238.12	145.34	0	653.33
Fungicide	Grams/ha	1377.86	1441.93	0	4900

[a]1 Bag = 110 kg
Source: Computed from Field Survey Data

The quantity of seed per hectare is an important variable, which might cause considerable variation in yield per hectare. The average quantity of seeds per hectare planted in the study area by the sample farmers was 1592.10 kgs/ha and this was found to vary from 1326.67 to 2975.38 kgs/ha. This average quantity of seed per hectare is lower than the recommended quantity of 1960 kg/ha (KARI, 1995). This has negative implication on output and eventually on yield. Average labour use was 154 man-days per hectare which varied widely from a minimum of 95 to a maximum of 345 man-days.

Fertilizer is another important variable and is one of the critical inputs in Irish potato production because of high nutrient requirements of the crop. Average fertilizer use was 238.12 kilograms per hectare. However, fertilizer application varied widely between non-application and 653 kgs/ha for the respondents. The average quantity falls below the recommended fertilizer quantity of 500 kilograms per hectare of Diammonium Phosphate (MoA, 2002). A survey by Odero (1997) in Kinangop division of Nyandarua district also found that on average farmers applied 156.06 kg/ha while Kinyae et al. (1996) reported majority of farmers using 122.5-245 kg/ha of DAP fertilizer in Nyandarua district. This low fertilizer application has implications on achievable yields.

Table 10 presents the frequency distribution of Irish potato plot sizes by division. Of the sample households, about 78 percent grew Irish potatoes on a plot size of less than 0.41 hectares while 15.8 percent and 6.3 percent of the households had plot sizes of 0.41-0.61 hectares and over 0.61 hectares respectively.

Table 10: Frequency Distribution of Potato Plot Size by Division

Plot size (ha)	Division			Total
	Ndaragwa	Ol joro orok	Ol Kalou	
≤0.20	25(62.5)	20(45.5)	10(23.3)	55(43.3)
0.21 – 0.40	11(27.7)	15(34.1)	18(41.9)	44(34.6)
0.41 – 0.60	2(5)	9(20.5)	9(24.3)	20(15.7)
0.61+	2(5)	0(0)	6(14.0)	8(6.3)
Total	40(100)	44(100)	43(100)	127(100)

Note: Numbers in parentheses are percentage of plots
Source: Computed from Field Survey Data

Ol kalou division had a higher percentage of farmers with plot sizes of 0.21-0.4 ha (41.9%). In Ndaragwa and Ol joro orok, plot sizes devoted to potato production were smaller relative to Ol kalou division. In Ndaragwa, 62.5% had plot sizes of about 0.20 ha or less while 45.5% had similar potato plots in Ol joro orok division. There are similarities between these findings and those in a study by Kinyae et al. (1996), who found that 57% of the farmers interviewed grew Irish potatoes on less than 0.4 hectares while 43% had 0.4 to 1.22 hectares of land under Irish potato production.

Table 11 shows the frequency distribution of sample households growing the different varieties of Irish potatoes. Of the sample households, 41.7% grew 'Tigoni' variety while 'Nyayo' variety was planted by 28.3%. Others are Kerr's pink, 'Tana' and 'Asante' which were planted by 11.8, 5.5 and 3.9 percent of the households respectively.

Table 11: Major Irish Potato Varieties Grown and Frequency Distribution

Variety	Frequency	Percent
Kerr's Pink	15	11.8
Tigoni	53	41.7
Nyayo	36	28.3
Asante	5	3.9
Tana	7	5.5
Other	11	8.7
Total	127	100.0

Source: Field survey data

Figure 4 shows the mean yields of the varieties planted by the sample households. Generally, 'Tigoni' variety had the highest mean yield of 115.75 bags per hectare and therefore appears more popular with farmers followed by 'Asante' with a mean yield of 97.62 bags per hectare. Despite the yield for 'Tigoni' being the highest, perceived weaknesses of 'Tigoni' variety are poor storage, rapid greening of tubers and limited availability of planting materials (Walingo et al., 2002; Kabira, 2002).

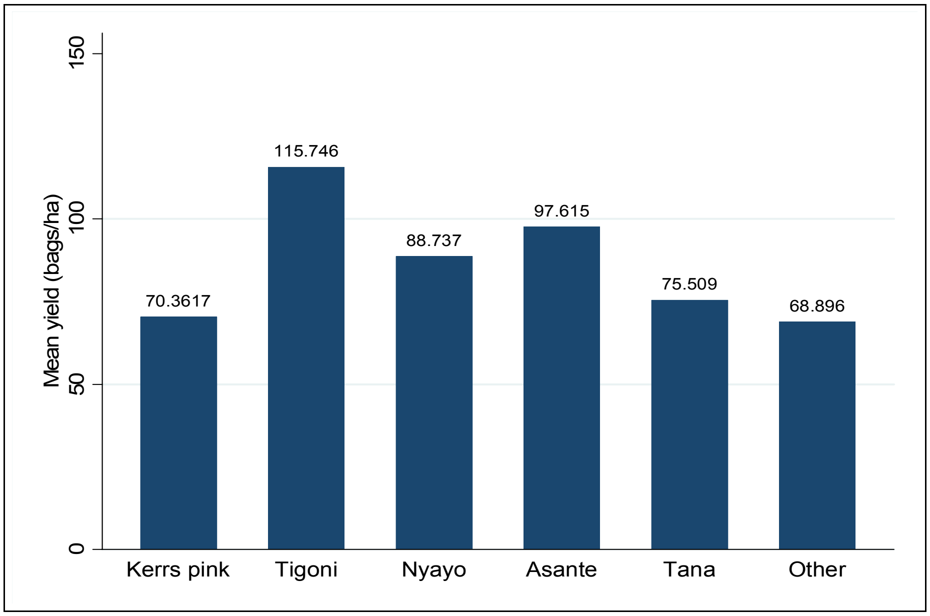

Figure 4: Mean Yield of Irish Potato Varieties

Source: Computed from Field Survey Data

4.2 Stochastic Production Frontier Estimation Results for Irish Potato Production

4.2.1 Stochastic Production Frontier Estimates

Table 12 presents the results of the maximum likelihood (ML) estimates of Cobb-Douglas stochastic frontier production function. The maximum likelihood estimates of the parameters defined by equation (9) were obtained by using FRONTIER 4.1 (Coelli, 1996) computer programme. Ordinary least squares (OLS) production function estimation results are presented for comparison purposes.

Before examining the parameter estimates of the production frontier and the factors affecting the efficiency of smallholder farmers, the validity of the model was analyzed. To analyze the impact of variety on output, variety dummies were included in the production function as explanatory variables. All the coefficients for the varieties were found to be insignificant and therefore excluded from the final estimation.

Table 12: Stochastic Production Frontier and Ordinary Least Squares (OLS) Production Function Estimates

Variables	Stochastic frontier (ML) estimates		Ordinary least squares (OLS) estimates	
	Coefficient	p-value[1]	Coefficient	p-value
Intercept	1.506**	0.016	0.639	0.394
Ln(Plot size)	0.373***	0.004	0.260*	0.077
In(Labour)	0.205**	0.033	0.241**	0.021
Ln(Seed)	0.175**	0.042	0.216*	0.057
Ln(Fertilizer)	0.071***	0.002	0.082***	0.002
Ln(Fungicide)	0.031***	0.003	0.033***	0.006
Function coefficient	0.855		0.832	
F statistic model			55.80	
F-statistic CRTS			7.287	
σ_μ	0.491			
σ_v	0.203			
$\lambda = \sigma_\mu / \sigma_v$	2.418			
σ^2	0.282***	0.000		
$\gamma = \sigma_\mu^2 / \left(\sigma_\mu^2 + \sigma_v^2\right)$	0.854***	0.000		
Log-likelihood	-46.759		-50.32	
Adj. R^2			0.70	

*, ** and *** Significant at the 10%, 5%, and 1% level, respectively. CRTS - Constant returns to size.
[1]p-values are computed from t-ratios (source: Abramowitz and Stegan. Hand book of Math Functions. http://www.graphpad.com)
Source: Computed from Field Survey Data

The sigma-squared, gamma, and log likelihood parameters shown in Tables 12 presents results on the behavior of the error term outlined in equation 9. These parameters are used for statistical tests for inefficiency effects in the model and the appropriateness of the model to represent the data. The gamma (γ) parameter is defined as the ratio of the unexplained inefficiency error term (σ_μ^2) to the total sum of errors, that is $\gamma = \sigma_\mu^2/(\sigma_v^2 + \sigma_\mu^2)$. The gamma ($\gamma$) parameter was employed to test for inefficiency effects in the model. The gamma (γ) tests whether the observed variations in efficiency are simply random or systematic. In other words the γ-parameter measures the effect of technical inefficiency in the total variation of observed output (i.e., $\gamma = \sigma_\mu^2/(\sigma_v^2 + \sigma_\mu^2)$ from the frontier output. It is bounded by 0 and 1, where if γ is zero, then inefficiency effects are not present in the model, and if it is one inefficiency exists and is not random.

The significance of this (γ) parameter was used in this study to test the null hypothesis that Irish potato producers in Nyandarua North district are technically efficient. The estimate of the variance parameter, γ, was significantly different from zero at the 1% level of significance. Therefore the null hypothesis that Irish potato producers are technically efficient was rejected.

The estimate of the value of the variance parameter was close to unit (0.85). The variance, σ_μ^2, associated with inefficiency effect is about 85% of the total variance which indicates that the one sided error (inefficiency) component strongly dominates the total variance. This implies that the inefficiency effects are significant in determining the level and variability of output of Irish potato producers. Therefore the observed variations in output among the Irish potato farmers are mainly due to differences in farm practices and characteristics of sample Irish potato farmers rather than random factors beyond their control like weather, pests and diseases, e.t.c.. In other words, the shortfall of observed output from the frontier output was primarily due to factors, which are within the control of the Irish potato producers in the sample under study. Alternatively, the ordinary least squares (OLS) production function with no technical inefficiency is not an adequate representation of the data.

The generalized log-likelihood ratio (LR) statistic, defined by equation (12) was used to test the validity of the stochastic frontier production function over the ordinary least squares model. Under the null hypothesis (H_0), the value of the restricted log-likelihood function for the ordinary least squares production function is -50.32, while under the alternative hypothesis (H_1) for the stochastic Cobb-Douglas function, the value of the unrestricted log likelihood function is -46.759. This implies that the generalized likelihood-ratio (LR) statistic for testing the absence of technical inefficiency effect from the frontier is calculated to be, LR = -2*(-50.32+46.759) =7.122. This value exceeds the critical $\chi^2(5\%,1)$ value of 3.84 at 5% level of significance. Thus the null hypothesis was rejected indicating that the stochastic frontier production function was an adequate representation of the data, given the corresponding ordinary least squares production function.

The maximum-likelihood parameter estimates of the model show that all the parameter estimates have expected positive signs and are statistically significant in the frontier model. Plot size, fertilizer and fungicide were statistically significant at the 1% level while labour and seed are statistically significant at 5% level (Table 12).

The production elasticity measures the proportional change in output resulting from a proportional change in a given input with all other input levels held constant. The results indicate that the inputs with the largest coefficients (elasticity) are land (0.373) and labour (0.205), implying that these two inputs have a major influence on output in Irish potato production in the study area. This suggests that, *ceteris paribus*, an increase in the extent of land under Irish potato production, in terms of larger plot sizes, would lead to a significant increase in Irish potato output.

The returns-to-scale parameter indicates what would happen to output if all inputs are increased simultaneously. Restricted least squares regression was used to test the null hypothesis that the production frontier exhibits the property of constant returns to scale. The computed F-statistic in the least squares regression is 7.287 which exceed the critical F-value of 3.919 at the 1% level of significance. Based on the results of the restricted least squares regression[2], the null hypothesis of constant returns to size was therefore rejected.

The sum of the estimates for the coefficients is 0.855 which implies that on average, the production frontier exhibits decreasing returns to scale. The implication of this result is that every proportionate increase to the production inputs would lead to less than proportionate addition to the Irish potato output for the farmers.

The estimated average production function indicates the potential contribution of physical inputs to the level of Irish potato output. The adjusted R-squared show that the model fits the data well. The results of the ordinary least squares estimates shows that 70% (Adj. R^2=0.70) of the variation in Irish potato output is explained by the inputs modeled in the analysis (i.e. plot size, labour, seed, fertilizer and fungicide).

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[2] The restricted regression equation is only valid if there are constant returns to scale. To test if this restricted regression is valid, it is compared to the unrestricted regression by means of an F-Test

$$F = \frac{(RSS_R - RSS_{UR})/m}{RSS_{UR}/(n - k)}$$

where R and UR stand for restricted and unrestricted, respectively; *m* is number of linear restrictions (1 in present example); *k* is number of parameters in unrestricted regression (including intercept).

The Maximum-likelihood (ML) estimates of the parameters of the stochastic production frontier model, are given in the following equation:

$$\begin{aligned} \ln Y_i &= 1.506 + 0.373 \ln Psize_i + 0.205 \ln Lab_i + 0.175 \ln Seed_i \\ &+ 0.071 \ln Fert_i + 0.031 \ln Agchem_i \end{aligned} \quad (26)$$

where $\ln Y_i$ is the log of Irish potato output (in bags) for the ith farm; $\ln Psize$ is the natural log of the Irish potato plot size (in acres); $\ln Lab$ is the natural logarithm of the labour input (in man-days); $\ln Seed$ is the natural logarithm of the quantity of seed (in kgs); $\ln Fert$ represents the natural logarithm of the quantity of fertilizer (in kgs); and $\ln Agchem$ refers to the natural logarithm of amount of fungicide used (in grams).

All the coefficients in the stochastic frontier showed the expected positive relationship with Irish potato output implying that increasing the amounts of the respective inputs results in increases in output. The coefficients of plot size, fertilizer, and fungicides are statistically significant at 1% level of significance, while coefficients of labour and seeds are significant at 5% level.

The coefficients, which represent partial elasticities of the respective inputs, have magnitudes less than one. This implies that output is inelastic with respect to changes in inputs (plot size, labour, seed, fertilizer and fungicide) which means that on average, when they are changed by 1%, the proportionate change in Irish potato output is less than 1%. Furthermore, this implies they were positive decreasing functions, indicating that input use was in stage two of the production function (i.e., the stage of economic relevance of the production function).

In terms of magnitude, the size of plot ($\ln Psize$), measured by land area planted to Irish potatoes, has the largest coefficient. The partial elasticity for plot size is 0.373 ($p<0.01$) which indicate that this coefficient is statistically significant at 1% level. On average, for a 1% percent increase in area cultivated to Irish potato, there will be increase by 0.373 percent increase in potato output. Plot size has the largest coefficient meaning the largest impacts on output would be experienced if farmers could increase their plot sizes under Irish potatoes. This finding is similar to those reported by Bravo-Ureta and Pinheiro (1997) who found a partial elasticity of 0.357 for farmers in the Dominican Republic.

Results also show that production elasticity for labour is 0.205 ($p<0.05$) which indicates that the coefficient is statistically significant at 5% level of significance. This implies that using labour for cultivation of Irish potatoes influenced the level of output. Iraizoz et al. (2003) and Alene et al. (2003) found similar results in Spain and Ethiopia respectively. From the partial elasticity we can infer that, on average, a 1% increase in amount of labour, will increase Irish potato output by 0.205 percent. It also emphasizes the importance of human capital development for higher productivity and growth. In a situation where farmers do not have means to hire labour or have access to adequate family labour the level of Irish potato productivity could be reduced.

The value of the coefficient for seed is 0.175. This indicates that a 1% increase in quantity of seed used will result, on average, in a 0.175 percent increase in Irish potato. The greater use of seed increases plant population and thus increases yield. The calculated p-value is 0.042, which indicates that this coefficient is statistically significant at 5% level of significance. This finding is consistent with results obtained by Bravo-Ureta and Pinheiro (1997) in the Dominican Republic, in which they found the partial elasticity for seed to be 0.169.

The production elasticity of output with respect to quantity of fertilizer is 0.071 ($p<0.01$). On average, by increasing the quantity of fertilizer by 1% the level of output of Irish potato will increase by a margin of 0.071%. The estimated coefficient is highly statistically significant at 1%. Alene et al. (2003) in their study of the impact of Ethiopia's new extension programme found a partial elasticity of 0.098 for fertilizer. This is also consistent with other studies. Xu and Jeffrey (1998) for conventional rice in China found a partial elasticity of fertilizer of 0.080, whereas Bravo-Ureta and Pinheiro (1997) in a study of peasant farmers in Dominican Republic obtained a partial elasticity of 0.057. In contrast, Khai et al. (2007), in their analysis of Soybean production in Vietnam found a higher figure of 0.356.

Fungicide has a coefficient value of 0.031 ($p<0.01$). Use of fungicides influences the level of Irish potato production. From the result a 1% increase in the quantity of fungicide used, will on average, result in an increase of 0.032 percent Irish potato output. The calculated p-value for this coefficient is 0.003 hence the coefficient is significant at 1% level of significance. This result tallies with that of Xu and Jeffery (1998) in an earlier study for conventional rice production in China. The authors found a partial elasticity of 0.055.

The sum of the partial elasticities (function coefficient) indicates the scale of production. A function coefficient of one indicates constant returns to scale. Similarly, a function coefficient less than one and greater than one indicates decreasing and increasing returns to scale respectively. The function coefficient under the maximum likelihood estimates is 0.855 (Table 12). This indicates that farmers are facing decreasing returns to scale and that Irish potato production in the study area is in stage II of the production region. In other words, if all the inputs are increased by 1%, output of Irish potatoes will increase on average by 0.855%.

The important conclusion from analysis of the production elasticities and returns to scale is that farmers are operating on the rational part of the production process (i.e., stage II). However an important issue here is how efficiently these farmers are organizing their production activities so as to maximize their returns given the prevailing input and output prices.

4.2.2 Dual Cost Frontier Estimate

The production function in defined by equation (26) was estimated by a Cobb-Douglas production function and is therefore self-dual. This estimated Irish potato production function was used in combination with the average input prices to derive the dual frontier cost function. The dual cost frontier was derived analytically from the estimated production frontier and used to estimate the economic and allocative efficiency.

The resulting parameter estimates of the dual cost frontier for sample Irish potato producers are presented in Table 13. The results show that all the parameter of the dual cost frontier conform to a priori expectation of positive coefficients for all the inputs modeled in this study. This implies that as these inputs are increased, total Irish potato production cost increases.

Table 13: Parameter Estimates of Dual Cost Frontier

Variable	Coefficient	Description	Value
P_R	α_1	Seasonal rent of an acre of land (Kshs)	0.436
P_L	α_2	Daily wage of labour per man-day (Kshs)	0.240
P_{SD}	α_3	Price of seed per kilogram (Kshs)	0.205
P_{CF}	α_4	Price of fertilizer per kilogram (Kshs)	0.083
P_{AC}	α_5	Price of fungicide per gram (Kshs)	0.036
Y_i^*	α_6	Output adjusted for statistical noise	1.17

Kshs = Kenya shillings.

Source: Derived from Stochastic Production Frontier

The dual cost frontier function derived analytically from the stochastic production frontier shown in equation (26), is given as follows:

$$C_i = 0.667P_R^{0.436}P_L^{0.24}P_{SD}^{0.205}P_{CF}^{0.083}P_{AC}^{0.036}Y_i^{*1.17} \quad (27)$$

which in log-linear form becomes

$$\begin{aligned} \ln C_i &= -0.405 + 0.436\ln P_R + 0.240\ln P_L + 0.205\ln P_{SD} \\ &+ 0.083\ln P_{CF} + 0.036\ln P_{AC} + 1.17\ln Y_i^* \end{aligned} \quad (28)$$

where the subscript i, indicates the ith household in the sample (i=1,….,127); ln represents the natural logarithm (i.e. logarithm to base e); α_k are estimated parameters (k =1,….,5). C is the minimum cost of producing Irish potato; P_R is the seasonal rent of an acre of land in the study area (in Kshs); P_L is the daily wage rate per man-day (in Kshs); P_{SD} is the price of seed per kilogram (in Kshs); P_{CF} is the price of fertilizer per kilogram (in Kshs); and Y_i^* is the quantity of Irish potato output (in bags) adjusted for any statistical noise.

4.3 Technical, Allocative and Economic Efficiency Estimates for Irish Potato Producers

4.3.1 Farm-specific Technical, Allocative and Economic Efficiency Estimates

The frequency distribution and summary statistics of farm-specific efficiency indices is presented in Table 14. The technical, allocative and economic efficiency indices were estimated using the dual frontier cost function defined by equation (27), average input prices and equations (23), (24) and (25).

The results of efficiency analysis revealed that technical efficiency of the smallholder Irish potato producers varied from a minimum of 21.2% to a maximum 92.9% with a mean of 66.7%. In other words, on average smallholder Irish potato producers in the study area incur a 33.3 percent loss in output due to technical inefficiency. This implies that on average output can be increased by at least 33.3 percent while utilizing existing resources and technology if inefficiency factors are fully addressed.

Similar results have been reported by other researchers elsewhere. Abdulai and Huffman's (2000) study of rice farmers in four districts in Northern Ghana reported a wide variation in the level of efficiency for rice farmers that ranged from 16 percent to a maximum of 95.5 percent. The mean technical efficiency of 66.7% is comparable to the 69.8 percent figure reported by Abdulai and Eberlin (2001) for a sample of maize farmers in Nicaragua. Similarly, Khai et al. (2007) found a mean technical efficiency (*TE*) of 73.9 for Soybean producers in the Mekong River delta in China. The mean technical efficiency found in this study is lower than the 80 percent reported by Abedullah and Khuda (2006) for a sample of potato producers in Punjab, Pakistan. Irish potato farms have a potential to reduce input use without reducing their Irish potato production, simply by improving technical efficiency. It can therefore be concluded from this finding that to increase Irish potato output, there is need to increase and improve on technical efficiency in its production.

Table 14: Frequency Distribution of Technical, Allocative and Economic Efficiency Estimates

Efficiency (%)	Technical Efficiency			Allocative Efficiency			Economic Efficiency		
	No.[a]	%[b]	Cum.[c]	No.	%	Cum.	No.	%	Cum.
>90	1	1	100	0	0	100	0	0	100
>85≤90	12	9	99	1	1	100	0	0	100
>80≤85	13	10	90	0	0	99	0	0	100
>75≤80	24	19	80	0	0	99	0	0	100
>70≤75	18	14	61	2	2	99	0	0	100
>65≤70	8	6	47	7	5	97	1	1	100
>60≤65	13	10	41	42	33	92	2	2	99
>55≤60	7	6	31	29	23	59	1	1	97
>50≤55	5	4	25	23	18	36	9	7	96
>45≤50	10	8	21	20	16	18	17	13	89
>40≤45	7	6	13	3	2	2	26	20	76
>35≤40	4	3	7	0	0	0	27	21	56
>30≤35	3	2	4	0	0	0	17	13	35
>25≤30	0	0	2	0	0	0	12	10	22
>20≤25	2	2	2	0	0	0	9	7	12
>15≤20	0	0	0	0	0	0	4	3	5
>10≤15	0	0	0	0	0	0	2	2	2
≤10	0	0	0	0	0	0	0	0	0
Sample size	127			127			127		
Mean (%)	66.7			57.3			38.1		
Minimum (%)	21.2			40.6			12.3		
Maximum (%)	92.9			85.5			66.1		

[a], [b] and [c] refers to the number of farms, percentage (rounded) of total farms, and the percent cumulative frequency respectively.

Source: Computed from Field Survey Data

Another implication of this result is that if the average farmer in the sample were to achieve the technical efficiency (*TE*) level of the most efficient counterpart, then the average farmer could realize a 28.2 percent cost savings [i.e., (1-(66.7/92.9)) x100]. Thus, sample farmers could on average, reduce production cost by 28.2 percent by reducing input applications to the technically efficient input mix. A similar calculation for the most technically inefficient farmer reveals a cost saving of 77.2 percent [i.e., (1-(21.2/92.9)) x100]. Therefore in the short run it is possible to reduce production cost in Irish potato production in the study area by an average of 28% by adopting the technology and techniques used by the best performers. Improved efficiency would reduce production costs and increase the gross margin of Irish potato production and enhance profitability.

The distribution of technical efficiency show that although operating below the frontier, the majority of the farmers (69%) attained technical efficiency scores of 60% and greater while 7% of the sampled farms have technical efficiency scores that are 40% and less.

With regard to allocative efficiency (*AE*), a wide variation is observed ranging from 40.6 percent to 85.5 percent with a mean of 57.3 percent (Table 14). This implies that if the average farmer in the sample were to achieve the allocative efficiency level of its most efficient counterpart, then the average farmer in the sample could achieve a 33 percent cost saving [i.e. (1-(57.3/85.5) x100]. A similar calculation for the most allocatively inefficient farmer reveals cost savings of 52.5 percent [i.e. (1-(40.6/85.5)) x100]. The 57.3 percent mean allocative efficiency found in this study is close to the 51.5 percent figure reported by Khai et al. (2007) for a sample of Soybean producers in Vietnam. In addition, this finding is comparable with mean allocative efficiency of 58 percent obtained by Binam et al. (2005) for a sample of peasant farmers in Cameroon. However, Bravo-Ureta and Pinheiro (1997), in their analysis of peasant farmers in Dominican Republic, reported lower estimates of allocative efficiency (*AE*) of 44 percent.

The mean economic efficiency (*EE*) of the sample is 38.1 percent with a high of 66.1 percent and a low of 12.3 percent. This indicates that if the average farmer were to reach the economic efficiency level of its most efficient counterpart, then the average farmer could experience a cost saving of 42.4 percent [i.e., (1-(38.1/66.1)) x100]. This implies that small-scale potato farmers in the sample could reduce total production costs by 42.4 percent if they reduce input applications to technically efficient input levels and then obtain optimal input mix for given input prices and technology. The same computation for the most economically inefficient farmer suggests a cost reduction of 81.4 percent [i.e., 1-(12.3/66.1) x100]. Other studies that have estimated economic efficiency using farm level data from developing countries present similar results. The 38.1 percent mean economic efficiency found in this study is close to 38 percent mean economic efficiency found by Khai et al. (2007) for a sample of Soybean farmers in Vietnam. Binam et al. (2005) also found comparable results of mean economic efficiency of 44 percent. However, Alene et al. (2003) in their analysis of impact of a new extension programme in Ethiopia found higher estimates (63 and 65 percent for participating and non-participating farmers respectively).

Table 15 presents the summary statistics and mean efficiency estimates for male and female headed households. The mean technical, allocative and economic efficiency for male headed households was 0.70, 0.58 and 0.40 respectively, whereas the computed figures for female headed households were 0.58, 0.56 and 0.32.

Table 15: Summary Statistics of Production Efficiency Estimates by Gender

Measure	Technical efficiency		Allocative efficiency		Economic efficiency	
	Male	Female	Male	Female	Male	Female
Observations	89	38	89	38	89	38
Mean	0.70***	0.58	0.58	0.56	0.40***	0.32
Std. dev	0.151	0.166	0.066	0.078	0.095	0.095
Min	0.21	0.30	0.45	0.41	0.12	0.12
Max	0.92	0.85	0.86	0.68	0.66	0.51

***indicates that means are significantly different at 1%
Source: Computed from Field Survey Data

The t-test for differences between the means was estimated for male and female headed households for each efficiency measure. A significant difference was found between the mean technical efficiency (*TE*) (t=3.739) at 1% level of significance. Similarly, the mean economic efficiency (*EE*) was statistically different (t=4.389) at 1% level, while the higher allocative efficiency (*AE*) for male headed households (0.58) versus female headed households (0.56) is not significant at the 1% level.

The mean efficiency indices obtained in this study results are not comparable to evidence from empirical analysis for a sample of cassava-based farm holdings in South-western Nigeria by Awoyemi and Adetola (2006). The authors found average technical, allocative and economic efficiency for male respondents in the sample were 89.34 percent, 88.06 percent and 79.67 percent respectively, while the same computed for the female sample were 74.85 percent, 71.03 percent and 94.9 percent respectively.

4.3.2 Potential Impact on Poverty of Scale of Production

Table 16 presents the actual and minimum or economically efficient costs and potential cost reductions for the sample Irish potato producers. According to the results, by reaching full efficiency (i.e., by operating at full technical and allocative efficiency levels) levels, on average, the sample Irish potato producers would in one season be able to reduce their actual production costs by Ksh35,803 per hectare.

Table 16: Potential Cost Reduction for Sample Potato Producers by Farm Size

Farm size (hectares)	Observed cost levels* (Ksh/ha)	Minimum cost levels (Ksh/ha)	Potential cost reduction at full efficiency			
			TE	AE	Total	%
Small (≤4)	95,712.40	48,559.00	24,349.80	22,801.90	47,150.25	49.3
Medium (4-8)	67,009.95	33,528.25	21,273.35	12,204.70	33,478.50	50.0
Large (>8)	70,619.50	46,000.70	13,964.30	10,654.60	24,618.80	34.9
All farms	92,086.90	56,242.45	20,685.10	14,841.90	35,802.80	38.9

*Actual seasonal cost levels calculated to per hectare in Kenya shillings
Source: Computed from Field Survey Data

These results indicate considerable amount of production inefficiencies among the sample households and substantial potential for enhancing profitability by reducing costs through improved efficiency. The sample farms on average could reduce, in one season, their production costs by about Ksh47,150, Ksh33,479 and Ksh24,619 per hectare for small, medium and large farms respectively if they could operate at full efficiency level. In the face of high and increasing input costs, this could reduce the high production costs hence improve farm revenue.

Cost reductions from improvements in efficiency are very important to enhance profitability of Irish potato producers, especially small and medium producers who sometimes earn a negative return from Irish potato production. The Ksh24,619 to 47,150 per hectare potential cost reduction translates to an additional daily income of about Ksh138.70 to Ksh265.60 (US$ 1.80– 3.40). Given a poverty line of US$1 per day these are significant amounts which indicate that by improving efficiency, the resulting cost reduction will enhance profitability of the Irish potato producers, improved income, and a resultant impact on poverty reduction. The welfare and economic development of the study area can improve greatly if the farmers can improve the efficiency levels of the Irish potato producers.

4.4 Factors Affecting Productive Efficiency of Irish Potato Producers

Table 17 presents the results of the two-limit Tobit model for factors affecting efficiency levels. The parameters in equation (15) were estimated using a two-limit Tobit model procedure because, the values of the dependent variable range between 0 and 1. Three separate models were specified and used to investigate the relationship between technical (*TE*), allocative (*AE*) and economic (*EE*) efficiency, respectively, and the farm/farmer characteristics and institutional factors. Most of the explanatory factors were significant at 5% and 10% levels.

Table 17: Factors Affecting the Productive Efficiency of Irish Potato Producers (Dependent Variable = TE, AE and EE Indices)

Variable	TE		AE		EE	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Constant	3.909***	0.000	3.789***	0.000	3.094***	0.000
Gender of HH (1=male)	0.069	0.178	0.002	0.928	0.071	0.106
Age of HH (years)	-0.100	0.323	0.028	0.484	-0.071	0.407
Education Level (years)	0.161**	0.020	0.001	0.976	0.162***	0.006
Experience of HH (years)	0.056	0.157	0.029*	0.073	0.086**	0.012
Extension contact (No. of visits)	0.045**	0.026	0.019**	0.017	0.064***	0.000
Received credit (1=yes)	0.166***	0.002	0.046**	0.036	0.212***	0.000
Member farmers' association (1=yes)	0.193***	0.001	-0.092***	0.000	-0.101**	0.045
Log-likelihood	-16.05		116.78		-3.773	

*, ** and *** Represents significance at 10%, 5% and 1% level respectively. HH is household head. p-values are computed from t-ratios.
Source: Computed from Field Survey Data

The estimated coefficients for the education variable (*Educ*) are positive and statistically significant for technical (*TE*) and economic (*EE*) efficiency at 5% and 1% level respectively. This indicates an increase in efficiency with higher educational attainment implying that to an extent higher education attainment leads to higher efficiency levels in Irish potato production.

Better performance by more educated farmers may be attributed to the fact that they may have better access to new information, more receptive to adoption of yield-improving farming techniques and may readily respond to the use of improved technology such as fertilizers, pesticides and improved planting materials. This finding is consistent with results of other studies. For example Abdulai and Eberlin (2001) in their study on the technical efficiency during economic reform in Nicaragua found that education positively influences production efficiency. Other studies consistent with this study are: Bozoglu and Ceyhan (2007) for vegetable farms in Turkey; Bravo-Ureta and Pinheiro (1997) on peasant farming in the Dominican Republic; and Ike (2006) on Yam production for smallholder farmers in South-eastern Nigeria.

Abdulai and Eberlin (2001) argues that the role of human capital stems from the fact that reallocation of resources in response to changes in economic conditions requires (i) perceiving that changes has occurred, (ii) collecting, retrieving and analyzing useful information, (iii) drawing valid conclusions from the available information, and (iv) acting quickly and decisively. According to Bozoglu and Ceyhan (2007) education increases the ability to perceive, interpret and respond to new events and enhances farmers' managerial skills, including efficient use of agricultural inputs. Thus, ensuring improved educational attainment of Irish potato farmers would be very beneficial in improving efficiency in Irish production.

Experience (*Exp*) measured by the number of years the household head has spent producing Irish potatoes, has a positive and statistically significant relationship with economic efficiency (*EE*) at 5% level while the relationship with allocative efficiency (*AE*) is also positive and statistically significant at 10% level. However, the results indicate no statistically significant relationship between experience and technical efficiency. The significant impact of experience on allocative and economic efficiency implies that household heads with more years of experience in producing Irish potatoes are more allocatively and economically efficient than their counterparts. This suggests that the Irish potato farming in the study area is highly dependent on the experience of farmers which may lead to better managerial skills being acquired over time. The result is in agreement with findings of other studies such as Amara et al. (1998) who found a positive and significant influence of experience on efficiency of potato farmers in Quebec. Khai et al. (2007) also found a significant influence of experience on productive efficiency of Soybean farmers in Vietnam.

Contact with extension (*Ext*) has a positive and statistically significant impact on technical and allocative efficiency at 5% while it is significant at 1% level with respect to economic efficiency. This implies that farm households with increased frequency of contact with extension workers tend to be more efficient than their counterparts. This can be attributed to the fact that the knowledge gained from contact with extension agents could have influenced the Irish potato producers to adopt improved technologies and management practices leading to an improvement in efficiency. Extension workers play a central role in informing, motivating and educating farmers about the available technology. Extension workers also disseminate information about crop practices, optimal input use, and consult directly with farmers on specific production problems, thus facilitating a shift to more efficient methods of production. Contact with extension workers may have improved the managerial ability and know-how of potato farmers leading to efficient utilization of existing technologies. This finding confirms the results of Xu and Jeffrey (1998) that extension visits to farmers are important for reducing farm inefficiency. The result is also consistent with findings by Seyoum et al. (1998) who found a 14% difference in technical efficiency between farmers who had access to extension services and those who did not in a study on farmers within and outside the Sasakawa-Global 2000 project in Ethiopia.

The results also indicate that credit has a positive and statistically significant effect on technical and economic efficiency at 1% while being positive and statistically significant effect with respect to allocative efficiency (*AE*) at 5% level. This implies credit is a significant factor in enhancing efficiency of potato producers. This suggests that on average, farmers who received credit tend to exhibit higher levels of efficiency. This finding is consistent with the results by Binam et al. (2004) and Abdulai and Eberlin (2007) for farmers in Cameroon and Nicaragua respectively. Bozoglu and Ceyhan (2007) on vegetable farms in Turkey also found statistically significant relationship between credit and efficiency. These findings can be attributed to the fact that credit permits a farmer to enhance efficiency by overcoming liquidity constraints which may affect their ability to acquire and apply inputs and implement farm management decisions on time. Hence use of credit therefore loosens financial constraints, ensures timely acquisition and use of inputs and results in increased efficiency.

Since the purchase of agricultural inputs occurs during the planting period, whereas returns are received only after the Irish potatoes are harvested several months later, most Irish potato farmers face negative cash flow during the planting and growing period and besides potato production is labour intensive. Farmers who have little or no access to either formal or informal credit at the start of the season or during the growing period may have difficulties in their ability to acquire and apply inputs on time. Alleviating credit constraint eases the liquidity constraint that farmers face and enhance acquisition of inputs especially during planting time leading to timely operations. Binam et al. (2006) argues that access to credit can significantly increase the ability of households with little or no savings to acquire agricultural inputs by loosening the constraints to production and therefore facilitating them to get inputs on a timely basis. On the other hand, the effect of financial constraints may exist because, besides the quantities of input use, the timing of input use is also important in affecting yields.

The estimated coefficient associated with membership in a farmers' organization (*Assoc*) is positive and statistically significant at the 1% level with respect to technical (*TE*), however it is negative and statistically significant with respect to allocative (*AE*) and economic (*EE*) efficiency. This positive and significant influence of membership in a farmers' association with respect to technical efficiency can be attributed to the fact that being a member of a farmers' group such as Common Interest Group (CIG) e.t.c may lead to sharing of information on crop husbandry or farming technologies which tends to influence the production practices of members through peer learning. This finding is consistent with a study by Binam et al. (2005) for the small-scale maize and peanut farmers in Cameroon where they found evidence that affiliation to a members association improved efficiency. Similar results have been found by by: Nchare (2007) on coffee production in Cameroon and Chirwa (2007) on maize production in Malawi. Farmers indicated that some of the benefits obtained in being affiliated to an association include securing labour such as in mutual aid groups; acquiring skills through common interest groups which afford farmers the opportunity to have better access to information; and access to informal credit through lending among themselves in merry-go-rounds or table banking.

CHAPTER FIVE

CONCLUSIONS AND POLICY IMPLICATIONS

5.1 Conclusions

In this study the technical, allocative and economic efficiency levels for a sample of farmers in Nyandarua North district, Kenya were examined using a stochastic parametric efficiency decomposition technique. The parametric approach was based on the Kopp and Diewert's cost decomposition approach where a Cobb-Douglas stochastic production frontier was estimated and the corresponding dual cost frontier derived analytically. Socio-economic and institutional factors influencing the differences in observed levels of economic efficiency were also determined.

To determine the efficiency levels primary data was collected for Irish potato producers in Nyandarua North district. The data collected comprised of the output of Irish potatoes and quantities of input use which include land area under Irish potatoes, quantity of seed, quantity of fertilizer, and quantity of fungicides. In addition socio-economic data of the household heads were collected. This included: age, gender, level of education, and farming experience of the household head. Also collected was information regarding family size, farm size, and sources of income. Access to extension services and to credit was also obtained for each household. The data was collected using face to face interviews with questionnaires administered in all the sampled sub-locations during the months of May and June 2008.

First, descriptive statistics were used to analyze the socio-economic characteristics of the Irish potato producers and the production characteristics. Two econometric models were used to analyze the data collected. First, the stochastic frontier model was used to determine the maximum likelihood estimates of the production function. The estimated frontier function formed the basis for estimating the dual cost frontier and the farm specific technical, allocative and economic efficiency indices. Secondly, a two-limit Tobit model was used to determine factors that influence the observed levels of technical, allocative and economic efficiency indices. The stochastic frontier model was run on FRONTIER 4.1 (Coelli, 1996) and STATA software packages. STATA was used for the two-limit Tobit model while descriptive statistics were analyzed using STATA statistical software.

The maximum likelihood estimation of the Cobb-Douglas stochastic frontier model shows that the estimated values of the variance parameters were significant which indicates that technical inefficiency has an impact on output. This suggests that a ordinary least squares (OLS) production function was not an adequate representation of the data.

The results of the estimation revealed that all the inputs were significant in the Irish potato production function. Land area under Irish potato (plot size) and labour showed the greatest elasticity. This shows that these two inputs, land and labour, have a major influence on Irish potato production.

All the parameter estimates are statistically significant in the frontier model. The following elasticities were obtained: plot size 0.373 ($p<0.01$), labour 0.205 ($p<0.05$), seed 0.175 ($p<0.05$), fertilizer 0.071 ($p<0.01$) and agrochemicals 0.031 ($p<0.01$). The sum of the output elasticities is 0.855 implying decreasing returns to scale. A priori expectation was that Irish potato is more responsive to fertilizer than seed rate. However there is lower responsiveness of yield to fertilizer than seed rate.

Results indicate that the farms included in the study could achieve the same level of production while employing only a percentage of the inputs used at present. The mean technical, allocative and economic efficiency estimated is 66.7%, 57.3% and 39.1% respectively. These results reveal that there is substantial inefficiency in farming operations for the sample Irish potato producers considered. Farms could reduce their inputs by about 28% without reducing their output, simply by improving technical efficiency; 33% by applying inputs in the optimal proportions that is by improving allocative efficiency; and 42% by improving economic efficiency. Improved efficiency, therefore, could have a positive effect on the reduction of production costs and on the increase of gross margin obtained by the farms. Costs would be minimized without reducing output and therefore policy interventions should focus more on improving efficiency rather than quantity of factors of production.

In a second step analysis, a two-limit Tobit model was used to estimate three separate equations, where technical (*TE*), allocative (*AE*) and economic (*EE*) efficiency indices were expressed as functions of six socio-economic factors: age, gender of the household head, experience of household head, education of the household head, contact with extension, credit, and membership in a farmer association. Results show that those farmers who have more years of schooling, those who received credit, and those who are members in a farmers' association are associated with higher efficiencies. In addition, it was found that access to extension services have a positive influence in increasing productive efficiency of smallholder Irish potato producers in Nyandarua North district.

An analysis of the determinants of efficiency indicates indicate that the years of schooling of the household head, access to extension, credit and membership in a farmers' association are significant variables for improving technical efficiency. However, this study found no statistically significant relationship of years of experience and age of the household head on technical efficiency. This suggests that efficiency-enhancing policies need not discriminate among households on the basis of their age in Irish potato production.

Important factors influencing allocative efficiency were found to be experience, access to extension, credit and membership in a farmers' organization. This study found no significant relationship between gender, age and education of the household head on allocative efficiency. Factors positively correlated with economic efficiency include number of years of formal schooling of the household head (education), the number of years the producer household head has cultivated Irish potatoes (experience), access to extension and access to credit.

Based on the results, proposed strategies include providing better extension services and farmer training programs, raising the educational level of farmers, and providing farmers with greater access to credit, in order to increase the efficiency of Irish potato farms in the study area.

5.2 Policy Implications

The main objective of this study was to examine the production efficiency levels of Irish potato producers in Nyandarua North district. A subsidiary objective was to determine farm-specific factors that influence the observed variability in the efficiency levels.

These results indicate considerable production inefficiencies for sample potato producers in the study area and hence substantial potential for enhancing profitability by reducing costs through improved efficiency. On average, by operating at full economic efficiency levels, the sample producers would be able to reduce their costs by 34.9 - 50% depending on the farm size. If the sample potato producers were fully efficient in production, the range in potential cost saving is about Ksh49,238 to Ksh94,300 per hectare in production costs annually (two seasons). This translates to an additional daily income of about Ksh138.70 to Ksh265.60

(US$ 1.80– 3.40). Given a poverty line of US$1 per day these are significant amounts which indicate that by improving efficiency, the resulting cost reduction will enhance profitability of the potato producers, improved income, with a resultant impact on poverty reduction.

The finding from the second step two-limit Tobit analysis suggest that higher household head's education, receipt of credit, experience of the household head, access to extension, and being a member in a farmers' association are significant factors for increasing production efficiency. Gender of the household head and age, however, were not found to significantly influence efficiency. These findings have important policy implications in promoting efficiency among potato farmers in Nyandarua North district and Kenya in general. Firstly, to reduce the observed inefficiency, access to extension services must be improved by enhancing smallholder potato farmer's access to agricultural information and new technologies. Extension services play an important role in the adoption of agricultural innovations. In the face of declining financial, human and material resources for public extension services, policy makers should focus on: (i) promoting group approach; (ii) promoting farmer-led extension e.g., farmer field schools; and (iii) strengthening mass media to supplement and complement extension besides extensive use of Information and Communication Technology (ICT) to support agricultural extension.

Secondly, increased use of groups need to be encouraged and facilitated. The use of groups has many advantages: first, it offers economies of scale by maximizing the extension agent-to-farmer ratio; saves travel time and increases the time spent on actual task of the extension agent; groups provide a setting where farmers can learn and practice new technical skills before embarking on their own activities; and groups offer farmers opportunity for pooling of resources. Secondly, given declining public extension services innovative extension approaches need to be explored such as utilizing services of progressive farmers as para-professionals through approaches like Farmer Field Schools. The Farmer Field School[3] (FFS) offers an opportunity for selected farmers within a village or local farmers' group to be trained in these informal schools. Once they receive additional training to become farmer trainers they should be supported to organize field schools for Irish potato producers within the study area. This approach of farmer-to-farmer knowledge dissemination is expected to be cost effective and financially sustainable issues that hamper public extension.

[3] Farmer Field School (FFS) is a group learning approach which builds knowledge and capacity among farmers to enable them diagnose their problems, identify solutions, develop plans and implement them with or without external support.

Thirdly, policy makers should explore ways of strengthening mass media to supplement and complement extension besides extensive use of Information and Communication Technology to support Agricultural Extension. Under the Ministry of Agriculture's strategic plan government policy is geared towards reforming the agricultural extension system and promoting utilization of current and emerging information technology (MoA, 2004). The recently launched initiative like the National Farmers Information Service (NAFIS) web site under the National Agriculture and Extension Programme (NALEP) intended to offer agricultural information should be targeted to Irish potato producers.

Recent initiatives such as Agricultural Technology Information Response Initiative (ATIRI) should be upscaled in the study area and targeted to Irish potato producers to aid farmers' access to information and new Irish potato technologies. To ensure technology reaches the farmers, ATIRI empowers farmers to make technology and information demands on agricultural service providers through small grants. Grants cover acquisition of technology (e.g. planting materials), exchange visits to other farmers who have already adopted the technology and other costs of observing, learning and adopting technologies.

The finding of the relationship between credit and efficiency suggest that improving farmers' access to credit will improve production efficiency in Irish potato production. Policy makers should focus on strategies that will provide Irish potato farmers with greater access to adequate and timely credit. To counter factors enumerated by farmers that constrain them from borrowing such as high interest rates, lack of collateral and unfavourable payment plans, government efforts should aim at loosening these various constraints to encourage greater borrowing by farmers. Efforts should include influencing interest rates and ensuring that credit payment plans coordinate with the harvesting seasons. Lenders should be encouraged to give a "grace" period to farmers and ensure that credit payment plans coordinate with the harvesting seasons. In addition mobilization of financial resources should be encouraged through savings and credit other community based lending systems.

The results for the influence of membership in a farmers' association suggest that policy makers need to improve efforts by governmental and non-governmental organizations in mobilizing farmers to join associations where they exist or form new ones such as Common Interest groups (CIG) where they don't exist so as to channel their support to these groups. Such interest groups should be organized around the Irish potato commodity (e.g. Kenya National Potato Farmers Association) for getting benefits mutually within the groups and in interaction with external agencies. These Irish potato associations formed should be federated at the location, division, district and national levels so as to link their Irish potato economic activities and ensure they exploit the expected benefits of access to information and market potential more effectively.

The positive impact of education on efficiency indicates that education is a very important determinant of efficiency. Education increases human capital which enhances the farmer's ability to receive and understand information relating to new agricultural technology. However, in the study area policy makers have little opportunity to increase the educational level of farmers. One option is for extension service to develop and implement informal vocational education programs. In the long-tem, however, policy makers need to promote formal education as a means of enhancing efficiency in production. Under the Economic Recovery Strategy for Wealth and Employment Creation (ERSWC), the Government of Kenya instituted free primary education which will go a long way in ensuring increased enrollment for children in primary schools (MoP&ND, 2004). This finding similarly supports the overall goal under vision 2030 of reducing illiteracy by increasing access to education, improving the transition rate from primary to secondary schools, and the quality and relevance of education.

Overall, this study indicates that substantial productivity gains can be obtained by improving the production efficiency of smallholder Irish potato producers. Therefore in future, agricultural policies should include measures to improve the capacity of farmers to apply the available technology more efficiently. This can be done by improving access to extension services, access to credit and trying to raise the educational level of farmers.

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APPENDICES

Appendix 1: Questionnaire

TITLE: TECHNICAL, ECONOMIC AND ALLOCATIVE EFFICIENCY FOR IRISH POTATO PRODUCERS: THE CASE OF NYANDARUA NORTH DISTRICT, KENYA.

Code___________

This questionnaire is totally for academic research purpose. The answers given to the questions will not be passed over to government officials, tax collectors or any other third party that the respondents do not allow access to such information. Therefore, respondents are kindly requested to give their honest response to every question. Thanks.

Name of Enumerator --

Date of Interview---

District--

Location ---

Sub-location --

SECTION A: SOCIO-DEMOGRAPHIC

1 Respondent's name --

1.1. Respondent's sex. Male ☐ Female ☐

1.2. Age_____________ yrs

1.3. Educational level____________years. *Please state the number of years of schooling.*

1.2. Are you the head of the household?

Yes ☐ No ☐

2. If no please provide the information below regarding the household head

2.1 Name of Household Head

……………………………………………………………

2.2. Sex ☐ Male ☐ Female

2.3. Age ____________yrs.

2.4. Educational level ___________years. *Please state the number years of schooling.*

3. When did you start potato production? *Please state the year you began.*

☐

3. How many members were in the household including non-biological?

a. Male adult [ ]
b. Female adult [ ]
c. Male children [ ]
d. Female children [ ]

4. Please, fill the following table with the information regarding the household members.

Table1. Household composition

No.	Name of household member	Relation to HH head. 0=Head 1= Spouse 3=Brother/Sister 4= Child 5= other	Sex 1=M 2=F	Year of birth	Educational level (Years of schooling)
1					
2					
3					
4					
5					
6					

SECTION B: INCOME SOURCES

5. Please list the top three sources of income for the household.

Income sources:	**Tick**	**Rank**
1. Production/sale of crops	[ ]	[ ]
2. Production/sale of livestock & livestock products	[ ]	[ ]
3. Agricultural output trading,	[ ]	[ ]
4. Agricultural input trading	[ ]	[ ]
5. Salaried employment	[ ]	[ ]
6. Casual laborer	[ ]	[ ]
7. Pension	[ ]	[ ]
8. .Remittances (income from relatives/friends etc)	[ ]	[ ]
9. Others (specify)………………………………………..		

SECTION C: POTATO PRODUCTION

Land

6. How much total land do you have? *Please state in acres*.

………..acres

7. How much of this land was occupied by agricultural crops last season?

………..acres

8. How many plots of potatoes did you cultivate last season? *Please state the size of each plot in acres and variety planted.*

Potato plots and varieties

Plot No.	Size of the plot (acres)	Major decision maker	Variety of Irish potato planted
1.			
2			
3			

Farm inputs

9. Did you use any inputs (fertilizers, manure, fungicides) in potato production last season?

Yes ☐

No ☐

10. If yes which ones did you use and what quantity was used in each plot?

Plot No.	Seed		1st Fertlizer			2nd Fertilizer			Fungicides		
	Qty (kg)	Price (Ksh/kg)	Type 1= DAP 2 = MAP 3= TSP 4= 20:20:0	Qty. (kg)	Price (per kg)	Type	Qty. (kg)	Price (per kg)	Type	Qty. (gms)	Price (per unit)
1											
2											
3											
4											

Labour

11. Please fill the table below regarding the family labour input in potato production.

Table2: Family Labor Input. (Fill *the information for each potato plot separately for all potato plots)*.

Plot No.	Activity	Male Family Labour			Female Family Labour			Child Family Labour		
		No of men	Hrs /day	Days	No of women	Hrs /day	No. of days	No of children	Hrs /day /child	Total days
1	1st ploughing									
	2nd ploughing									
	Planting									
	Weeding									
	1st Ridging									
	2nd Ridging									
	Fungicide application									
	Harvesting									
	Other									
2	1st ploughing									
	2nd ploughing									
	Planting									
	Weeding									
	1st Ridging									
	2nd Ridging									
	Fungicide application									
	Harvesting									
	Other									
3	1st ploughing									
	2nd ploughing									
	Planting									
	Weeding									
	1st Ridging									
	2nd Ridging									
	Fungicide application									
	Harvesting									
	Other									

12. Did you hire any labor for potato production activities last season?

Yes ☐

No. ☐

If yes please fill the table below regarding the hired labour.

Table: Hired Labor Input. (*Fill information for each potato plot separately for all potato plots)*.

Plot No.	Activity	Male Hired Labour			Wage rate (ksh/ day)	Female Hired Labour			Wage rate (ksh/day)
		No of men	Hrs /day	No. of days		No of women	Hrs /day	No. of Days	
1	1st ploughing								
	2nd ploughing								
	Planting								
	Weeding								
	1st Ridging								
	2nd Ridging								
	Fungicide application								
	Harvesting								
	Other								
2	1st ploughing								
	2nd ploughing								
	Planting								
	Weeding								
	1st Ridging								
	2nd Ridging								
	Fungicide application								
	Harvesting								
	Other								
3	1st ploughing								
	2nd ploughing								
	Planting								
	Weeding								
	1st Ridging								
	2nd Ridging								
	Fungicide application								
	Harvesting								
	Other								

13. If no, why? --

14.What farm implements did you use in potato production?

Type of equipment	Number owned	Year bought	Purchase price (Ksh).
Hoes			
Pangas			
Ox plough			
Basket			
Wheel barrow			
Others (specify)			

SECTION D: POTATO PRODUCTION AND MARKETING

15. Was any of the harvested potatoes consumed at home?

Yes ☐

No ☐

If yes please provide the following information:

Plot No.	Harvest consumed* at home				Average selling price
	*Unit	Weight (kg)	Quantity (No. of units)	Conversion factor	
1					
2					
3					
4					

*1=Debe 2=Bag(110kg) 3=other(specify) (*Include quantity retained as seed and quantity given out in kind)*

16. Was any of the harvested Irish potatoes sold in the market?

Yes ☐

No ☐

If yes please provide the following information:

Plot No.	Harvest sold in the market			Average selling price
	Unit 1=Debe 2=Bag(110kg) 3=Other(specify)	Quantity (No. of units)	Conversion factor	
1				
2				
3				
4				

17. Are there any groups dealing with potato production or marketing in your area?

Yes ☐

No ☐

18. If yes, did any household member belong to any of these groups last season?

Yes ☐

No ☐

Name of HH member	Group 1= Potato producer 2=Potato marketing	Year HH member joined	Main activities of the organization	Benefits received by member

SECTION F: ACCESS TO EXTENSION SERVICES

19. Did any extension worker visit you to talk about potato production last season?

Yes ☐

No ☐

If yes please fill in the table below. *Please indicate the member whom the extension agent contacted.*

Provider/extension agent 1= Government 2= NGO 3=Fellow farmer 4= other (specify)	2007			Name of household member contacted
	Subject/ extension message.	Number of visits by ext. agent	Avg. time for each visit (hrs)	

NB: Extension is an informal out of class exchange of information between extension agents and farmers and takes a short time per contact.

20. If extension workers did not visit you for advice on potato production did you visit any extension worker/organization to seek for advice?

Yes ☐

No ☐

21. If yes, whom did you contact and what type of information did you look for?

Provider/extension agent 1= Government 2= NGO 3=Fellow farmer 4= other (specify)	Subject/ extension message.	No. of visits to ext. agent	Avg. time for each visit made to ext. agent (hrs)	Name of household member who made visit.

22. Apart from extension agents how else do you get information on production of Irish potatoes?

a) Radio ☐
b) Neighbour ☐
c) Newspapers ☐
d) Family ☐
e) Other (specify)……………………….......

SECTION F: MEMBERSHIP IN A FARMERS' ORGANIZATION

23. Did any member of the household belong to any local or external farmers' organization in 2007?

Yes ☐
No ☐

If yes please fill the table below. .

Name of HH member	Organization 1= NGO 2=CBO 3=Govern. project 4=Other(specify)	Year HH member joined	Main activities of the organization 1= Financial services (SACCO) 2= Mutual support 3= Extension services 4= Marketing agric. products	Benefits received by member

NB: Farmers associations include women's associations, youth associations, church, mutual support group, input supply cooperatives, a marketing cooperative, savings or credit group, etc.) that deal with agricultural activities.

SECTION G: ACCESS TO CREDIT

24. Did you have access to formal/informal credit last season?

Yes ☐

No ☐

25. Did any member of the household apply/ask for any credit/loan from any of this source(s)?

Yes ☐

No ☐

26. Did you get any credit (formal or informal) to use in potato production last season?

Yes ☐

No ☐

If yes please fill the following table. *(Specifically for credit use in potato production)*

Did you applied for credit for potato production 1=yes 2=no	Main source of credit obtained	Credit code 1=Formal 2=Informal	What was the credit used for in potato production	Remarks

NB: Formal sources include banks, cooperatives, NGOs, and other programs. Informal sources may include moneylenders, traders, intermediaries, rotating savings and credit associations, other associations, friends, and relatives.

Thank you for your patience and responses.

Appendix 2: Map of Kenya Showing Irish Potato Producing Areas

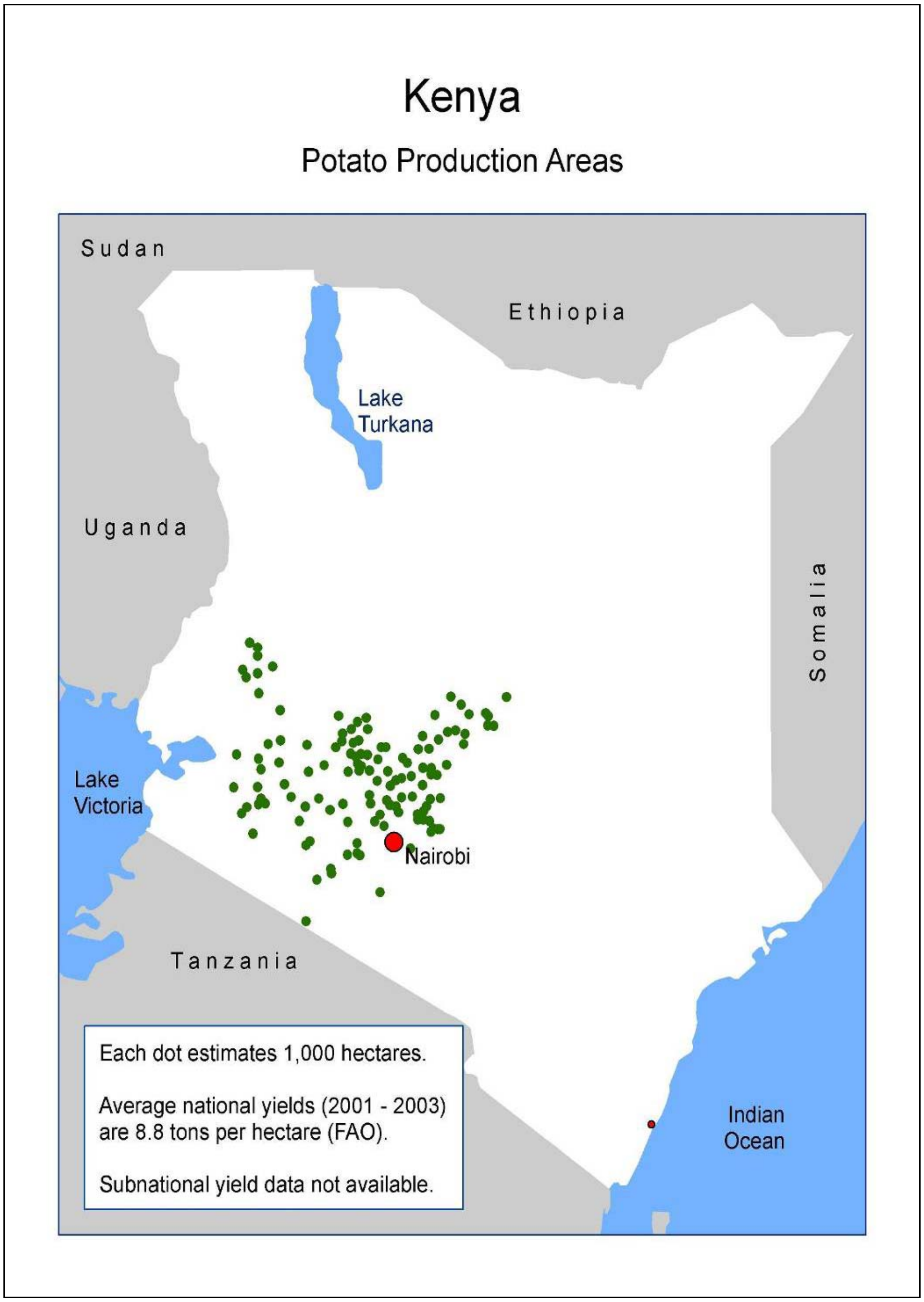

Figure 5: Map of Kenya Showing Irish Potato Producing Areas

Source: www.research.cip.org/confluence/display/wpa/country. Accessed 17.11.2007

Appendix 3: Observed and Adjusted Output

Figure 6 illustrates the difference between observed and adjusted output.

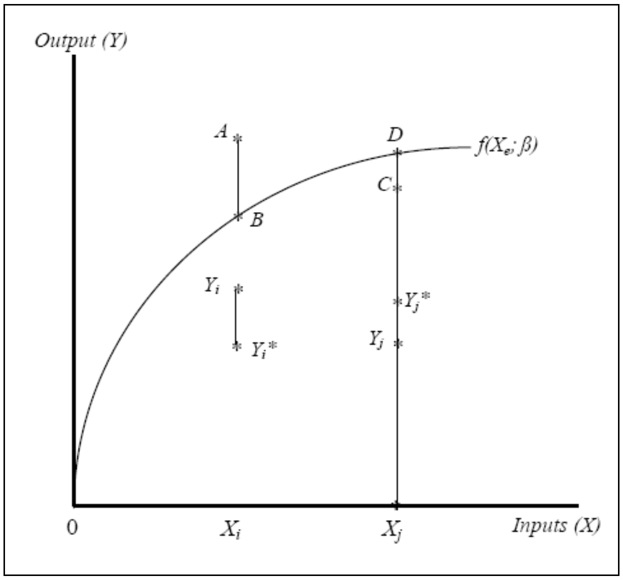

Figure 6: Illustration of Observed and Adjusted Output
Source: Adopted from Xu and Jeffrey (1997).

For firm i, X_i is the vector of actual input use and Y_i is the observed output. Given the level of input use X_i, the stochastic frontier output is represented by A. This is greater than the deterministic frontier output $(\text{i.e}, B = f(X_i;\beta)$ due to favourable conditions $(\text{i.e.}, \nu_i > 0)$. The total deviation from the frontier function for this firm that is, $\nu_i - \mu_i$, is the distance BY_i. This distance may be partitioned into the random component (i.e., ν = AB) and the inefficiency component (i.e., $\mu = AY_i$,) using the method developed by Jondrow et al. (1982). As indicated by equation (20), μ_i (i.e., distance AY_i,) is subtracted from the deterministic frontier output to obtain the adjusted output for firm i $(\text{i.e.}, Y_i^*)$.

Similarly, firm j uses inputs X_j to produce Y_j. Frontier output for this firm is C. The total deviation from the deterministic frontier function (i.e., DY_j,) may be partitioned into the random component CD (i.e., $\nu < 0$) and the inefficiency component CY_j. From Figure 6 adjusted output Y_i^* is equal to the deterministic frontier output minus μ_j (i.e., D - CY_j). Adjusted output (Y^*) is used to calculate the technical efficient input vector (X_{ie}).

Adjusted output represents the observed output (Y) adjusted for statistical noise. It is calculated as follows:

$$Y_i^* = f(X_i;\beta) - \mu_i = Y - \nu_i \qquad (29)$$

where Y* is the observed output adjusted for the statistical noise captured by ν; X_i represents the actual input use; $f(Xi;\beta)$ is the deterministic frontier output; and ν and μ are estimates of the random and inefficiency components of overall deviations from the frontier.

Appendix 4: Key Interventions in the Irish Potato Industry

Year	Intervention
1903	New Irish potato varieties introduced at National Agricultural Laboratories, Kabete.
1927	Seed potato production introduced at Plant Breeding Station, Njoro.
1945	Vegetable dehydration established in Kerugoya and Karatina including potato processing. New potato varieties (Roselyn Eburu, Dutch Robjyn, Annet, Feldeslohn and Desiree) introduced.
1961	Potato Research Advisory Committee formed to oversee seed production and screening, plant breeding and pathology studies
1963	New varieties imported from Germany to promote Irish potato production.
1967	Potato Development Programme established for variety screening, plant breeding, seed multiplication and agronomy. Research facilities specific to potato established at Tigoni with sub-centres in Marimba (Meru), Marindas (Molo) and Njabini (S. Kinangop).
1979	Government established a Commercial Seed Potato Programme under the Agricultural Development Corporation (ADC).
1985	A cold storage complex with capacity of 2,250 tonnes constructed at Molo to solve the problem of increased production.
2005	The draft potato policy and strategy, National Potato Industry Policy (NPIP) formulated. Legal Notice No. 44 of 27th May 2005 on potato standards issued.

Source: Ministry of Agriculture, National Potato Policy, 2004.