UNIVERSITY OF STRATHCLYDE

DEPARTMENT OF ECONOMICS

INVESTMENT IN FENCING AND ITS CONTRIBUTION TO AGRICULTURAL PRODUCTION IN SEMI-ARID KENYA

BY

IRENE CHEROTICH ASIENGA

A thesis submitted to the Department of Economics, University of Strathclyde in accordance with the requirements for the degree of Doctor of Philosophy'

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

Signed..
IRENE C. ASIENGA

Date …………………………………………..........

DEDICATION

‘This thesis is dedicated to my parents; my late mum, Mrs. Martha Koech and late dad Mr Paul Koech to whom my education had always been a priority.’

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ABSTRACT

Good land management strategies are known to play an important role in improving agricultural production. Fencing is an example and for this reason, this study builds on the existing literature to find out its contribution to agricultural production in semi-arid Kenya. The motivation is that there is lack of empirical data that has evaluated the contribution of fence as a productive investment in Kenya.

Fencing was treated as a productive input in the production function alongside capital, labour, land and land quality. Cross-sectional primary data is used to achieve the objectives of the study. The Cobb-Douglas (CD) specification was used in measuring the contribution of fence to production. The instrumental variable technique was applied to test for endogeneity of the fence variable. Technical efficiency was estimated and two alternative approaches were applied, stochastic frontier analysis (SFA) and data envelopment analysis (DEA). In the DEA analysis, the output-oriented frontier was estimated under the specifications of constant and variable returns to scale.

Ordinary least squares (OLS) results indicated that fencing improves agricultural production. Findings from the two stage least squares (TSLS) regression show that the decision to fence can be affected by cost of fencing, age and education level of household head and the farming activity undertaken by households but the effect is insignificant. Maximum likelihood estimates (MLE) from the SFA also show that fencing has an impact on production. Further results from both SFA and DEA also indicated that there are substantial production inefficiencies among the sample farmers. Analysis of variance (ANOVA) results showed that there are differences in the means of fence variable and that fenced households are more efficient than unfenced homesteads though the difference is insignificant. Further, the Spearman rank coefficients show that the correlation between SFA and DEA is positive and significant at 5 percent level. More results show that the importance of fencing in different regions does not vary significantly and the aggregated data showed a positive impact of fence on production. It was therefore concluded that fence improves production and the policy implication is that since fencing has led to a series of positive benefits, there is need for the government to recognize the positive impact of fence and empower those communities who would wish to fence their land. Last but not least, the results are consistent with the theoretical view that fencing is expected to improve output.

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ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of variance
APP	Average physical product
ASALs	Arid and semi-arid lands
CBS	Central Bureau of Statistics
CD	Cobb-Douglas
CRS	Constant returns to scale
DEA	Data envelopment analysis
DMUs	Decision making units
DRS	Decreasing returns to scale
FAO	Food and Agricultural Organisation
GDP	Gross Domestic Product
GOK	Government of Kenya
IDPs	Internally displaced persons
iid	Independent and identically distributed
IPAR	Institute of Policy Analysis and Research
IR	Inverse relationship
IRS	Increasing returns to scale
IV	Instrumental variables
KWS	Kenya Wildlife Service
LDCs	Less developed countries
MDGs	Millennium Development Goals
MLE	Maximum likelihood estimates
MTP	Medium Term Plan
NIRS	Non-increasing returns to scale
OLS	Ordinary least squares

SE	Scale efficiency
SFA	Stochastic frontier analysis
SRA	Strategy for Revitalizing Agriculture
TSLS	Two stage least squares
TE	Technical efficiency
TPP	Total physical product
MPP	Marginal physical product
VRS	Variable returns to scale

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Q = Value of aggregate output (in Kshs)

K =Value of physical capital available for use in farming activity in Kshs

L =Total work hours per day by family members and hired labourers in crop and livestock farming

N =Total amount of land on which farming is carried out (in acres)

LQ =Land quality proxied by price of land

F =Area of fenced homestead in square meters.

D =Dummy variable

ε =error term

$\ln$ = Natural logarithm

q = Natural logarithm of Q

k = Natural logarithm of K

l = Natural logarithm of L

n = Natural logarithm of N

lq = Natural logarithm of LQ

f = Natural logarithm of F

P = Price

v =The symmetric error component that accounts for random effects and exogenous shocks

u =One sided error component that measures technical inefficiency

θ =Efficiency score of each farm.
λ = Weight of the decision making unit (DMU).
U =Utility

C =Consumption goods

HT =Leisure (home time)

$\wp$ =Socio-economic and demographic characteristics.

F_l =Family labour input

E =Exogenous income

TS =Total stock

T =Time

$\bar{x}$ = Sample mean

s = Sample standard deviation

n =Sample size

z =Confidence factor

Z =Instrument

x = Vector of all the inputs used by the producer

β = Vector of unknown parameters to be estimated

μ =Mean

γ =Gamma

σ^2 =Sigma squared

CHAPTER 1
INTRODUCTION

1.1 Preamble

This chapter introduces the study and the aim is to enable the understanding of the country and areas of study. It gives some background to the study, description of the study area, an overview of the arid and semi-arid regions in Kenya and the history and current land policy in the country. In this chapter also, the problem statement and the objectives of the study are reported.

1.2 Background of Study

Economic development in most developing countries relies crucially on the agricultural sector and on the productivity of natural systems. It is therefore deducible that any degradation of the environment or misuse of natural resources results in real losses in the long run and this tends to undermine the very basic objective of development i.e. the sustainable improvement of human welfare (Barbier, 1987).

The improvement of human welfare is very important for society worldwide, and Kenya is no exception. Kenya as a country falls in the category of developing economies and is predominantly a primary goods net exporter. Most of these primary exports are agricultural in nature with coffee, tea and horticultural produce being the main ones. However, there are other agricultural goods like maize, beans, wheat, sugarcane, fruit, vegetables, dairy products, beef, pork, poultry and eggs which are primarily used for local consumption. It is also known that over 80 percent of the Kenyan population derive their livelihood from agricultural activities and that it contributes greatly to the country’s Gross Domestic Product (GDP) (Government of Kenya, 2011).

Table 1.1, for example, gives an indication of how agriculture, compared to other sectors, accounts for a large portion of the GDP in the Kenyan economy. The table also shows that the agriculture sector contributes an average of about 23 percent of GDP.

Generally in sub-Saharan Africa, agriculture accounts for 30 percent of GDP and at least 40 percent of export value (Daily Nation, May 4, 2010).

Table 1.1: Sectorial contribution to GDP (%)

Industry	2004	2005	2006	2007	2008	2009	2010
Agriculture and forestry	24.3	23.8	23.4	21.7	22.3	23.5	21.5
Manufacturing	11.1	10.5	10.3	10.4	10.8	9.9	10.0
Hotels & restaurants	1.2	1.4	1.5	1.6	1.1	1.7	1.7
Transport & communication	11.5	10.3	10.6	10.6	10.2	9.8	9.8

Source*: Kenya facts and figures and economic survey (Various issues)*

Other statistics also show that agriculture contributes about 19 percent of the formal wage employment. It is the main employer, job creator, and exporter in most developing countries. In addition, an estimated 69 percent of all households are engaged in farming activities, and 84 percent of rural households keep livestock (Kenya Economic Report, 2009).

In terms of future development of the country, it is estimated that by the year 2030, a reasonable percentage of the GDP of Sub Saharan Africa will mainly be accounted for in terms of sustainable agricultural production (Kenya Economic Report, 2009). As such, the Kenya government has come up with its Vision 2030, a document that spells out where the country wants to be in the year 2030 and in which agricultural production has featured as key in the economy. The Vision 2030 document targets a GDP growth of 10 percent per annum, which implies that Kenya’s income per capita would double by 2018 (Kenya Economic Report, 2009). Some of the strategies contained in the Vision 2030 include increasing productivity of crops and livestock, transforming key institutions in agriculture and livestock to promote agricultural growth.

The government’s strategy for the development and transformation of the agricultural sector is also outlined in the Strategy for Revitalizing Agriculture (SRA), 2004-2014(Government of Kenya, 2004) and the first Medium Term Plan (MTP) for implementation of Vision 2030(Government of Kenya, 2007). Boosting agricultural production is likely to facilitate the attainment of the much desired Millennium

Development Goals (MDGs). Agriculture therefore remains to play a dominant role in the economies of developing countries and this still holds in spite of slight decline in agricultural output in recent years and this is manifested in food insecurity.

Given the importance of the sector to the economy, its dismal performance on productivity has remained of much policy concern. Investment in agricultural development is therefore vital to food security and sustainable economic development (Daily Nation, May 4, 2010, Belloumi *et al*., 2009). In fact, Kenya has become the ninth country in Africa to achieve the minimum 10 percent budgetary allocation to farming as prescribed in the 2003 Maputo Declaration on agriculture and food security in Africa besides other African countries such as Burkina Faso, Ethiopia, Ghana, Guinea, Malawi, Mali, Niger and Senegal. This move is expected to improve food security in Kenya (Daily Nation, June 21, 2011). Moreover, food security is largely determined by agricultural production and it is also dependent on sustainable use of natural resources (Kenya Economic Report, 2009). In addition, one of the major roles of agriculture is to provide food for the population. This role assumes important position in situations such as Kenya where the population growth rate of 2.3 percent per annum is higher than the declining rate of growth of food production of 2.1 percent per annum. Hence, the production of food has not increased at the rate that can meet the increasing population.

Therefore, for the agricultural sector to be successful and for food insecurity problems to be combated, the sector must also be complemented by sustainable environmental programs. This is because the environment can influence agricultural production both positively or negatively. With the increasing effects of climatic changes due to global warming, degradation of the environment in some parts of the world has been witnessed on an alarming scale. Lack of or too much rain can result in a devastating drought, famine or floods which have a direct impact on agricultural production. For example, a severe drought from 1999 to 2000 compounded Kenya's problems, causing water and energy rationing thereby reducing agricultural output. As a result, the GDP contracted by 0.2 percent in 2000 (Government of Kenya, 2001). This therefore calls for better approaches in managing the natural resources like land for sustainable agricultural and environmental benefits.

Land is primarily a valuable resource for human survival and development and thus effective and sustainable land use is vital for the current and future human generations. Land is elaborately defined in FAO (1997) as " a delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface, including those of the near-surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes and swamps), the near-surface sedimentary layers and associated groundwater reserve, the plant and animal populations, the human settlement pattern and physical results of past and present human activity (terracing, water storage or drainage structures, roads, buildings...e.t.c)."

As pointed out by Harvey *et al.* (2005), fences are important features of agricultural landscapes that merit much greater attention in sustainable land management strategies. Besides, Kenya still suffers high food deficits and hunger and although the government can increase national food reserves according to the Kenya Economic Report (2009), it should also provide incentives to increase output and production and helping farmers to fence their land could be one such incentive. In addition, with some 80 million small farms in Sub-Saharan Africa producing 80 percent of agricultural goods, small holder farmers have a key role to play in resolving the food crises and unleashing Africa’s potential to feed itself. To lift people out of poverty and ensure food security, a sustained effort is needed to develop Africa’s agriculture and the associated infrastructure (Daily Nation, May 4, 2010). According to the Kenya Economic Report (2009), there exist regional differences in food poverty in that some districts especially those in marginal areas and ASALs are food poorer. It further states that one policy option for uplifting the food security status is by increasing agricultural production and this may be done by fencing farms.

1.3 Overview of Kenya

Kenya, officially the Republic of Kenya, is a country in East Africa. Lying along the Indian Ocean to its southeast and at the equator, it is bordered by Somalia to the northeast, Ethiopia to the north, Sudan to the northwest, Uganda to the west and Tanzania to the south. Lake Victoria is situated to the southwest, and is shared with

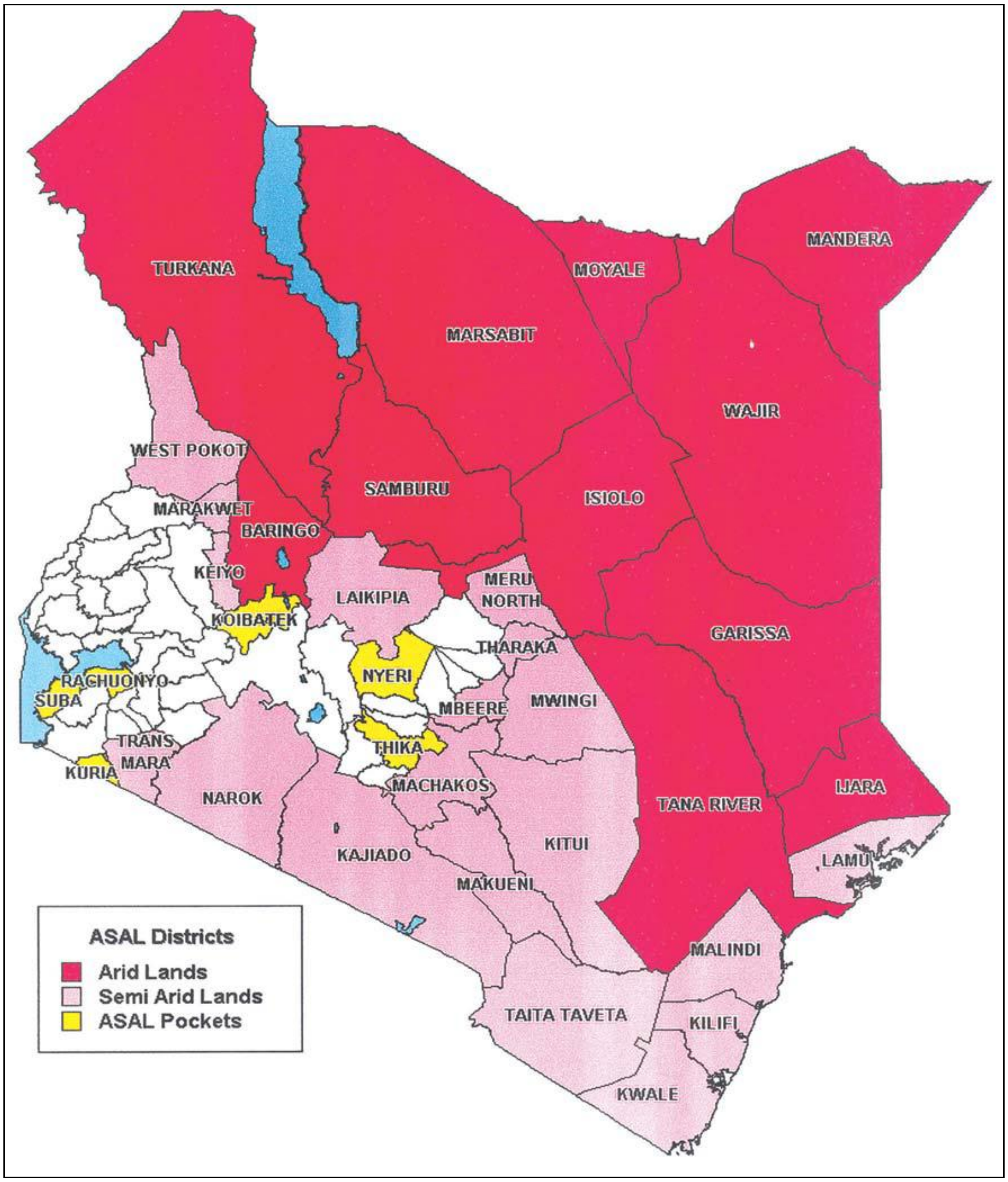
Uganda and Tanzania (Figure 1.1). Kenya has a total area of 580,000 $km^2$and this comprises of 98 percent land and 2 percent water surface. Kenya is the world's forty-seventh largest country. It lies between latitudes 5°N and 5°S, and longitudes 34° and 42°E. The country is named after Mount Kenya, a significant landmark and second among Africa's highest mountain peaks. The country's geography is as diverse as its people and topographically, the country may be divided into four distinct geographical and ecological regions. It has a long coastline along the Indian Ocean and as one advances inland the landscape changes to savannah grasslands, arid and semi-arid bushes. The central regions and the western parts have forests and mountains while the northern regions are near desert landscapes. The rainfall patterns are extremely varied but generally follow these regions, with the Lake Victoria basin receiving the heaviest and most consistent rainfall.

With its capital city in Nairobi, Kenya has numerous wildlife reserves containing thousands of animal species. Kenya is a country of 47 counties each with its own government semi-autonomous from the central government in the capital, Nairobi. It is a former British colony and got its independence on 12 December 1963.

Kenya's population has rapidly increased over the past several decades, and currently has a population of nearly 39 million residents representing many different peoples and cultures. In about 80 years, Kenya's population has grown from 2.9 million to 39 million in 2010. Theoretically, the rate of economic growth should be equal to or higher than the population growth rate for an economy to adequately satisfy the needs of her people. However, Kenya is still at the early stages of a demographic transition characterized by a large proportion of youths resulting in high dependency ratio, currently estimated at about 84 percent (Kenya Economic Report, 2009).

The country has a comparatively low education index, implying that a big proportion of the Kenyan labour force has not attained basic education and skills and/or requisite technical skills and knowledge necessary for improved labour productivity, competitiveness and innovation. The highest level of education completed by majority of Kenyans (86.4 percent) is primary education, followed by secondary education (25.0

percent), pre-primary (9.5 percent), and university (1.2 percent). It is hypothesized in this study that fencing and education are positively related in that a household head with education is likely to have a fence in the homestead.



Source: *Arid Lands Resource Management Project (ALRMP 1993), Office of the President, Nairobi*

Figure 1.1: Extent of arid and semi-arid lands (ASALs) in Kenya

In terms of economic development, Kenya is classified as a developing, and sometimes an emerging African nation. From independence in 1963 to the oil crisis in 1973, the agricultural sector expanded by undergoing two basic changes. The first change was the widespread acceptance of private ownership (replacing tribal ownership) and cash crop farming. Secondly, it was the success of intensive nationwide efforts to expand and upgrade the production of African smallholders. Before World War II (1939–45) ended, agricultural development occurred almost exclusively in the "White Highlands," an area of some 31,000 sq km (12,000 sq mi) allocated to immigrant white settlers and plantation companies. Since independence, as part of a land consolidation and resettlement policy, the Kenya government, with financial aid from the United Kingdom, has gradually transferred large areas to African ownership. European-owned agriculture remains generally large-scale and almost entirely commercial.

After the 1973 oil crisis, agricultural growth slowed as less untapped land became available. Government involvement in marketing coupled with inefficient trade and exchange rate policies discouraged production during the 1970s. Coffee production booms in the late 1970s and in 1986 have in the past temporarily helped the economy in its struggle away from deficit spending and monetary expansion. Although the expansion of agricultural export crops has been the most important factor in stimulating economic development, much agricultural activity is also directed toward providing food for domestic consumption. Kenya's agriculture is sufficiently diversified to produce nearly all of the nation's basic foodstuffs. To some extent, Kenya also helps feed neighbouring countries.

Before the post-election violence in January 2008 that adversely affected agricultural production following the December 2007 general elections, Kenya was rapidly consolidating its position as a regional economic powerhouse (Kenya Economic Report, 2009). In 2007 for example the economy expanded by 7.1 percent, marking the fifth year of consecutive economic expansion. However, the events following the disputed presidential elections, coupled with an unfavourable international environment, have led to a downward revision of the country's growth prospects to about 1.5 to 1.9 percent (Kenya Economic Report, 2009). As at May 2010, economic prospects were positive with 4 to 5 percent GDP growth expected, largely because of a recovery in agriculture besides other sectors such as construction and manufacturing. The World Bank predicted a growth of 4 percent in 2010 and a potential of 4.9 percent growth in 2011(Daily Nation, May 4, 2010).

Therefore, the fact that the contribution of agriculture to GDP as shown in Table 1.1 has been declining yet agriculture is one of the sectors that spur up economic growth, semi-arid lands with so much untapped potential can be developed as well because people are now migrating to those areas due to increasing population.

1.4 Overview of arid and semi-arid lands (ASALs) in Kenya

Kenya’s land is divided into three ecological zones, arid and semi-arid lands (ASALs) sometimes referred to as dry lands, medium and high potential land. Approximately 75 percent of the country’s population lives within the medium to high potential agricultural areas while the rest of the population lives in the vast ASALs. Due to the fact that Kenya’s population is dependent on land and its resources, the medium and high potential land, which constitutes only 20 percent of total land area, has already been put into use (Figure 1.1) while the ASALs, representing 80 percent of the total land mass of the country, remain largely under-exploited.

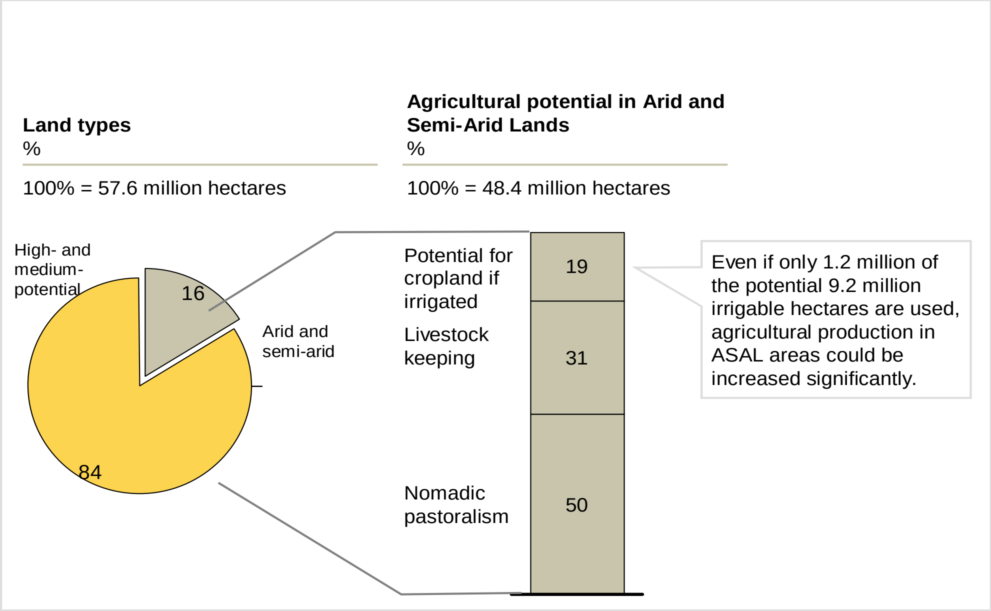
Since ASALs is the area of study in this research, it may be beneficial to highlight some of their climatic conditions. The ASALs in Kenya are characterized by high potential vapour-transpiration, exceeding twice the annual rainfall, and in certain areas as much as ten times the annual rainfall (Government of Kenya, 1992). The annual rainfall in these areas is also low, ranging from 150 to 450 mm (Government of Kenya, 1993). Moreover, rainfall is also highly variable in space and time, and often occurs as high intensity storms. As a result, considerable surface runoff is generated, which is exacerbated by sparse vegetation cover.

The ASALs are predominantly inhabited by migratory pastoralists although semi-pastoral and farming communities exist as well. Some of these communities are recent immigrants from the more densely populated, high agricultural potential areas of the country (Muniafu *et al*., 2008; Government of Kenya, 1993). Statistics also show that ASALs host about 70 percent of the national livestock herd with an annual slaughter of about 1.6 million tropical livestock which contributes about 14 percent of the country's GDP. It also employs 90 percent of the local population. Indeed, the country's livestock sector contributes about 42 percent of total agricultural output and about 30 percent of all marketed agricultural output (IPAR, 2002). More statistics also show that in Kenya, there are 24 million hectares in the ASALs that can be used for livestock production, but only 50 percent of the carrying capacity of the land is currently being exploited. Additionally, there are 9.2 million hectares in ASAL which have the potential for crop production (Onyango *et al.*, 2008; Government of Kenya, 2007).

The Kenyan ASALs poses greater challenges in terms of their productivity and vulnerability to droughts and flush floods. It is also estimated that in the ASAL regions there has been recurrent major droughts every 5 to 7 years in the last three decades (Government of Kenya, 2003b). As a result therefore, it is noted that ASAL's livelihood systems do not adequately recover well enough to withstand the next drought. Hence, any small shock such as a prolonged dry spell has a much bigger impact on people's livelihood strategies (Government of Kenya, 2003b). In addition, the incidence and prevalence of food insecurity is more severe in ASALs due to lack of adequate resource endowment, necessitating periodic government intervention in the provision of relief food (Government of Kenya, 2007).

Efforts at increasing agricultural and environmental sustainability in these areas can have greater impact on the country's GDP. As such the Government of Kenya (GOK) is committed to the development of ASALs and has renewed her focus in such regions by recently creating a new ministry that specifically addresses its developmental agenda. Therefore, the formation of the Ministry of Development of Northern Kenya & Other Arid Lands is a realization of this unexploited potential. Furthermore, the Government in its quest to improve the ASALs has outlined in vision 2030 four specific strategies to be implemented. Firstly, the government will invest in targeted rangeland developments such as water provision, infrastructure, pasture, fodder and veterinary services. Secondly, it will establish strategically located disease free zones to increase livestock productivity and quality. Thirdly, it will unify the efforts of different ministries and other stakeholders (e.g. Regional Development Authorities, The Ministry of Water, and the Office of the President) for coordinated development of the region and finally it will put more land under cultivation as shown in Figure1.2 (Government of Kenya, 2007).

The development of ASALs however still remains a major challenge. Despite challenges of underdevelopment of the livestock sector, the Ministries of Livestock and Fisheries have only absorbed, on average, about 40 percent of their allocated budgets in recent years (Kenya Economic Report, 2009). With the planned increased investment in the livestock sub-sector, there is need to ascertain the major constraints that have previously limited use of allocated funds and with proper management of funds, fencing can be enhanced in ASALs.



Source: Ministry of Agriculture;

***Source**: Adapted from – Vision 2030(2007), Republic of Kenya, Nairobi*

Figure 1.2: Agriculture in ASAL areas

Given the fact that the Government is committed to the development of ASALs and due to increasing population, the ASALs which can accommodate up to 12 million (36 percent) of the population (Government of Kenya, 2009b), have therefore ended up being used to cushion the continuously increasing population pressure which has been rising at an exponential rate. As per the 1991 Population Census, Kenya’s population stood at 30.4 million with an annual growth rate of 2.9 percent and this is expected to rise to 55 million by 2050 (Government of Kenya, 2007). Evidence from Kenya also suggests that Population pressure has resulted in severe fragmentation of holdings in many provinces according to Barrows *et al*. (1990) and this may explain why communities are settling in the ASALs.

Other studies such as that of Twyman *et al*. (2001) carried out in Namibia support the view that increasing pressure on resources from human and livestock populations and the threat of land and resource scarcity has led to an increase in enclosure of communal land through private fencing by individuals and communities. Resource scarcity as a cause of enclosure is supported by the fact that in Namibia, just like in many other African countries like Kenya, young men must leave their father's settlements and establish permanent residency elsewhere and hence, due to scarcity of arable land, most of the young men are moving out to ASALs .Besides, continued population growth, adding more than 70 million people to the world every year, changing dietary preferences, rising energy prices, and increasing needs for bio energy sources are putting tremendous pressure on the world's resources such as land. To keep up with these demands, agricultural production needs to double or triple in the next 30 to 40 years (Foley, 2009). Atwood (1990) also assert that population pressure is a cause of increasing scarcity of land in many rural areas of sub-Saharan Africa. The scarcity of arable land has an effect on agricultural production and what this means is that, increased agriculture production needs to rely heavily on productivity growth (Kenya Economic Report, 2009).

Also, according to the Kenya Economic Report (2009), migration to ASALs by farming communities and the changing socio-economic and traditional cultural practices of some Kenyan communities especially in semi-arid areas have seen an increase in fencing structures due to sub-division of land for settlement. Besides, the ASALs are already home to some of the most food-insecure people. Agricultural production is often hindered by intrusion of wildlife and livestock. One strategy for improving agricultural production is to install fences to reduce intrusion by livestock. It is hypothesized that fencing can intensify agricultural production and thereby improve livelihood. The opening up of these areas also often involves the clearing of vegetation cover thus exposing the soil to wind and water erosion. Therefore, to improve agricultural production while at the same time conserving the natural environment, it is important to study and come up with tangible suggestions and policies that can make lives of those living in and migrating into ASALs better.

1.5 Description of study areas

A brief description of all the study areas in which data was collected in order to accomplish the proposed objectives is captured in sub section 1.5.1 to 1.5.5

1.5.1 Mwala district[1]

Mwala district is in the Eastern province of Kenya. The district covers an area of 1,014 square kilometres most of which is semi-arid (Figure 1.3). The agricultural sector however remains the engine of growth for the Mwala district economy. Over 90 percent of the district population is engaged in activities in the agriculture and livestock production subsectors, making the sector the largest employer and by extension the largest contributor to household incomes. Specifically, an estimated 99 percent and 93 percent of households are respectively engaged in crop farming and livestock rearing in the district. However, the activities in both subsectors are mainly dependent on rainfall which is generally low and inadequate and is also influenced by altitude. Low altitude areas for example record an average annual rainfall of 250 mm and are characterized by open grassland with scattered acacia trees. High altitude areas receive an average annual rainfall of 1300 mm and have dense vegetation and are also suitable for rain-fed agriculture. In addition, land use and settlement patterns are based on the agro-ecological zones and are influenced by soil fertility and rainfall. The high density settlement is in the hilly areas that receive moderate rainfall and have very great agricultural potential and fertile soils while spatial settlement is found in the low plains where ranching and dairy farming is carried out. The low plains receive low rainfall and have got infertile soils that do not support any meaningful agricultural production. The district therefore experiences drought, crop failure and water shortages in most years.

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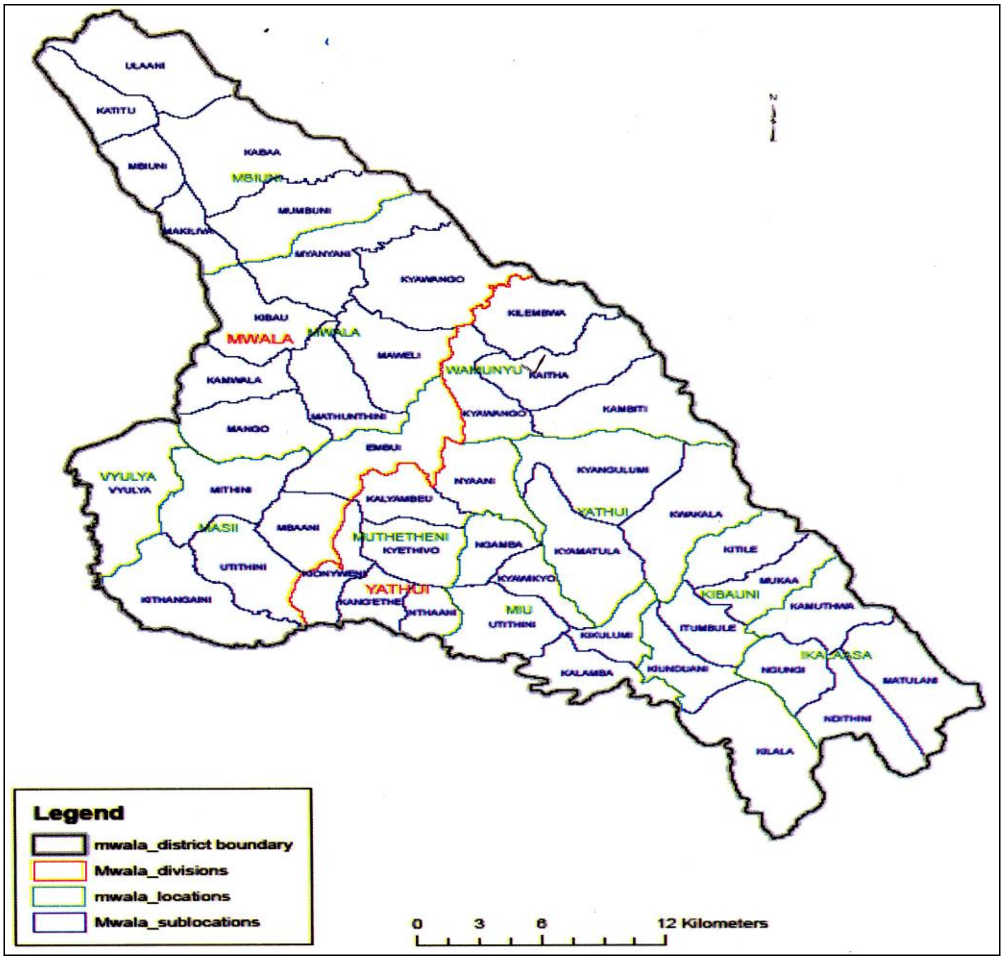
[1] In this research, district and counties are used interchangeably.

Most farmers are semi-subsistent and attain occasional surplus during the short rains. The fertile high density areas cover the least area and this population has put pressure on land and this will continue to increase over the years hence the need to institute aggressive land management programmes that will ensure reduced land degradation while increasing agricultural production (Government of Kenya, 2009c). Figure 1.3 is used to show the administrative boundaries of Mwala District.

1.5.2 Narok North district

Narok North district is situated in the south-western side of the country and lies in the southern part of Rift Valley province of Kenya. The district occupies a total area of 4754 square kilometres most of which is semi-arid (Figure 1.4). The agricultural sector remains the backbone of the local economy in Narok North district. There are four farming systems in the district namely:-agro-pastoralism, mixed farming, pastoralism and pastoral leasing. Livestock production is a source of livelihood for 50 percent of the total population (36,767 households). The main types of livestock kept in Narok North district include cattle, sheep, goats, camel, donkeys, pigs, rabbits, poultry and bee-keeping.

The average farm size (small scale) is 15 acres and that of large scale is 50 acres. Land is either individually owned in high potential areas or communally owned in low potential areas. The issuance of title deeds in the last five years has been successful and land survey undertaken. The number of households depending on agriculture is about 80 percent (169,600 persons) of the total district population (Government of Kenya, 2009b).



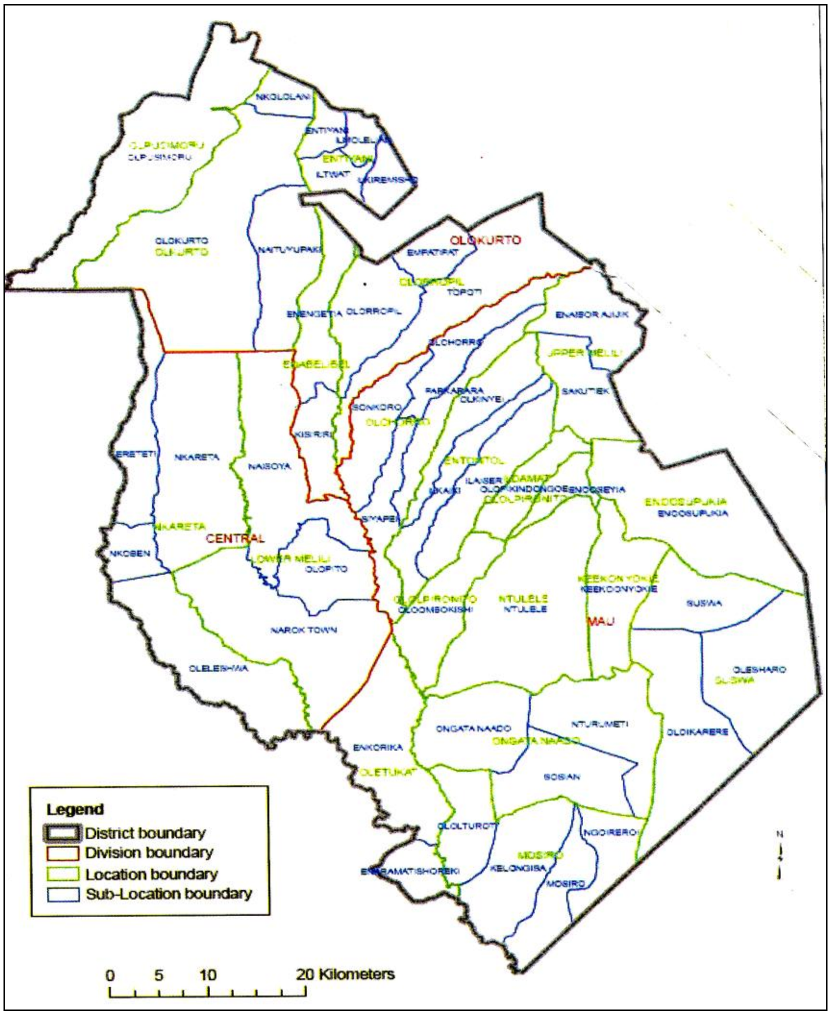
Source: Adopted from-Mwala District Development Plan 2008-2012, Government of Kenya

Figure 1.3: Mwala District Administrative Boundaries

Land use and settlement patterns are based on the agro-ecological zones and are influenced by soil fertility and rainfall. The high density settlements, which have a potential for wheat, barley, maize, beans and potatoes, is along the hilly areas that receive high rainfall and have great agricultural potential and fertile soils. Spatial settlement is found in the low plains where ranching is carried out. The promotion and production of drought tolerant crops such as sorghum, millet, cassava, dry land maize, beans, cow peas, pigeon peas coupled with the altitude change in community eating habits is being done to ensure food security in the lowlands. The district has a varying topography with altitude ranging from 3,100 metres above sea level in the highlands and to 460 metres above sea level in the lowlands.

The major development challenges the district face include high poverty levels, unsustainable population growth, drought and squatter problem. High poverty level is as a result of low incomes which have increasingly undermined the ability of the majority of residents of Narok North district to afford a decent lifestyle (Government of Kenya, 2009b). Land productivity also influences the distribution of poverty in the district. Besides environmental impacts such as encroachment of forests and river banks for farming; deforestation such as burning of charcoal; poor farming methods and lack of interest in environmental conservation. The district is also facing a challenge of unsustainable population growth. Animal keeping and crop farming, thus far the pride of the local community, have been greatly reduced due to unreliable rainfall distribution. For example, during the prolonged drought of 1999 to 2000, the district lost over 500,000 animals. Other researchers such as Barrett *et al.* (2000) concur that a major challenge in semi-arid areas is loss of livestock due to drought. The drought also exacerbates the wildlife-human animal conflict as they both compete for scarce resources such as water and grass among other things. Communities that lived harmoniously have lately been faced with estranged relationships due to clashes over water and pasture occasioned by the dangers of drought. Human-wildlife conflicts are increasingly becoming common. The drought compels the wild-animals to move out of the Mara game reserve to search for water and grass outside the parks thus causing massive destruction to properties and sometimes to human life hence the need of fencing.

Squatter habitation is a big challenge in the district as well and thousands of people still live as squatters in the district. The situation was aggravated by the post-election violence of the year 2007 in which most people were left homeless and some of whom are yet to be resettled. Their presence has greatly destabilised the implementation of planned programs. Due to the increased number of squatters and internally displaced persons (IDPs), most of them have been compelled to encroach into fragile ecosystems and water catchment areas. This has resulted in massive destruction of forest cover, environmental degradation and overcrowding in urban centres. Figure 1.4 shows administrative boundaries of Narok North district.



***Source**: Adopted from- Narok North District Development Plan 2008-2012, Government of Kenya*

Figure 1.4: Narok North District Administrative Boundaries

1.5.3 Koibatek district

Koibatek district is one of the districts in the Rift Valley province of Kenya. The district covers a total area of 2,306 square kilometres most of which is semi-arid (Figure 1.5). In addition, land use and settlement patterns are based on the agro-ecological zones and are influenced by soil fertility, rainfall and availability of arable land. Rainfall in the district is seasonal and fairly reliable. Average rainfall varies from 800 mm per annum in the lowlands to 1200 mm in the highlands. The district can be divided into two major zones namely the highlands and the lowlands. Farming activities are carried out in the high potential agricultural zones for the reason that the highlands are suitable for agricultural and improved livestock development. Koibatek the study area is least densely populated and it is located in the arid and semi-arid zones. This zone is mostly rangeland but there are isolated pockets of dry subsistence agriculture. The major socio-economic activities centre on livestock and bee keeping.

Agriculture is the main source of livelihood for majority of the people in Koibatek district. It contributes 75 percent of the total household income. Mixed farming (Crop and animal rearing) is generally practiced. Major crops grown include maize, finger millet, sorghum, beans, Irish potatoes, groundnuts and sweet potatoes. The lowlands such as Mogotio have however had recurrent food shortage due to late and suppressed rainfall. However, with the post-election violence, vulnerability of the district in terms of food security increased. Average land holding in the district is 10 acres (4.04 ha). Unregistered parcels of land account for 50 percent of the total land in the district (Government of Kenya, 2009d).

Koibatek district also faces development challenges and this includes high poverty levels, undeveloped agricultural potential and environmental degradation (Government of Kenya, 2009d).

According to geographic dimensions of wellbeing in Kenya (2005), poverty incidence of individuals below poverty line in Koibatek District is 50 percent (Government of Kenya, 2009d). It contributes 0.25 percent to national poverty and 1.5 percent to provincial poverty. Poverty is more pronounced in the rural areas, especially in the lower zone of the district. People in this area are agro-pastoralist and depend on rainfall for successful farming and therefore, unreliable rainfall has disastrous impact on their economic activities.

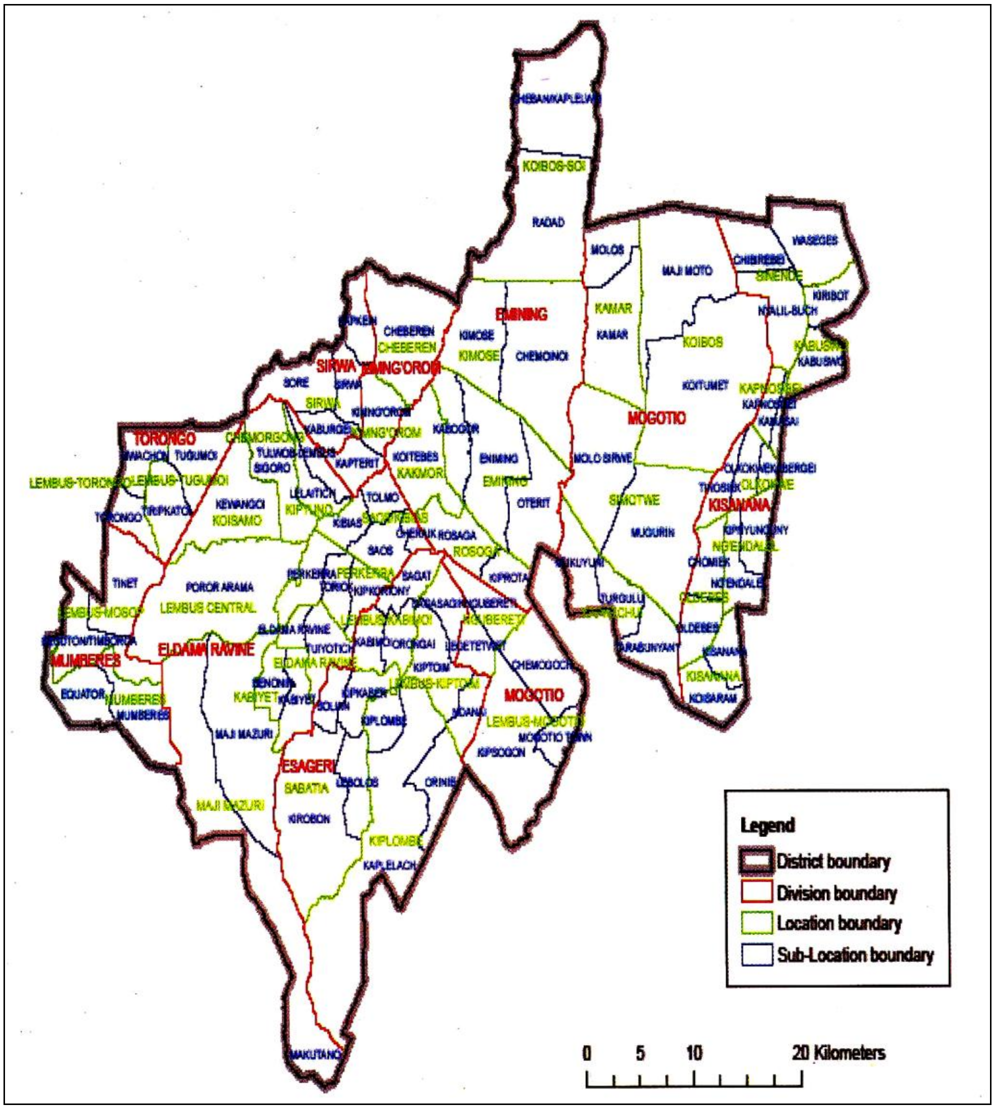
The district also has potential to produce raw materials for industrial use, but the main problem is that most of them have not been developed to a state whereby they can sustain viable industries. For example, honey production is still low in the district especially in the marginal areas. This is because there are few collection centres and no refineries in the district for value addition.

Environmental degradation in the district is common and this has led to decline in the quality of land due to unsustainable farming practices, effects of climate change and soil erosion. Soil erosion is prevalent in the district especially in the lower zones due to poor soil cover. Environmental shocks and stresses brought about by droughts compound poverty and affect the poor disproportionately because the poor tend to live in marginal and vulnerable areas. Figure 1.5 shows administrative boundaries of Koibatek district

1.5.4 Suba district

Suba district is one of the districts in the Nyanza province of Kenya. The district has a population of 204,099 and an area of 1,055 square kilometres. The district has five administrative divisions namely; Mbita, Lambwe, Central, Gwassi and Mfangano. Mbita the study area has a population of 46,223, an area of 211 square kilometres, 5 locations and 15 Sub-Divisions. Mbita has the most locations and sub-divisions besides Gwassi. It is also in the lowlands and it can get very hot unlike areas like Gwassi hills which are generally cooler.

Rural residents of Mbita mainly depend on agriculture as their main source of food and income. The human settlement pattern in the district is also determined mainly by the agricultural potential and closeness to the lake. Suba district has two rainy seasons. The long rains fall between March and June, with a peak in April and May. Short rains do not last as long and typically fall from late September to November. Distribution and amount of rainfall is influenced by the geography of the land. The district is drier in the Eastern part and is wetter towards the higher altitudes in the western parts.



Source: Adopted from- Koibatek District Development Plan 2008-2012, Government of Kenya

Figure 1.5: Koibatek District Administrative Boundaries

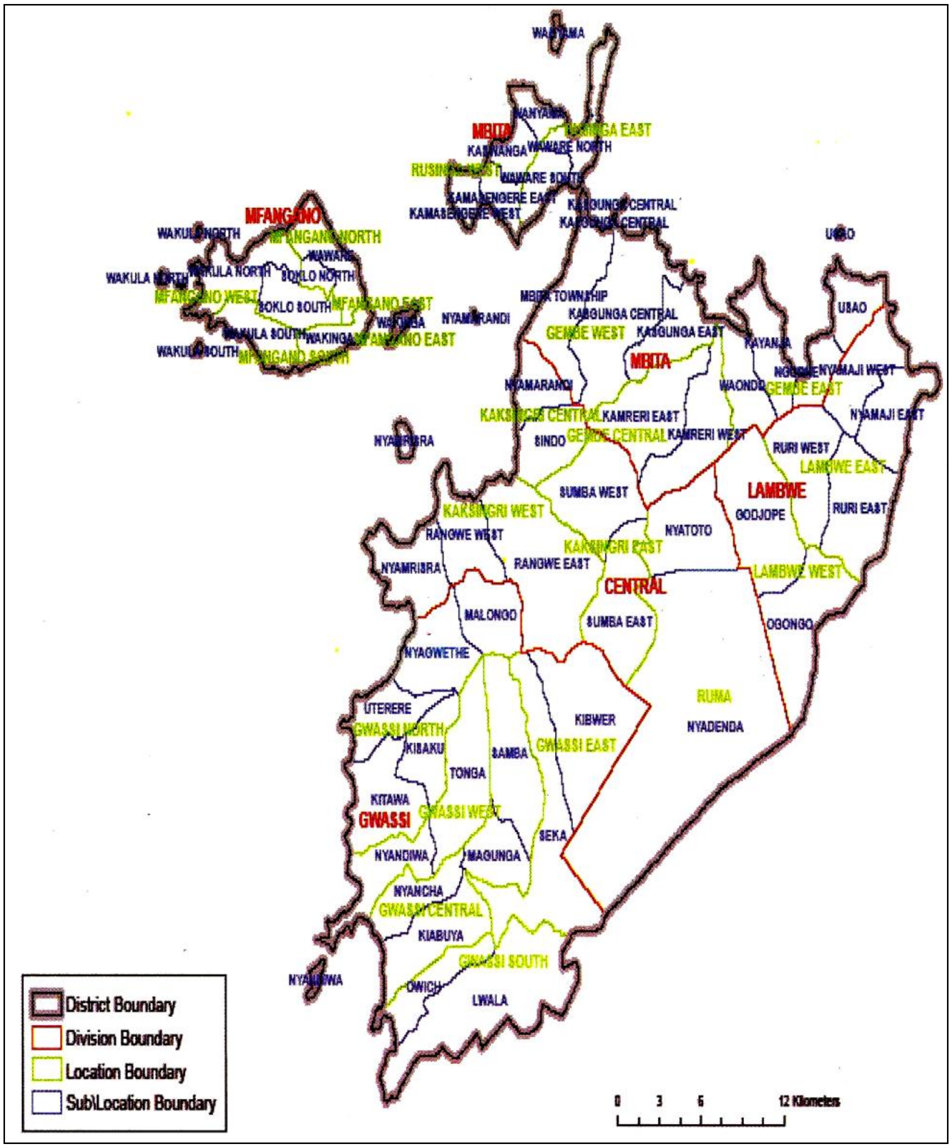
On the highlands the rainfall ranges between 800 to 1900 mm per annum. The lower areas receive between 800 to 1200 mm. In the past the pattern was consistent but now it can be unpredictable, having negative impact on farming. The farming is mostly subsistence based and major crops grown are sorghum, potatoes, cassava, beans and maize. Bananas, sweet potatoes and cassava do well when fed by rain and are grown widely as security crops that will withstand drought and feed families during famines.

These can also be sold for income, especially bananas. Fish products however form the economic mainstay of the district.

Local breeds make up most of the livestock in Suba district. Farmers crossbreed cattle and poultry to raise the quality of the local breeds. In the past there was enough land for cows to graze freely in fields and most families had large herds of more than 20 heads. The average family in Suba district has only around 4 cows. Most households have a flock of free-range chickens.

As per the District Development Plan (2009e), key investments are needed in agriculture, livestock, forestry and wildlife to increase production. Thus, measures that will ensure that the issues surrounding land as a factor of production are addressed. These include measures like regularisation of the tenure and ensuring that all parcels have title deeds. The provision of title deed is therefore expected to increase the demand for fence.

Though there are many development initiatives in the area, poverty is still a major challenge. Most families live on less than a dollar a day. Poverty hits hardest in areas facing low rainfall levels and poor soil fertility, such as the lower parts of the district. Many factors have caused poverty to spread during the last 20 years and this include growth in local population and new land use systems that shifted ownership from common to individual land. There was also growing pressure on natural resources such as trees (for firewood and building). Deforestation led to erosion and desertification and a decrease in soil fertility. Lack of trees also reduced rainfall and caused rivers and streams to dry up. Soil infertility and other causes led to low crop production and lower animal production.



***Source**: Adopted from- Suba District Development Plan 2008-2012, Government of Kenya*

Figure 1.6: Suba District Administrative Boundaries

1.5.5 Taita Taveta district

Taita Taveta district is one of the districts in Coast province of Kenya. The district covers a total area of 16,483 square kilometres (Figure 1.7). The district is divided into two major topographical zones, the upper zone and the lower zones. The altitude of the district varies between 481 m above sea level in the lowlands to 2,200 m above sea level in the highlands. Voi division, the study area is the least populated and this is attributed to harsh climatic conditions and limited economic activities and reliance on rain-fed agriculture. It is also lowland and the main means of livelihood is ranching, sisal farming and mining. On the other hand, the upper zone is suitable for horticultural farming and is the most populous. The district experiences two rainy seasons, the long rains between the months of March and May and the short rains between November and December. The rainfall distribution is uneven in the district, with the highlands receiving higher rainfall than the lowland areas. The lowlands receive bimodal rainfall which is mostly unreliable, thus experience frequent droughts and this affects the district’s food security. The lowlands also receive water stress resulting to human-wildlife conflict.

Tsavo East and Tsavo West National Parks, home to various types of wild animals, occupy a large portion of the lowlands. This poses a great challenge in the agricultural sector due to human/wildlife conflict and this may justify the need of a strong fence. Kenya Wildlife Services (KWS) has partnered with the community to protect the wildlife by ensuring that there is sustainable co-existence of human beings, domestic animals and the wildlife. Extra electric fences have been erected to protect animals from straying.

According to 1999 census, the population of the district was 193,633 and this is expected to increase from 225,647 in 2008 to 247,922 in 2012. Such an increase has a direct impact on the basic needs such as food, water, health and education for all ages. The first priority being food, it implies that efforts should be made to increase food production to cater for the increased population hence the need of a fence.

Agriculture is the major economic activity in the district contributing 95 percent of the household income. Approximately, 76 percent of the population lives in the rural areas where the main means of livelihood is agriculture. Maize and beans are the main food crops. Livestock development is also an important sector providing income and employment and more potential is in the lowlands. The main livestock breeds are cattle, goats and sheep and the average number of cattle and goats per household is 4.6 and 7.4 respectively. Also, the average number of trees per farm is 50.

Land is also an important factor of production in the district and is 95 percent depended on it directly or indirectly. The average farm size in the lowlands is 4.8 ha and the percentage of farmers with title deeds is 40 percent (Government of Kenya, 2009a).

Some development challenges in the district include bio diversity loss and environmental degradation, population growth, squatters' problem, human/wildlife conflict and poverty (Government of Kenya, 2009a).

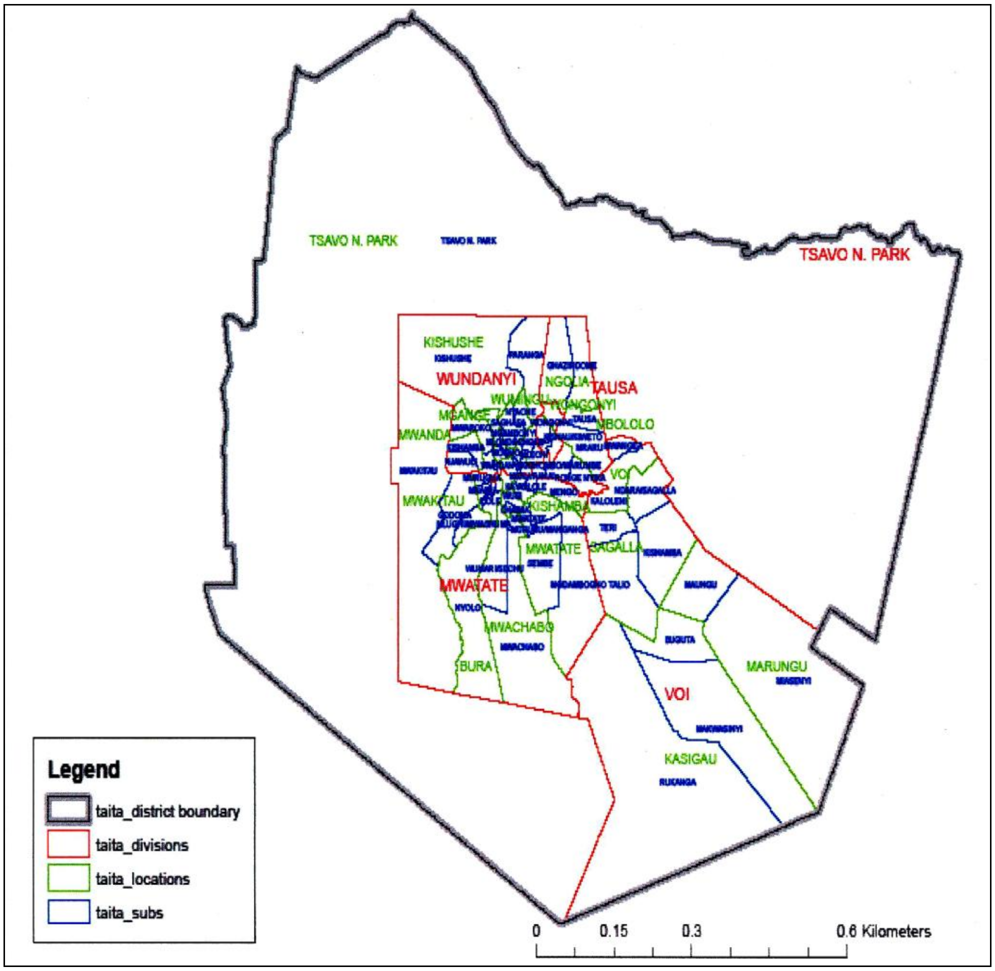
Environmental degradation needs to be addressed if the district is to achieve the MDG of ensuring environmental sustainability. Quest for development provides a challenge to biodiversity preservation. This includes overgrazing, loss of species and integrity of habitat, overexploitation of plant and animal species, population pressure and expansion of settlements.

Population has also been increasing steadily in the district. This poses several challenges such as increased poverty, pressure on agricultural land and environmental degradation through encroachment on the water catchments areas. Pressure on land is also bound to result into increased human-wildlife conflicts in the lower zones.

The heavy presence of squatters in the district is a potential area for conflicts and is a problem that needs to be addressed. Due to the increasing numbers of squatters, most of them have been compelled to settle in areas with fragile ecological base and water catchment areas for survival. This has resulted to massive destruction of forests, environmental degradation and overcrowding in urban centres. Other challenges that come about as a result of squatter problem include decrease in water resources due to destruction of water catchment areas, food deficits as a result of drought and poor farming methods and lastly, heavy migration of the population from the upper zones to lowlands where the environment is fragile .The migration from upper zones to lower zones has seen an increase in fence structures.

Large percentage of wildlife also resides outside protected areas where it competes with other land uses for limited resources causing human-wildlife conflicts. Other challenges include livestock-wildlife conflict and lack of adequate compensation when the animals from the park harm or kill a community member. There are also boundaries conflicts among the community and the parks. Considering all these challenges, it appears that a fence may help in reducing the problem of human-wildlife conflict.

The distribution of poverty in the district is biased towards the marginal farming areas such as Voi the study area and this can be attributed to erratic and inadequate rainfall, poor agricultural practices and wildlife destruction especially in the divisions bordering the Tsavo National Park.



***Source**: Adopted from- Taita District Development Plan 2008-2012, Government of Kenya*

Figure 1.7: Taita Taveta District Administrative Boundaries

1.6 Land history and policy in Kenya

Kenya has different land tenure system and cultural norms relating to land. This coupled with a fast growing population have led to the subdivision of very potent land into small plots that are too small to be economical for meaningful agricultural activities in high and medium potential land. The Land Policy of Kenya encourages individual demarcation, registration and private ownership of land (Government of Kenya, 2008). However, this is an area that needs to be addressed at policy level so that there is reasonable minimal land size subdivision for sustainable agricultural production.

Furthermore, land retains a central point in Kenya's history and it was the basis upon which the struggle for independence was waged. In addition, land currently still continues to command a key position in the country's social, economic, political and legal relations (Government of Kenya, 2004b). Land, in Kenya means the soil and everything above and below it. It includes any estate or interest in the land plus all permanent fixtures, and buildings, together with all paths, passages, ways, waters, watercourses, liberties, privileges, easements, plantations and gardens thereon or thereunder (Government of Kenya, 2004b). This definition however largely applies to registered land as opposed to land held under Customary Law. Land under Customary Law refers mainly to the soil.

Historically, land in pre-colonial Kenya was owned and held under a complex system of customary tenure in which rights of access to and use of land were regulated by intricate rules, usages and practices. These were often based on communal solidarity such as clan, and other lineal heritages[2] (Government of Kenya, 2004b).For example, under African Customary Land law, there was a distinction between rights of access to land and control of those rights. The power of control was vested in a recognized political authority or entity within a specific community. In addition, the political entity exercised these powers to allocate rights of access to individuals depending on the needs and status of the individual in question. Rights of access were guaranteed by the

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[2] In the diversity of customary tenures, a number of relevant features have been recorded by different writers such as Sorrenson, 1968; Ghai *et al.,* 1970 and Okoth, 1995 as laid down in the Report of the Commission of Inquiry into the Illegal/Irregular Allocation of Public Land.

political authority on the basis of reciprocal duties performed by the rights holder to the community. Rights to land were also determined on a continuum of flexibility; always adjusting and changing as circumstances demanded and lastly, there was no element of exclusivity to land under African Customary Law as found within English property jurisprudence.

Public land under African Customary Tenure fell under the commons and thus there was territory which served the interests of the community in its corporate status. In this category were found lands such as common pathways, watering points, grazing fields, recreational areas/grounds, meeting venues, ancestral and cultural grounds, and many others. No individual or group could be allocated rights of access to such public lands other than for purposes for which they had been set aside and recognized. The community’s needs could not yield to private interests.

However, the customary land tenure did no last for long with the British conquest and the subsequent declaration of a protectorate and later a colony in 1920. This fundamentally altered the African land relations in Kenya. This is because the promulgation of the Crown Lands Ordinance of 1902 and later the Crown Lands Ordinance of 1915 conferred enormous powers on the colonial government to deal with what had been declared crown land. In effect, the governor could make grants of freehold and leasehold in favour of individuals and corporate bodies on behalf of the crown. All “waste and unoccupied land” in Kenya was declared Crown Land in 1897 by European powers. By 1920, when Kenya was formally declared a colony, all land in the country, irrespective of whether it was occupied or unoccupied was regarded by the British authorities as ‘Crown Land’ hence available for alienation to white settlers for use as private estates. However, little consideration was given to land rights security for African cultivators and their land could be alienated by settlers anytime. For example, the Masai, a nomadic community in Kenya were to discover to their detriment that not even ‘treaties’ similar to those concluded elsewhere in Central and Southern Africa, were capable of offering protection. It was only after several inquiries and commissions that a clear separation in colonial law rather than fact was made in 1938 between ‘Crown Land’ out of which private titles could be granted, and ‘Native Lands’ which were to be held in trust for those in actual occupation (Okoth-Ogendo, 1999; Kabubo-Mariara, 2006).

Currently in Kenya thus, land is divided into three different legal categories namely, Government Land, Trust Land and Private Land. Government Land comprises of un-alienated Government Land and alienated Government Land. Un-alienated lands are those lands vested in the government and over which no private title has been created. They do not belong to individuals or bodies corporate in their private capacities. On the other hand alienated government land is land which the Government has leased to a private individual or body corporate, or which has been reserved for the use of a government ministry, department, State Corporation or other public institution.

On the other hand, Trust Lands are neither owned by the government nor by the county council. County councils simply hold lands on behalf of the local inhabitants of the area. For as long as Trust Land remains un-adjudicated and un-registered, it belongs to the local communities, groups, families and individuals in accordance with the applicable African Customary Law. Once registered under any of the land registration statuses, Trust Land is transformed into Private Land. It then becomes the sole property of the individual or group in favour of whom it is registered.

The last category of land, Private Land[3] is land to which the title is registered in accordance with any of the laws that provide for registration of title. Land may be registered in the name of an individual or company. Besides, acquisition of Private Land may follow up to three stages; the first is adjudication of individual or group rights under customary tenure to private tenure under the Land Adjudication Act, thus making Customary Land Law obsolete (Kabubo-Mariara, 2006, 2003; Odhiambo and Nyangito, 2002). In the second stage, consolidation, each individual or group has rights and is allocated a single consolidated piece of land equivalent to several units under the Land Consolidation Act. Finally, the third stage is registration and entry of rights in the

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[3] Private land is derived from the Government Land Act (Cap 280), the registration of Titles Act (RTA) (Cap 281), the Land Titles Act (LTA) (Cap 282), Registered Land Act (RLA) (Cap 300), Trust Land Act (Cap 288) and the Indian Transfer of Property Act (ITPA).

Adjudication Register (in the Land Registry) and the issuance of a certificate of ownership, under the Registered Land Act (Cap 300) and the Land Titles Act (Cap 282) (Kabubo-Mariara., 2006).

It is also important to note that individual freehold tenure was introduced in the Central province in the I950$_S$ during the Mau-Mau rebellion. Most of the former African Trust Lands there had been registered by the end of that decade, and nearly completed in the Nyanza and Western provinces by the mid-I970s. Land registration in the Eastern, Rift Valley, and Coast provinces began at a later date. By the end of 1981, over 6 million hectares had been registered nationally (Barrow *et al*., 1990, Odingo, 1985). This implies that customary tenure was already undergoing individualisation.

Kenya has however not had a single and clearly defined national land policy since independence in 1963 and it was not until August 2010 when the people of Kenya voted for a new constitution and in the constitution was the new land policy. The lack of a clear land policy in the previous years together with the existence of many land laws as discussed above resulted in a complex land management and administration system. The land question manifested itself in many ways such as fragmentation, breakdown in land administration, disparities in land ownership and poverty. This resulted in environmental, social, economic and political problems including deterioration in land quality, squatting and landlessness, disinheritance of some groups and individuals, urban squalor, under-utilization and abandonment of agricultural land, tenure insecurity and conflict (Government of Kenya,2008;Kabubo-Mariara, 2006).

The new national land policy process is thus geared towards clear definition and determination of the following core issues: Insecure land tenure, poor land administration, weak and/or ineffective mechanisms for fair, timely, affordable, transparent and accessible resolution of land disputes, continued land fragmentation, and the multiplicity of tenure regimes with limited harmonization. In particular, the overall objective of land policy should be to establish a land administration and management system that is economically efficient, socially equitable, environmentally sustainable and operationally accountable to the Kenyan people. In fact, it has also been pointed out that Kenya, compared to other neighbouring countries, has continued to promote the individualization of tenure through the introduction of formal land titling in what is now Trust Lands and formerly called African reserves on grounds of economic efficiency (Adams, 2003).

Thus, from the above discussion, it is clear that ownership of private land is acceptable in Kenya. Individualisation of land increases the demand of title deeds and as hypothesised in this study, fence and title deed are positively related. This therefore implies that privatisation of land increases the demand for fencing.

1.7 Fencing and Land policy

The discussion in the previous section 1.6 on land history and policy in Kenya illustrate that most land in Kenya is individual land and the coming of imperial powers in 1920 almost ended the customary land tenure in Kenya. However, even though traditionally land in Kenya was communally owned, the Registered Land Act (Cap 300), enacted in 1963, was the culmination of the reform program started by the colonial government aimed at replacing the Customary Law system of communal ownership of land with the English system. The fact that people can own their own land encourages land purchases, sales and transfers. Purchased land is fenced to confirm ownership and due to an influx of people into semi-arid lands as a result of increasing population (Muniafu *et al*., 2008), fence structures are now common in an otherwise unsettled land.

Also people are now resorting to crop farming. For instance, some Turkana and Masai people in the semi-arid areas have now, because of individual ownership of land resorted to practicing crop farming instead of nomadism (Boone *et al*., 2001).The view of individual ownership is also supported by some writers such as Livingstone (1981) who asserted that it offers security which is considered necessary in providing incentives for investment and improvement. Demeke (1989) also argued that the development of private land rights can be helpful in protecting land and improving its productivity. People are also fencing land due to changes in social institutions and land use policies (Tyman *et al*., 2001).

As a result of land privatisation policies in Kenya, there has been an apparent increase of fencing structures erected around individual farms for various reasons. In addition, the intrusion of livestock and wildlife into cultivated land has seemingly affected farm development by farmers in the semi-arid districts. To counter the problem of livestock and game animals grazing on crops and trees, households apparently tend to invest in fencing to protect their farms.

1.8 Problem statement

Various studies such as Dolan (2009), Boones *et al.* (2004), Boone and Coughenour, (2001) and Platt *et al.* (1999) have pointed out that fencing can be useful in controlling access either by humans or animals, protecting gardens and landscaping. Platt *et al.* (1999) further stated that fencing an area is one of the most effective steps that can be taken to protect native vegetation, the wildlife dependent on it and the benefits it offers to a property. This includes shade and shelter for livestock, erosion prevention as well as being a basic tool in the effective management of property. Other writers such as Harvey *et al.* (2005) point out other benefits and they argue that live fences have an added benefit of providing forage and shade for livestock and being self-sustaining. Field (1984, 1985) argues that fencing may be seen as a way of preventing environmental degradation and at the same time enhancing private ownership of land. Respect for property rights to land, whether owned by communities, individuals or companies, is an important driver of rapid economic transformation everywhere as spelt out in Vision 2030 (Government of Kenya, 2007) hence the need of a land policy to enforce it.

In addition, they are a source of products such as live stakes for new fences, timber, firewood and fruits. Fencing also fulfils service functions within the farms such as the provision of shade and wind protection. They further argue that shade is important for cattle in that it reduces heat stress particularly in the dry season resulting in higher weight gain, milk production and reproductive rates. However fencing may also have a drawback in that too much shade may reduce grass productivity hence overall productivity.

The studies explain the role of fencing in the production process but seemingly none has attempted to directly measure the empirical value of fencing as a productive input. It is with this background that this study aims to fill this research gap by investigating the contribution of fencing to agricultural production in semi-arid Kenya, with the aim of offering possible policy prescriptions for increased farm productivity.

Semi-arid districts are used for the empirical analysis because arid areas are in the main deserts and minimal agricultural activity takes place due to unfavourable rainfall patterns. Moreover, the communities who live there are predominantly pastoralists. On the other hand, in the productive areas, it has been observed that individual ownership of land is widespread and fencing of farmlands is highly developed. This is due to the fact that the colonial powers chose to settle in these places rather than in the arid and semi-arid regions as it was classified as being productive.

This study will also attempt to measure efficiency of production in fenced households and the contribution of fence to efficiency. Ajibefun *et al.* (1999) argues that increased production is a direct consequence of efficiency of production, resulting from efficiency of input combination, given the applied technology. Therefore, improving agricultural output in semi-arid areas could be sustained with a proper analysis of the productivity and efficiency of factors involved in the production process such as fence. The expected outcome of this research on fencing is thus expected to go a long way in complementing other efforts in making semi-arid regions more productive thereby empowering the inhabitants and raising their standards of living through poverty alleviation. This study also hopes to come up with findings that will help the policy makers in deciding how to help households in semi-arid areas who may need to fence their land to prevent intrusion from human beings and wildlife but who cannot afford it because of reasons such as low incomes a problem most households in the sampled regions face.

1.9 Objectives of the study

The general motivation of the study is to evaluate how investment in fencing contributes to agricultural production with special reference to semi-arid regions of

Kenya. Owing to the many factors that go into productivity, the following specific objectives of the study have been developed:

- To relate how fencing impacts on marginal productivity of labour, land, land quality and capital.
- To determine the relative role of socio-economic and demographic characteristics in relation to fencing decisions.
- To carry out a comparative analysis of the regions under study.
- To examine the relationship between fencing and the land policy in Kenya.
- To draw conclusions and recommendations for improving farm productivity in semi-arid regions of Kenya and the greater Africa with possible incorporation into policy.

1.10 Conclusion

A more general conclusion that can be drawn from chapter 1 is that ASALs in Kenya have a potential for increasing agricultural output in that existing literature show that it hosts about 70 percent of existing livestock population and also has the potential of increasing crop production (Government of Kenya, 2007). The driving force thus of carrying out the research is because agriculture is the mainstay of Kenya's economy and improving agricultural production especially in semi-arid areas is critical for Kenya to achieve accelerated growth, sustainable development, and reduction of poverty and inequality. Similarly, declining food production in recent years due to factors such as drought and tribal wars coupled with an increasing population has led to an influx of people into semi-arid areas. Furthermore, due to increasing population in Kenya, individuals are now moving out of high and medium potential lands into the low potential lands. Migration as a result of high population coupled with the current Land Policy that allows individualisation of land has seen an increase in fence structures in the ASALs and hence the motivation to find out the role of fence on agricultural production in semi-arid areas. In fact, the growing gap between food production and population growth is the most worrying feature in Kenya's agriculture. There are hopes however that Africa will increase yields by exploiting unfarmed land ("Food in Africa, a recipe for riots, rising prices can cause mayhem" The Economist, May 26th 2011).

Finally in this chapter, it is also noted that even though the sampled districts have different traditional and cultural practices and different challenges such as high poverty levels, environmental degradation, squatter problems, human-wildlife animal conflict and high population growth, it appears that fence is an important investment that is worth undertaking to prevent intrusion amongst other benefits.

CHAPTER 2
THEORY & LITERATURE REVIEW

2.1 Preamble

This chapter will critically discuss previous works on fencing and the production function from Kenya and other parts of the world relevant to this research. The chapter is divided into two parts, A and B. Part A will look at literature on fencing. Specifically, literature on the benefits of fencing in relation to grazing land, wildlife and property ownership will be reviewed. Part B will review literature on the production function, stochastic frontier analysis and data envelopment analysis. In addition, literature on the relationship between productivity and the various inputs useful in production; capital, land, labour, land quality is also discussed in part B. This will form the basis of the empirical work.

SECTION A

Literature on fencing and its associated benefits will be discussed in sections 2.2 to 2.4

2.2 Fencing and grazing land

In one experimental study in West Pokot, a semi-arid district of Kenya, Nyberg (2007) observed that fencing can make a great difference especially in reducing soil erosion and overgrazing. By using fencing to prevent access of grazing animals to the sample area, good tree survival and impressive natural grass regeneration occurred. Hoare (1992) further highlighted that fencing allowed managers of a ranch to move livestock between landscape patches, optimising grazing and allowing resting of unused patches. There was also improved security from thieves and reduced disease spread. Maschinski *et al.* (1996) documented how the destruction of a plant called sentry milk vetch (*Astragalus cremnophylax* var. *cremnophylax*) from a plot in Arizona was prevented or delayed by fencing-out herbivores.

Moreover, Turner *et al.* (2009) in a study on fencing systems for intensive grazing management assert that for intensive grazing to be managed effectively, controlled grazing needs to be in place, by subdividing the pasture through the use of fencing.

They concluded that rotating animals among these paddocks will optimise forage and beef production. This deduction appears to be consistent with the hypothesis of this study that fencing enhances agricultural output. Other researchers however have different views on the importance of fencing on grazing land.

For example, Wang *et al.* (2004) in a cross-sectional survey on fenced pasture demonstrated that partial fencing of pastures could promote a disease *Alveolar echinococcosis* in semi-nomadic pastoral communities. They argued that this may be due to overgrazing, an assumed cause of population outbreaks of small mammal intermediate hosts of the parasite on the Tibetan plateau, China. Overgrazing may have been exacerbated by the reduction of communal pastures nearby the settlements due to introduction of partial fencing around group tenure pastures acquired by pastoralist families.

Twyman *et al*. (2001) in a case study on the people of Okonyoka in Eastern Namibia elicited that those farmers who erect fences obtain exclusive rights of access to rangeland resources, and they are also able to utilise dual grazing rights on the remaining communal land. In addition, they noted that a transition in ecological state occurred in these marginal areas since fence was constructed as a result of the significant reductions in grazing intensity. This is evidenced by varied bush cover, in terms of providing dry season fodder for cattle and browse for small stock throughout the year. Moreover, significant variations in the grass cover *ScIliiidfia kalaliarensis* were also recorded spatially across the land indicative of the changing pattern of grazing pressure brought about by fence construction. Prior to fencing the land, the local residents confirmed that the majority of the enclosed land was dominated by an annual sour grass with only an occasional presence of long-lived perennial grasses. However, after fencing the land, perennial grass species, *Stipagrost Is tnip/iumis* and the less nutritious stick grass, *Aristida stipidata* have been re-established and has even become the dominant ecological cover.

Harvey *et al.* (2005) in their study on contribution of live fences to the ecological integrity of agricultural landscape show that live fences are important features of agricultural landscapes that merit much greater attention in sustainable land management strategies.

2.3 Fencing and wildlife

Apart from regeneration of plant cover, other benefits of fencing have also been documented. It has been shown that fencing can reduce human and animal conflict and reduce crop damage. Kenya Economic Report (2009) states that Kenya has diverse and abundant wildlife resources, but about 70 percent of the wild animals live outside the protected areas and are the main source of serious human-wildlife conflict. A case in point is the government's commitment to reduce human –wildlife animal conflict. This came to actuality in March 2010 when the president of Kenya inaugurated the longest conservation fence around Aberdare's National Park built for 21 years. It also hoped that this move would increase the country's forest cover from 2 percent to 4 percent by the year 2012. This would also be scaled up to international standards of at least 10 percent by the year 2030. The erection of the fence has also encouraged land owners bordering the park to plant trees on at least a tenth of their land. The fence is a very good management tool to conserve the ecosystem and not to separate people from the ecosystem (Daily Nation, 12th March 2010).

Others such as Waithaka (1993) carried out a survey in Mbololo, Kenya on the extent of crop damage by elephants and found out that the installation of a fence around a game reserve helped a great deal in that it eliminated encroachment by elephants .In Amboseli National Park in Kenya, Ricciuti (1993) observed that the fenced forest had dense and green vegetation, whereas the acacias outside the fence were broken and stripped of leaves. This also indicates that fencing can be useful in increasing plant cover. Researchers have observed that where fencing was done, some crops such us pawpaw and vegetables thrived unlike the unfenced homesteads. Furthermore, anecdotal and observational evidences suggest that fencing may increase the biomass and biodiversity hence improving the environment.

Clevenger *et al.* (*2001*) further asserted that fencing can be a tool for reducing vehicle accidents, injuries and deaths. In a study on wildlife vehicle collision in Alberta, Canada, they found out that highway mitigation fencing reduced highway vehicle - wildlife collision. This view is supported by statistics tracked by Colorado State that show that wildlife-vehicle collisions accounted for about 20 percent of all accidents between Glenwood Springs and the outskirts of Aspen in 2005. A fence erected along a 4 mile stretch drastically reduced road deaths and collisions, according to Colorado division of wildlife officers (The Aspen Times, 22nd April 2010).

As reported by Dolan (2009), fences can be built to completely exclude most animals from property or be built in a way that allows access by some species while excluding others depending on the goal. Where livestock and human safety are issues, fences can be designed to exclude most wild animals completely while keeping pets or livestock in. Where safety is not an issue, fences can be built that do not restrict the movement of wild animals and can benefit them by allowing movements along seasonal migration routes as well as daily movements to food, cover and water.

While there appear to be numerous advantages of fencing, other studies have however indicated otherwise. A case in point is the study by Boones and Hobb (2004). Their work involved comparing stocking levels of large herbivores in fenced and non-fenced areas of the game park. They found out that with the increasing population of resident herbivores, vegetation damage occurred. This consequently reduced the carrying capacity of the land. Besides, they noted that fencing can cause electrocution to the animals and may also interfere with their migratory routes. These views are also supported by Gadd (2008) who asserted that fences disrupt individual daily movements of wildlife and may lead to death by starvation, dehydration or entanglement. The author further claims that fences facilitate poaching and that fencing which disrupts the movement of large mammals, especially carnivores and elephants, can increase conflict with local people.

Harvey *et al.* (2005) assess the ecological roles of live fences as potential habitats, resources and landscape connectivity for wildlife. The researchers define live fences as those made by planting large cuttings, that easily produce roots and on which several strings of wire are attached with the aim of keeping livestock in or out. Live fences thus plays a role in wildlife conservation due to the fact that as farmers establish and manage live fences to facilitate farm and cattle management, they unconsciously increase the total tree cover within the farming landscape, creating alternative habitat, stopover points, and resources for wildlife. The researchers however conclude that the main intended function of a live fence is to demarcate farm boundaries and partition pastures, thereby restricting animal movement.

2.4 Fencing and property ownership

In a study among the Ilchamus tribe in Kenya, Little (1992) noted that fencing was also a way of staking a claim to exclusive ownership. He noted that those who fenced their land had double advantage in that they could use the communally owned pasture land during favourable times for grazing their animals but exclusively use their fenced ones in dry seasons. Others who have argued that fencing provides a step toward exclusive ownership are Anderson and Hill (1977).

Exclusive property ownership rights have also been regarded as one way of preventing environmental degradation and consequently promoting economic development as well as agricultural production (Demsetz, 1967; Hardin, 1968 and North and Thomas, 1973). Besides, other studies suggest that highly individualised rights to land are also important for long-term investments (Place and Otsuka, 2002; Place and Swallow, 2000; Gebremedhin and Swinton, 2003)

Twyman *et al.* (2001) have also pointed out that fence can be viewed as a symbol of community self-empowerment, and a catalyst for further community-initiated developments. He further noted that a fenced community may be seen to be securing exclusive access to resources and that fence construction may lead to a greater community control of natural resource management and hence a good rangeland management tool. Fence can hence be said to be a defensive and conservation tool as well.

Dahlman (1980) have highlighted the pros of private ownership as opposed to communal ownership. In particular, Hardin (1968) came up with what he called the “tragedy of the commons” that symbolizes the degradation of the environment. He explained that whenever many individuals use a scarce resource in common, exploitation and resource degradation become inevitable. This is because the rational individual would always have an incentive to extract an additional resource unit, as all the benefits would be theirs alone while the costs would be spread amongst all users. It is this behaviour that eventually results in the overexploitation of the resource and its degradation. Further, Olson (1965) and Hardin (1968) and Brown and Lee (2004) used a rational choice framework to put forward a similar view that the common use of resources, would always tend towards failure owing to the intrinsic conflict between individuals and common interests. Olson (1965) explained this in terms of the tendency for self-interested individuals to “free ride” on other group members, asserting that they will not act to achieve group interests without some kind of coercive device.

Therefore it is this tragedy of the commons that may give credence to the arguments of individual property ownership. Anderson and Hill (1977) maintained that as utility maximizing individuals make decisions, the costs and the benefits must be internalised if society is to obtain the optimal results. This is the opposite of those in communal arrangement who appear averse to cost yet want to get every benefit from the resource. Kumbhakar *et al.* (2000) also support the view that public production is naturally less efficient than private production for the reason that private owners are able to manage performance of their firms unlike public owners. On the other hand some researchers such as Gavian and Fafchamps (1996) advocate that no significant differences exist in farmer’s investment behaviour when land is owned individually and when the land is communally owned.

Others such as Brown and Lee (2004) assert that the problem of the commons was that of incomplete or non-existent property rights. They held the view that without well defined and exclusive property rights, the market would fail to work efficiently to bring about the harmonization of individuals and collective rationale. More specifically, the central power of their argument was that private property is the most suitable way to maximise efficiency in the use of resources, as it creates greater incentives for the internalisation of externalities and thus promotes economic growth (Demsetz, 1967). Other economists have also used the property rights paradigm based on neo-classical theory to argue that traditional African land-tenure systems induce inefficient allocation of resources because property rights are not clearly defined, costs and rewards are not internalised, and contracts are not legal or enforceable (Barrow *et al.*,1990).

These views for private property ownership appear to concur with the themes of the land reforms in Kenya today. The enforcement of property rights may be done by dividing land into separate parcels and assigning individual rights to hold and use the land. One way of doing it is by investing in fences as suggested by Field (1984; 1985). According to Kenya Economic Report (2009), lack of adequate property rights especially in the ASALs is a challenge in the management of land in Kenya besides land degradation such as soil erosion and political economy.

Some studies have also found a positive and significant relationship between investment in fencing and registration of land. For example, Roth, Cochrane and Kisamba-Mugerwa (1994) and Roth, Unruh and Barrows (1994) found that registration in Uganda was significantly and positively related to investment in fencing, use of manure and mulching, but appeared to have little effect on long-term investments. The issues of property rights and land privatisations are also recurring themes that have stimulus effect on the need for land fencing and productive use.

Ostrom (1990) also acknowledges that some benefits may exist in communal ownership of resources but can be limited. She argues that common resources may be subject to exploitation by multiple appropriators who have arrangements to contribute to maintaining the valuable resource and to exclude others from using the resource to prevent exploitation. Moreover, while Hardin (1968) recommended that the tragedy of the commons could be prevented by either more government regulation or privatizing the common property, Ostrom (1994) suggests that handing control of local areas to national and international regulators can create further problems and she recommended that community level institutions may manage resources well. This implies that resource users themselves can cooperate to conserve the resource in the name of mutual benefit and this is possible if people can get organized and use the resource in a renewable way over time (Ostrom, 2009). It therefore appears that it is hard to avoid property rights in trying to achieve a greater efficiency in the use of the resources

In Kenya for example, communities like the Pokot who own communal grazing lands have a sense of duty to protect such areas against the invasion of other tribes. Unfortunately such efforts have resulted into inter ethnic tensions and fighting which are counterproductive for production. Since customary land tenure can also be considered as a common pool resource, it has other disadvantages over private ownership of resources. Ostrom (1999) asserts that common pool resources are characterized by difficulty of exclusion and that they also generate finite quantities of resource units so that one person's use subtracts from the quantity of the resource available to others.

As noted by Kabubo-Mariara (2006), customary land tenure and land law in Kenya have been systematically misinterpreted by the judiciary and ignored by legislatures since pre independence. Such factors have hindered efficient and productive land usage where they are communally held. The envisaged land policy hopes to increase private ownership as opposed to communal systems so as to spur up productivity.

SECTION B

Literature on the production function and measures of efficiency will be discussed in sections 2.5 to 2.11.

2.5 Agricultural Household Model Theory

Agricultural household models provide a framework for analysing household behaviour in less-developed countries (LDCs) rural economies. The model assumes that consumption, production and leisure are linked because the deciding entity is both a producer and a consumer. This implies that as a producer, the household has to decide on the allocation of labour and other inputs to farm production. Moreover, the deciding entity is also a consumer for the reason that the household has to choose the allocation of income from farm profits and labour sales to the consumption of commodities and services (Taylor *et al*., 2003). Given this sequential decision making, the appropriate analytical framework is a model with profit and utility maximizing components. The households also have to take into account the fact that they are constrained by external environmental and socio-economic characteristics.

Therefore, for any production phase, the household is assumed to maximize a utility function:

$$U = U(C, HT, \wp) \tag{2.1}$$

Where U denotes utility, C is consumption goods, HT is leisure (home time) and $\wp$ is socio-economic and demographic characteristics. Utility is maximized subject to a cash income constraint:

$$P_m C_m = P_a(Q - C_a) - \left[P_1(L - F_l) + P_2 K + P_3 N\right] + E \tag{2.2}$$

where P_m and P_a are the prices of market and farm –gate commodity prices respectively, C_m and C_a are vectors of market purchased and household produced consumption commodities respectively. Q is the total household's production, P_1 is the market wage(Price of labour), L is total labour input, F_l is family labour input(so that $L - F_l$ is hired labour if positive and off-farm labour if negative), P_2 is price of capital, K is capital stock, P_3 is price of land, N is total land area and E is exogenous income. Exogenous income refers to any nonfarm income.

The model in Equation 2.2 further assumes that the household can obtain perfect substitutes for family labour in local labour markets and in return, it can sell its own labour at a given market wage. This permits the household to increase production while at the same time consuming more leisure, by hiring workers to fill the resulting excess demand for labour. Finally, the model assumes that the prices in the model are not affected by actions of the household. They are price takers.

The household also faces resource constraints that indicate that the household cannot allocate more resources to activities than is available in terms of total stock (TS): The households attempt to derive maximum benefit from the meagre resources they control.

$$L, K, N \leq TS \tag{2.3}$$

The household also faces a time constraint in that it cannot allocate more time to leisure, on-farm production, or off-farm employment than the total time, T available to the household:

$$HT + F_l = T \tag{2.4}$$

The household as well faces a production constraint reflected by a technology function that depicts the relationship between inputs (L, K, N) and farm output (Q) conditional on fencing F

$$Q = f(L, K, N, F) \tag{2.5}$$

The solution to agricultural household models yields a set of equations for outputs, input demands, consumption demands and either prices or marketed surplus. Alternatively, the three constraints on household behaviour may be combined into a single full income constraint by substituting the production constraint into the cash income constraint for Q, substituting the time constraint into the cash income constraint for F_l and finally substituting the resource constraint into the cash income for either L, K or N.

However, standard agricultural household theory assumes that in developing countries, consumption and production decisions are inseparable (Taylor *et al.*, 2002). This assumption implies that it may be complex to estimate production and consumption behaviour in rural households. This is because a farmer may for instance purchase a tractor to be used for production purposes such as ploughing and for consumption purposes such as family transport and firewood carrying (Ellis, 1988) .Nevertheless, Previous researchers, such as Delgado (1999) and Singh *et al*. (1986) used whole household models, in which both the consumption and production sides of the model were estimated.

It is also worth mentioning at this point that in an African context, extended family networks and payments in kind may be useful in the analysis of the Agricultural Household Utility theory. As already mentioned, rural farm households integrate production and consumption decisions and that the preferred analytical framework is a model with profit and utility maximising components. Extended family networks may have a positive effect on profit resulting from an increase in income. This assumption is supported by Binswanger *et al*. (1987) who asserts that a household can be both vertically and horizontally extended. A vertically extended household is made up of nuclear units of successive generations while a horizontally extended household is composed of nuclear units of siblings. Binswanger *et al*. (1987) further hypothesize that extended households provide insurance. This is because consumption out of a common store can insure household members against crop failures or from a loss of cultivation labour resulting from illness or accident. This thus enables the household head to provide extended family networks insurance in exchange for cheap labour or payment in kind that might enable the household to accumulate faster than it would otherwise. Moreover, older household members have exclusive claim over their accumulated assets and they may provide insurance to younger household members against risks such as crop failure. Furthermore, the older members of the society also sometimes promise to bequeath their wealth to the younger ones when they die. In addition, marriage networks may provide some form of marriage insurance. This is especially so in years of local crop failure when some or all family members move in with distant in-laws who provide them with consumption.

Other researchers such as Morduch (1995) have however elicited that households can cope with risks by smoothing income. This can be achieved for example by using more labour than would be called for on the grounds of profit maximisation .Also, it is important to time rainfall and it is sensible for households to postpone making investments until better information on expected weather conditions is known. In this way, households take steps to protect themselves from adverse income shocks before they occur. Binswanger *et al.* (1993) further argues that income smoothing can be done by diversifying plots. This is a common means of reducing the impact of weather shocks that vary with location. Rosenzweig *et al*. (1989) on the other hand assert that income smoothing can be achieved by engaging in off-farm activity. For example, having a household member employed in steady wage employment and as Morduch (1995) argues, migrants remitting income back to family members in their home province.

Therefore, in an LDC context, the assumption that household production and consumption decisions should be joint is supported by the insurance argument that output that is intended for consumption should be produced jointly.

Nonetheless, inspired partly by Lopez (1986), exploitation of the potential separability of agricultural household production from consumption decisions, a new generation of empirical rural economic research has emerged. It is grounded on household farm theory but involves estimation of partial agricultural household models. This research will adopt the approach of separability due to data limitations and in order to strongly investigate the impact of fencing (F) on agricultural productivity, F will be treated as a productive input in the production process. Total households production, output (Q) will be a proxy for production

2.6 The neoclassical theory of farm production

Ellis (1988) states that the neoclassical economic theory assumes that the farmer is an individual decision maker concerned with questions such as how much input to allocate to the farming of crops and whether or not to use procured inputs amongst other choices the farmer has to make. The farmer can generally vary the level and kind of farm inputs and outputs. In addition, he distinguishes between 3 types of relationship among farm inputs and outputs that are normally known as encompassing the economic decision making ability of the farmer. These 3 relationships also tally with the 3 key steps in the construction of the theory of the farm firm and they are firstly, the factor-product or input-output relationship also known as the production function, secondly, the factor-

factor relationship also sometimes referred to as the method or technique of production and thirdly, the product-product relationship also termed as the enterprise choice. This research however places emphasize in the production function subsequently discussed in sub section 2.6.1

2.6.1 Production function

The concept of a production function refers to the relationship between the output of a good and the input factors of production required to make that good. At the micro –level it is of interest because of its usefulness in the analysis of such problems as the degree to which substitution between the various factors of production is possible and the extent firms experience decreasing or increasing returns to scale as output expands.

In terms of formal notation a simple production function has the following general form:

$$Q = f(L, K,) \qquad (2.6)$$

Where Q is output, L is labour, K is capital. This production function is typically used in the context theory of the firm. Output (Q) can also be referred to as the total physical product (TPP). This production relationship can be presented in several forms such as: linear functional forms, polynomial functional forms and Cobb-Douglas functional form. The latter can further be modified into the transcendental and translog functional forms. The marginal physical product (MPP) of an input is the additional output that can be produced by employing one more unit of that input while holding all other inputs constant. Mathematically, the MPP is the slope of the total product curve at any particular point. For example; The MPP of labour is given as;

$$\mathrm{MP_L} = \frac{\partial Q}{\partial L} = f_l \qquad (2.7)$$

This is derived from the first derivative of the production function. However, if labour is considered as the only input while all the other inputs of production are held constant;

this results in diminishing marginal productivity where an increase in use of additional input results in lower production. Therefore the second derivative is less than zero:

$$\frac{\partial MP_L}{\partial L} = \frac{\partial^2 Q}{\partial L^2} = f_{ll} < 0 \tag{2.8}$$

The average physical product (APP) is a measure of labour efficiency. The APP can also be said to be a productivity measure given by the APP of the input. It also depends on the level of other inputs employed and it is defined as the total physical product divided by the total amount of the input used in production.

$$AP_l = \frac{Output}{Labour} = \frac{Q}{L} = \frac{f(L,K)}{L} \tag{2.9}$$

Another measure of the physical relationship between output and a single variable input such as labour is the input elasticity. It is also known as the partial elasticity of production. This is defined as the percentage change of output resulting from a given percentage change in the variable input.

$$E = \frac{\%\, changeinou \quad tput}{\%\, changeinin \quad put} = \frac{\delta Q \big/ Q}{\delta L \big/ L} = \frac{\delta Q}{\delta L} . \frac{L}{Q} \tag{2.10}$$

$$E = MPP\ . \frac{1}{APP} = \frac{MPP}{APP} \tag{2.11}$$

What elasticity (E) does is that the ratio of two proportional changes obtains a measure of the effect of one variable on another which is autonomous of the physical units in which the variables are expressed. Also, in looking at the relationship between the input elasticity, APP and MPP, it is important to note that the area of diminishing marginal returns on the production function occurs when, $MPP < APP$ but is not negative, i.e. when E is between 1 and zero expressed as $0 < E < 1$ Similarly, $E > 1$ and $E < 0$

describe parts of the production function in which it would not be economically rational for the farmer to function (Ellis, 1988).The concept of returns to scale on the other hand shows how output responds to increase in all inputs together. Returns to scale can either be constant, decreasing or increasing.

Production functions may take many algebraic forms e.g. Economists usually work with homogenous production functions. A production function is homogenous of degree n when inputs are multiplied by some constant, say k**,** and the output that results is a multiple of k^n times that original output. It is however important to note that all production functions must satisfy two conditions to make economic sense. The conditions are that the marginal physical product should be positive and it should be declining. What this implies is that the equations should have positive first derivatives (Equation 2.7) and a negative second derivative (Equation 2.8)

2.7 Inputs in production

Labour, capital, land, land quality and fence are considered as inputs in this study. Therefore, in the next sub-section 2.7.1 to 2.7.4, a brief discussion on the relationship between the inputs used in the analysis of this research and productivity is undertaken.

2.7.1 Labour and capital in agriculture

Many writers attest to the fact that the way labour markets work is the critical feature of the farm size question (Ellis, 1998).Studies that capture labour and capital in Kenya include those of Ekborm (1998) and it uses survey data collected over a period of three years in the Kenya highlands in 252 households. For each farm, agricultural productivity is the crop yield weighted by farm area and crop price. This is hypothesized to be a function of labour inputs, materials, physical capital investment, human capital and physical resource endowments. A CD production function is estimated using a linear estimation technique, the ordinary least squares method (OLS). Ekborm (1998) finds a positive and significant correlation between labour input per farm and production. The study also finds that household capital, proxied by the value of domestic animals, capital availability, and non-agricultural farm incomes are positively related to agricultural productivity.

2.7.2 Farm size and productivity

Evidence suggests that there is an inverse relationship (IR) between farm size and productivity in Agriculture. In this research, area size of farms will be used to refer to farm size for reasons of simplicity and straightforwardness. Using the area of farm size will be useful in distinguishing the farm as an enterprise usually measured by joint volume of resources used in production, gross output or farm capital (Assuncao *et al.*, 2003, Heltberg, 1998, Barrett, 1996, Ellis, 1988).

The researchers argue that the inverse relationship is based on diminishing returns, with respect to land and other inputs besides other reasons such as heterogeneity in farmer skills even if there are no diminishing returns with respect to any input. Heterogeneity in farmer skills is based on the fact that, at a given level of wealth, skilled peasants are more likely to become farmers than unskilled peasants. Other researchers such as Eswaran and Kotwal (1986) and Feder (1984) explain the inverse relationship by looking at economies in which labour is subject to supervision problems and land provides better access to credit. They illustrate that as a result of increasing marginal cost of supervision, the land to labour ratio is higher for richer farmers, which leads to decreasing output per hectare with respect to farm size. Besides, small farmers have advantages in labour supervision because they rely mostly on family labour. This argument appears to concur with developing countries agriculture like Kenya where most peasant farmers own an average of five acres of land.

To further support the inverse relationship, Ellis (1988) argue that the reason of the IR is the way rural labour markets work and some of the reasons highlighted are land use and labour intensity. This implies that diminishing land productivity as farm size increases results from under-utilisation of the total land area on hand and that smaller farms use more labour per unit area than huge farms. Sometimes as far as land utilisation is concerned, larger farmers hold land as a portfolio investment, for social prestige and political influence rather than as a productive resource. Additionally, larger farms may be inclined more towards land extensive enterprises like livestock pasturing than smaller farms. Smaller farms have also been found to do more double cropping than larger farms and the aim is to raise the total output value for a given area of land. It is also argued that large farms may have on average less fertile soils than smaller farms for the reason that high population density and fragmentation of holdings occur in areas of fertile soil and that large farms only improve the best land within their total farm area and ignore the productive potential of less favourable land.

Barrett (1996) on the other hand assert that a non-degenerate land distribution and price risk can produce an inverse relationship in that when land or credit market failures constrain small farmers' capacity to outbid larger farmers for land, food price risk create food security stress hence inducing small farms to utilize extraordinary amounts of labour.

Ekborm (1998) in his study of the Kenyan highlands also finds a negative but statistically significant relationship between farm size and agricultural productivity. This implies that smaller farms are more productive than larger farms.

2.7.3 Land quality and productivity

Land quality is also one of the factors considered in this study as affecting agricultural production and it is proxied by the price of land .Theory suggests that land as a factor of production may appear cheap to the large landowner and expensive to those who own small pieces of land. One reason for this is that large landowners inherit their land from their forefathers and they may in fact undervalue its advantage as a productive resource. A further reason is that they can afford to finance purchase of huge pieces of land in that they usually get them at fairly low interest rates (Ellis, 1988). Therefore, small farmers may value their land more because in most instances, even if they acquire land by inheritance, it is usually in inadequate amounts and they also have no capacity to finance purchase of land in that the interest is usually high from the credit institutions.

Theoretically also, high quality land is expected to raise the production of crops and the converse is true. Other economists have however suggested that differences in land quality are what cause the inverse relationship between size of land and productivity.

The argument is that if high quality land is subdivided more often than low quality land resulting in smaller plots of higher quality, yields per acre will be greater for smaller farmers (Lamb, 2002, Benjamin, 1995) .Benjamin (1995) further showed three ways in which land quality may affect production. Firstly, the neutral quality effect assuming constant returns to scale. The case predicts that the elasticity of labour and profits with respect to land quality measure will be equal. Secondly, land augmenting quality effect. In this case, output depends on effective land quality. Thirdly, labour augmenting land quality effect. In this case, the marginal product of labour is relatively more enhanced by land quality.

2.7.4 Fencing and productivity

It is argued that individualised tenure which could come about as a result of fencing land, typically defined as demarcation and registration of freehold title is viewed as superior to communal land tenure when land has scarcity value. This is because owners of the land are given incentives to use land most efficiently and thereby maximise agriculture's contribution to social well-being (Barrows *et al.*, 1990). It can thus be hypothesized that individualising land tenure increases security and agricultural investment and this can be resolved empirically instead of just theory. It is worth noting that neo-classical theory has been used to analyse the evolution of African land-tenure systems. Under conditions of very low population density the supply of land exceeds the demand even at zero price and so individual rights to property are exercised (Ault and Rutman, 1979). The neo-classical model can thus be said to generate hypotheses about economic behaviour such as individualisation of land tenure increases tenure security of the landholder, thereby reducing economic costs of legal action over land disputes .This hypothesis may also imply that fencing reduces disputes in that as a result of individualisation, disputes in form of communal land ownership reduce. Evidence from Kenya show that land-holders in East Kadianga sub-location in Nyanza province witnessed a higher incidence of land disputes and enclosures and it became common to fence holdings to protect crops from straying livestock. It is also documented that the shift from clan to individual rights over land started among the Luo long before World War II (Barrows *et al.*, 1990). Another hypothesis generated by the neoclassical model is individualisation increases investment by improving tenure security and reducing transaction costs. Higher tenure security implies that expected investment returns will increase thus leading to an increase in the demand for capital for investment and evidence from Kenya supports this hypothesis. This hypothesis again may imply that fencing increases investment (Barrows *et al.*, 1990). People however tend to fence their land when they know it rightfully belongs to them (Pule *et al.*, 2004).

Besides, from the earlier discussion that fencing provides exclusive property ownership (Demsetz, 1967), fencing can serve as a public good but to a varying degree. This is for the reason that a neighbour may not be excluded from enjoying the part of fence constructed between the two properties. However, both owners are responsible for keeping the fence in good repair in case of wear and tear. Thus, it can be claimed that fencing has got a strong positive externality because of the positive spill over effect on the neighbour’s homestead. However as noted by Barrows *et al.* (1990), there is little evidence to support the hypothesis that registration, through increased tenure security, has increased investment in agriculture. This study has attempted to fill the gap by looking at it in terms of fencing.

2.8 Empirical literature on stochastic frontier and data envelopment analysis.

Stochastic frontier approach has been used at length within the agricultural economics literature mainly because of its consistency with theory. The measurement of efficiency has remained an area of important research both in the developing and developed countries. This is especially important in developing countries like Kenya where resources are scarce and opportunities for developing and adopting better technologies are diminishing due to slow economic growth. Efficiency studies are important in that they benefit developing economies by determining the extent to which it is possible to raise productivity by improving efficiency, with the existing resource base and available technology hence reason why this study seeks to find if fence can improve efficiency in semi-arid areas.

Bedassa and Krishnamoorthy (1997) examined the level of technical efficiency across ecological zones and farm size groups in rice farms of Tamil Nadu in India. They found that the mean technical efficiency was 83 percent, showing potential for increasing rice production by 17 percent using present technology. They used ANOVA to show that the level of technical efficiency among paddy farms differed significantly among different ecological zones. In addition, they concluded that small and medium-scale-farmers were more efficient than the large-scale farms and that the rice farmers could still benefit by increasing the fertilizer use and expansion of land.

Other studies that applied stochastic frontier analysis (SFA) to explain technical efficiency are those by Wilson, *et al*. (1998) who analysed UK potato production. They explained technical efficiency through managerial and farm characteristics and they concluded that mean technical efficiency across regions ranged from 33 to 97 percent. On the other hand, Liu, *et al*. (2000) in a study on technical efficiency in post-collective Chinese agriculture concluded that 76 and 48 percent of technical inefficiency in Sichuan and Jiangsu, respectively, could be explained by inefficiency variables. Ajibefun *et al.* (1999) on the other hand modelled the technical effects of individual farmers for cross sectional data in Nigeria using the FRONTIER PROGRAM version 4.1. They concluded that technical efficiencies vary widely across farms.

Other studies have applied both a non-parametric and a parametric approach to a frontier production function. Belen, *et al*. (2003) for example made an assessment of technical efficiency of horticultural production in Navarra, Spain. They analysed tomato and asparagus production separately. They found out that the results hold regardless of whether the frontier was parametric or non-parametric. They concluded that tomato producing farms were 80 percent efficient while those that raised asparagus were 90 percent efficient. Therefore, they concluded that there exists a potential for improving farm incomes by improving efficiency. Others such as Theodoridis *et al.* (2008) and Sharma *et al.*(1997) in their study on efficiency measurement compared the CD SFA and the constant returns to scale (CRS) and variable returns to scale (VRS) output-oriented DEA models on a sample of 165 dairy farms in Greece and 60 Swine farms in Hawaii respectively. They found out that there is a potential for increasing production in the farms through improved efficiency. Wadud *et al.* (2000) compared estimates of technical efficiency obtained from the SFA and DEA approach using farm-level survey data for rice farmers in Bangladesh to assess if there were any significant differences in the estimates of efficiency. Both approaches nevertheless gave similar results.

Some researchers such as Monchuk *et al.* (2010) took a slightly different approach to explain production efficiency. Their approach involved a two-stage procedure that combines non-parametric and parametric techniques. First, DEA was used to estimate output oriented measures of technical efficiency and secondly, a truncated regression model with inference based on a semi-parametric bootstrap routine was used. Other researchers such as Reig-Martinez *et al.* (2004) used a simple DEA output-oriented mathematical optimising problem to analyse farming systems in Spain.

Serrao (2003) on the other hand used a translog SFA and DEA to examine the sources of agricultural productivity growth over time and of productivity differences among countries and regions in the European Union. He found that the mean technical efficiency obtained by DEA is higher than that obtained by SFA. In addition, Nkamleu, 2004 used DEA to examine the economic performance of a large number of African countries Kenya being among the countries studied. They showed that institutional factors as well as agro-ecological factors are important determinants of agricultural productivity growth.

2.9 Conclusion

This chapter broadly discusses the benefits of fencing land besides the theoretical aspects of productivity and efficiency. Some benefits of fence from literature are that fence controls access both by humans or animals, it protects gardens, it helps in landscaping, and it protects native vegetation, the wildlife dependent on it and the benefits it offers to a property. It also provides shade and shelter for livestock, it prevents soil erosion and it is also a basic tool in the effective management of property. Others have also argued that fencing may be seen as a way of preventing environmental degradation and at the same time enhancing private ownership of land. In addition, they are a source of products such as live stakes for new fences, timber, firewood and fruits. Fencing also fulfils service functions within the farms such as the provision of shade and wind protection. They further argue that shade is important for cattle in that it reduces heat stress particularly in the dry season resulting in higher weight gain, milk production and reproductive rates. Additionally, this chapter has also looked at the relationship between the inputs land, land quality, labour, capital and fence. Thus, the main conclusion drawn from this chapter is that fence is an important investment if the benefit it offers is taken into consideration. It is also worth noting that as far as many studies on efficiency have been done and researchers have tried to come up with ways of improving efficiency, none has actually tried to measure how fencing land may improve efficiency.

CHAPTER 3
METHODOLOGY

3.1 Preamble

This chapter provides details of how data was collected, treated and analysed (Section A). Also presented are all the parametric (econometric) and non-parametric (linear programming) models used to estimate the impact of fence on agricultural output (Section B).Specifically, the study adopted the method proposed by Battese (1996) of estimating Cobb-Douglas production functions when some explanatory variables have zero values. In addition, stochastic frontier analysis (SFA) and data envelopment analysis (DEA) models are also derived in that they are used in measuring the technical efficiency of all the farms.

SECTION A

In this section**,** sampling procedure, stages at which data was collected and the interview process is discussed.

3.2 Sampling.

Data used in this study represent cross-sectional primary data gathered directly from 251 households between the months of May to August inclusive 2010.Random selection was ensured[4] with the aim of making sure that every household sampled had an equal chance of being selected. To the best of the researcher's knowledge, data on fencing is not available in Kenya. To this effect, the initial methodological approach was to collect primary data and employ it according to research objectives and hence for this purpose, a detailed questionnaire (Appendix 1) was used to collect the required information. The questionnaire was designed to collect information regarding economic and demographic characteristics of sampled households, total output, and the factors of production (capital, labour and land) as well as information on land rights among other variables of interest from both fenced and unfenced farms.

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[4] The interviews were conducted by the researcher and so reduced the chance of interview bias.

Regional sampling and analysis is carried out separately owing to the economic, social and cultural differences of the areas to be studied before aggregation. As mentioned in the introductory chapter of this thesis, Kenya as a country is administratively divided into 8 provinces. Each of these provinces is mostly made up of people with diverse traditional and cultural practices. It is further subdivided into 47 districts, now called counties as from August 2010, when Kenya changed its constitution. Out of the 47 districts, 13 are classified as being arid or semi-arid. It is therefore important to note that it would not be practical to survey the entire population of 13 semi-arid districts owing to restrictions of time, money and access. In this note, it is assumed that sampling saves on time and money. For security reasons as well, sampling helps in identifying areas that are easily accessible and secure. The main data is thus made up of five data sets spread wide apart to give a representation of the country's situation on collation. Data from the chosen districts was collected in stages.

The first stage in the sampling procedure involved identifying and selecting study districts, based on differences in traditional and cultural practices. Five districts of a total of 13 semi-arid districts were selected. The second stage involved selecting administrative divisions, locations and sub-locations within each of the five districts, based on agro-ecological diversity. The third stage involved selection of sample points (clusters), which was based on the total number of villages within a sub-location. One advantage however of using cluster sampling is that there are savings in travel costs and time as well (Kombo *et al.*, 2006). The fourth stage involved selecting the desired number of households from each cluster (village) after a simple household listing. In the final stage, the household head or a person with information about the farming activities was interviewed along with other individual members where necessary in each selected household.

Households were selected randomly. Some had fenced their farm and some had not. Information was however collected from those without fence as well in order to serve as control for differences in production. In addition, a total of approximately 7 sub-locations in the chosen division were randomly selected for the administration of the questionnaire. At least 7 households in each selected enumeration area were randomly selected, after a simple household listing.

A spreadsheet software (EXCEL) and statistical software GRETL, FRONTIER 4.1C, General Algebraic Modelling System (GAMS) displayed in appendix 6 and 7 and non-parametric software PIMXDEA is used in analysing the data. This is carried out on the basis of the appropriate production model framework.

3.2.1 Sample size

One of the major determinants of sample size is the level of precision required. The level of precision refers to how much sampling error is acceptable when an estimate is used to represent a population parameter (Saunders *et al.*, 2003). A statistical technique for determining sample size can be derived from the concept of confidence interval, which, like sample size, depends on the maximum error acceptable for a given sampling situation at a specific level of confidence. A confidence interval for the unknown population mean, μ is given by Equation;

$$\mu = \bar{x} \pm z \frac{s}{\sqrt{n}} \tag{3.1}$$

where:

$\bar{x}$ is the sample mean

s is the sample standard deviation

n is the sample size

z is the confidence factor (1.64 for 90%; 1.96 for 95%; 2.58 for 99%)

The method assumes that the sample standard deviation (s) is known. In practice, s is unknown. The common practice is to find its estimate from previous surveys that have studied similar characteristics in similar populations. The method outlined above can only therefore be used if there are similar studies in which estimates of population variability are available or a pilot survey is undertaken.

3.2.2 Training assistants and pilot enquiry

Despite the fact that the researcher herself undertook a number of interviews, there was need to hire two enumerators to help in conducting the interview due to time constraints. University students from the selected region with previous experience in fieldwork were used. Two days training was conducted and the main purpose was to discuss the questionnaires, give instructions and to clarify the purpose of the survey. Among the instructions was to make sure that each interviewer began by assuring the representatives from the households that no information would be passed to the government or the tax office and that confidentiality would be kept up to the latter.

A pilot survey was undertaken and the main purpose was to choose questions that have analytical value. The pilot test moreover enabled the researcher to obtain some assessment of the questions validity and the likely reliability of the data that was to be collected. In addition, the pilot test helped in refining the questionnaire to avoid the problem of respondents not being able to answer questions and to also make sure that there would be no problem in recording the data. It was also useful in that it helped in preparing a time schedule for the respondents. Preliminary analysis using the pilot test data from 30 households was undertaken and this was to ensure that the data collected would enable analytical questions to be answered.

3.2.3 Interviewing

The process of interviewing was preceded by a short meeting with the respondent. The objective of the meeting was to explain the purpose of the research and to avoid misunderstanding or misinterpretation of the survey. The implications of incorrect answers in view of the survey’s educational value for all those who want to help households were also explained.

Data published by the Government printer, Central Bureau of Statistics (CBS) and the Ministry of Agriculture have been used mainly in the background chapters.

SECTION B

This section will discuss the parametric and non-parametric approaches used in later analysis to estimate the contribution of fence to agricultural production.

3.3 Measuring productivity

In many economics studies dealing with issues of growth and productivity, the most commonly used theoretical model is the production function. This is because it incorporates capital and labour as the factor inputs which are usually considered the major resources in the production process. However, to complete the production function, defined as a function that represents the maximum output that can be produced using a given amount of input, capital and labour can be supplemented with "other" inputs such as land, materials, management and energy just to mention a few (Mefford,1986). The list of "other" factors in agricultural production may not be exhaustive. Fencing is one such input that may have not been fully studied. Battese *et al.* (1977) however included the cost of fencing land in the estimation of a production frontier for sheep production in the pastoral zone of Eastern Australia. For that matter, this research will consider fencing as a productive input in the production function as well as in the non-parametric approach, DEA.

3.3.1 Theoretical models

The parametric and non-parametric approach is used in this study. The parametric approach is composed of the Cobb-Douglas production stochastic models and the non-parametric approach is composed of the Data Envelopment Analysis (DEA). In addition, the parametric and non-parametric models can be deterministic or non-deterministic. A deterministic model is one in which every set of variable is uniquely determined by parameters in the model and it assumes that any deviation from the frontier function is due to inefficiency. They are very sensitive to outliers and they are not able to separate statistical noise from inefficiency. DEA can be said to be deterministic in that it attributes all the deviations from the frontier to inefficiencies (Theodoridis *et al.*, 2008). Conversely, the stochastic approach allows for statistical noise and it is mostly concerned with the estimation of frontiers which envelop data (Thiam *et al.*, 2001; Kumbhakar *et al.*, 2000; Demeke, 1989). The next sub-section shall thus derive the model to be estimated starting with the Cobb-Douglas production function.

3.3.1.1 Cobb-Douglas production function

A Cobb-Douglas production function is used to estimate quantitatively the effect of F upon the amount of Q and the model may be written as:

$$Q = \alpha_0 K^{\alpha_1} L^{\alpha_2} N^{\alpha_3} LQ^{\alpha_4} F^{\alpha_5} \qquad (3.2)$$

$$0<\alpha_1< 1, 0<\alpha_2<1, 0<\alpha_3<1, 0<\alpha_4<1, 0<\alpha_5<1$$

Where: $Q =$ Value of output, K = Value of capital, L= Total work hours, N= Land area, LQ=Land quality, F=Area of fence.

In addition, because Equation 3.2 is deterministic, an error term, ε, to account for random or unexplained variations in output will be introduced. It is also assumed that the error term, ε, has expectation zero and the other inputs K, L, N, LQ and F are taken as given. Hence for the *i*th firm, we have

$$Q = \alpha_0 K^{\alpha_1} L^{\alpha_2} N^{\alpha_3} LQ^{\alpha_4} F^{\alpha_5} \varepsilon \tag{3.3}$$

$\alpha_{0,} \alpha_{1,} \alpha_{2,} \alpha_{3,} \alpha_4, \alpha_5$ are unknown parameters to be estimated. The parameter in equation 3.3 $\alpha_{0,}$ may be regarded as an efficiency parameter since for fixed inputs; the larger is $\alpha_{0,}$ the greater is the maximum output Q obtainable from such inputs. Hence, it can therefore be hypothesized that the larger the fenced area, the larger the output obtained from the farm. The coefficient on F in Equation 3.3 will thus measure the effect of fencing on the expected output if all the other variables are kept constant. Besides, in this research, fence is the variable of interest but the difference in K, L, N, LQ is controlled.

$\alpha_0 + \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 = 1$ depicts constant returns to scale and decreasing (increasing) returns to scale as $\alpha_0 + \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 < (>) 1$

Equation 3.3 is convenient since it is linear in the logarithms and it facilitates estimation if fence is treated as a productive input. It is worth noting also that the logarithms of the coefficients will measure elasticities rather than the marginal effects. Hence, Logarithm of Equation 3.3 is

$$\begin{aligned} \ln Q &= \ln a_0 + \alpha_1 \ln K + \alpha_2 \ln L + \alpha_3 \ln N + \alpha_4 \ln LQ + \alpha_5 \ln F + \ln \varepsilon_i \\ \ln Q &= \ln a_0 + \alpha_1 k + \alpha_2 l + \alpha_3 n + \alpha_4 lq + \alpha_5 f + \ln \varepsilon_i \end{aligned} \tag{3.4}$$

The observations on ε are independently and identically distributed (iid) and that the other inputs *K, L, N, LQ* and *F* are exogenous. Other assumptions are mean zero errors, constant variance errors (homoscedasticity) and that ε is normally distributed.

An advantage of the Cobb Douglas functional form is that it is convenient and it can work well with relatively small data samples. However, it may be too restrictive in that it assumes that all firms have the same production elasticities, the same scale elasticities, and unitary elasticities of substitution and model error is likely (Coelli *et al.*, 2003). A more flexible functional form such as the translog model may perhaps have been used in this study, but the number of parameters involved could have been considerably greater and the nature of our data could not allow the use of the translog. The CD production function is therefore used and it was also considered in that it will help in comparing the results with findings of other similar studies. The Cobb-Douglas functional form also meets the requirement of being self-dual, allowing an examination of economic efficiency (Xu *et al.*, 1995)

Equation 3.4 may be extended to allow dummy variables to enter it. As discussed earlier, fence will be measured in two ways; as a variable which measures area and as a binary dummy variable. Measuring fence as a binary dummy variable will capture the changes in the regression intercept and in slopes of associated variables. The changes in slopes will be estimated by multiplying the fence dummy by the natural log of all inputs. The natural log of the inputs can be referred to as the multiplicative terms as shown in Equation 3.6a to 3.6d. Moreover, the derivative of the dummy variable F will measure the marginal effect of changing F. Introducing a multiplicative effect in Equation 3.4 will thus give

$$q = a_0 + \alpha_1 k + \alpha_2 l + \alpha_3 n + \alpha_4 lq + \alpha_5 F + \alpha_6 F_k + \alpha_7 F_l + \alpha_8 F_n + \alpha_9 F_{lq} + \ln \varepsilon_i \tag{3.5}$$

Where:

$$F_k = F(\ln K) \tag{3.6a}$$

$$F_l = F(\ln F) \tag{3.6b}$$

$$F_n = F(\ln N) \tag{3.6c}$$

$$F_{lq} = F(\ln LQ) \tag{3.6d}$$

Impact of fencing on the marginal productivity of capital, labour, land quality and land will also be estimated. A marginal product shows how much more gross output (or value) a producer is likely to get by increasing a particular input by a unit. Marginal productivity hence refers to a change in output (Q) that results from a change in a given input (K) when the levels of all other inputs are held constant. When the logged form of the production function is used, marginal productivity can be expressed as:

$$\frac{\delta Q}{\delta K_i} = \beta_i \frac{Q}{K_i} \tag{3.7}$$

and the parameter β_i will be a measure of marginal productivity .It is also possible with marginal values to predict how farmers are likely to respond to various policies. In terms of relevance to policy making, approaches that generate marginal productivity indicators are however preferable.

3.3.1.2 Specification of output and input variables

Output (Q) is measured by the product of price and quantity of total yields, typically shown as:

$$Q = \sum_{i=1}^{n} py \tag{3.8}$$

Most studies have measured output by the product of price and quantity of total yields. For instance, Rick *et al.* (2007), Carter *et al.* (1999) and Shenggen (1997) calculated the output values by first multiplying the output quantity of each product by its price. Coelli *et al.* (2005) also use aggregates to measure output. Since in this study aggregates are formed across products that exhibit similar movements in relative prices or quantities, Coelli's approach then appears reasonable to use. Current prices are used in calculating values from the fact that it is a cross sectional study. Aggregate production can be defined as the amount of output that can be obtained from given levels of input in a sector or an economy. Therefore increases in production occur when output from a given level of inputs increases (Belloumi *et al.*, 2009).

Capital (K) in this study is defined as all the equipment available for use in farming activity. It is thus measured as the value of total equipment available for use directly in farming activity on repeated occasions. This for example includes agricultural machinery such as tractors, threshers, ploughs, sprayers among others. The researcher therefore calculates the value of (K) as the product of the total number of equipment by the current price of each unit of equipment (Coelli, 2003).

Different researchers have measured labour input (L) in various ways. For instance, Coelli *et al.* (2003;2005), Diewert (2008), Mefford (1986) and Carter *et al.* (1999) used a single aggregate variable of aggregate hours worked because of degrees of freedom limitations and the inconsistency of labour categorisation across different firms. They measured labour by considering the number of persons employed, number of hours of all people engaged in production and the number of days worked. This amounted to the aggregate hours and therefore in this study, labour is defined and measured by taking the total work hours

Land input (N) is defined as the total farm area (acres) in which there is a farming activity carried out. Land input (N) is thus measured by total farm area. It is assumed that the households practise some farming and that they have right to use the resource of land as the basis of their livelihood (Ellis, 1988). The estimation of (N) in this way is both practical and consistent with the works of other researchers such as Cornia (1985) and Shenggen (1997).

Land price per acre is used as a proxy for land quality *(LQ).* The assumption made here is that the higher the value of land, the more productive land may tend to be.

Having discussed the inputs of L, K, N, LQ , fence (F) will be the next "other" input in the production function to be considered. In this study, a fence is defined as a barrier that has coverage of at least 75 percent and a height of between 1 to 2 meters. This description is consistent with the casual observation of the researcher in the study area. In measuring fence, only the area of the fenced homestead in square meters is considered and not the total fenced land. This is because in most cases in the ASALs of Kenya, it is the homestead that is fenced in order to keep out wild animals from livestock at night. Since fence has got zero observations from the fact that the data includes information from homesteads that are not fenced, a dummy variable is used in solving the zero problem .The dummy variable F will be equal to one if the homestead is not fenced and zero if otherwise. Also, in this study, a model that allows for changes in the slope is estimated. In this case, the dummy variable F will be equal to one if the homestead is fenced and zero if otherwise.

3.3.1.3 Functional form of the model to be estimated

The OLS regression that explains the impact of fencing on output for a sample of 249 observations and the corresponding instrumental variable (IV) regression are estimated. The estimating Equation is 3.3 but since one of the explanatory variables, fence, has zero values, the study will adopt the method proposed by Battese (1996a) of estimating CD production functions when some explanatory variables have zero values. The zero values come about due to the fact that data on fence is made up of households with and without fence. Those without fence take a value of zero. And because households without fence form a significant proportion of the total number of sample observations, it is important to find a way of solving the zero problems as suggested by Battese *et al.* (1996a). Analysing only those farmers who have fence may not be the appropriate method of estimation because the data on households without fence may be useful in the estimation of parameters which are common to all farmers. Ahmad *et al.* (2002) and Battese *et al.* (1996b) used the same approach.

Battese *et al.* (1996a) thus proposed the use of dummy variable that is associated with the incidence of the zero observations such that efficient estimators are obtained using the full data set but no bias is introduced.

To use this method, we extend Equation 3.3 by introducing a dummy. Thus, the production relationships, involving one output and five inputs are defined by;

$$\ln Q = \alpha_0 + \alpha_1 \ln K_i + \alpha_2 \ln L_i + \alpha_3 \ln N_i + \alpha_4 \ln LQ_i + \alpha_5 \ln F_i + \ln \varepsilon_i, i = 1,2,..., n_I \tag{3.9}$$

$$= \beta_0 + \alpha_1 \ln K_i + \alpha_2 \ln L_i + \alpha_3 \ln N_i + \alpha_4 \ln LQ_i + \ln \varepsilon_i, i = n_i + 1,..., n_I + n_2 = n \tag{3.10}$$

where

n_1 is the number of observations for which F>0

n_2 is the number of observations for which F=0

ε is the uncorrelated error term and

$\beta_0, \alpha_0, \alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ are unknown parameters to be estimated

This model specifies that the relationship between the output and the inputs is such that the output elasticity with respect to all inputs is the same value for the observations involving positive and zero values of fence. It is also specified that the constant parameters, β_0 and α_0 are not necessarily the same, but the variances of the errors are the same.

Given that the production system is defined by Equations (3.9) and (3.10), the parameters are estimated by pooling the data, as specified in the following model:

$$\ln Q = \alpha_0 + (\beta_0 - \alpha_0)D_i + \alpha_1 \ln K_i + \alpha_2 \ln L_i + \alpha_3 \ln N_i + \alpha_4 \ln LQ_i + \alpha_5 \ln F_i + \ln \varepsilon_i, i = 1,2,..., n \tag{3.11}$$

where D=1 if F=0 and D=0 if F>0

ln	denotes the natural logarithm
Q	represents the value of output (in Kshs)
K	represents the value of physical capital available for use in farming activity in Kshs
L	represents total work hours by family members and hired labourers in crop and livestock farming
N	represents the total amount of land on which farming is carried out (in acres)
LQ	represents land quality proxied by price of land

F represents the area of fenced homestead in square meters.

The parameters of the production function as shown in Equations 3.9 and 3.10 are estimated by using ordinary least squares regression of the model specified by Equation 3.11. In addition, a test of the hypothesis that the intercepts are equal is obtained by a t-test on the coefficient of the dummy variable, D.

Equation 3.11 allows for a change in the intercept of the equation. A model that also allows for a change in the slope can be estimated by multiplying the dummy by the natural log of all inputs. Thus;

$$\begin{aligned} ln\,Q &= \alpha_0 + \alpha_1 ln\,K_i + \alpha_2 ln\,L_i + \alpha_3 ln\,N_i + \alpha_4 ln\,LQ_i + \alpha_5 ln\,F_i + \alpha_6 D_i ln\,K_i + \alpha_7 D_i ln\,L_i \\ &+ \alpha_8 D_i ln\,N_i + \alpha_9 D_i ln\,LQ_i + \alpha_{10} D_i ln\,F_i + ln\,\varepsilon_i \end{aligned} \tag{3.12}$$

3.4 Instrumental variables method

Instrumental Variable (IV) technique is also used in this study. This is for the reason that there is a possibility that one or more explanatory variables might be correlated with the regression error (ε).However, if none of the explanatory variables is correlated with the error, then under the classical assumptions, OLS is the best linear unbiased estimator (BLUE) and hence is more efficient than IV and there would be no need to use an IV estimator. The standard text book agreement is that an explanatory variable must not be correlated with ε and hence various tests will be undertaken to find out if any of the explanatory variable is correlated with the error (Koop, 2008; Stock & Watson, 2007).

To further support the intuition that an explanatory variable must not be correlated with ε , an example is assumed that if X is the explanatory variable and if X and ε are correlated, then the OLS estimator is inconsistent. Inconsistency means that the OLS estimator may not be close to the true value of the regression coefficient even when the sample is very large. The correlation between X and ε may be as a result of omitted variables, measurement errors in the regressor, functional form mis-specification, sample selection or simultaneous causality (Stock & Watson, 2007; Wooldridge,2003). IV technique, a general way of obtaining a consistent estimator of the unknown coefficients of the population regression function is thus used to remove the correlation between X and ε .Another observable variable (Z) called an instrument must satisfy two conditions for OLS to be efficient: It must be correlated with X (instrument relevance)[5] and uncorrelated with ε (Instrument exogeneity).

Fence (F) is suspected to be an endogenous variable in that it may also be affected by other omitted factors that determine output Q. Also if the non-random dummy[6] (Koop, 2008) is used as in Equation 3.5, biased results may be produced as the error term would likely be correlated with the dummy because it does not control for unobservable household characteristics which may affect the decision to fence. The results will therefore be biased because the dummy variable F would be correlated with the ε .The method of instrumental variables as mentioned earlier removes the correlation between F and the ε. Thus the instrument called Z will be correlated with fence but it is uncorrelated with the contribution outcomes of the fence (Stock & Watson, 2003). However, if the explanatory variables are random but independent of the regression error, then the OLS is still a good estimator (Koop, 2008).Generally, it is not easy to find a variable that can be used as an instrument but this study will attempt to use cost of fencing an area of land, age of household, years of schooling and farming activity undertaken by households. It is also assumed that the instruments chosen will be used to capture the role of socio-economic and demographic characteristics of households in relation to fencing.

If the instruments satisfy the conditions of instrument relevance and exogeneity, then the coefficient of fence can be estimated using an IV estimator called two stage least squares (TSLS) under the assumption that the TSLS estimator is consistent and has a sampling distribution that, in large samples, is approximately normal .The TSLS estimator is calculated in two stages and the two stages referred to are firstly, the

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[5] The condition for instrument relevance is that at least one instrument is useful for predicting X; given the exogenous variables if there is one included endogenous variable but multiple instruments.

[6] Since the values for the explanatory variables are chosen, it is not a random variable. It is also referred to as fixed variable.

creation of new dependent variables to replace the originals, and secondly, regression calculated as normal but using the new variables. This gives a more accurate result than simply running the equations normally. A formalization of IV technique is shown in appendix 3.

Thus the IV regression model with a single endogenous regressor applied in this study is

$$\ln Q = \alpha_0 + (\beta_0 - \alpha_0)D_i + \alpha_1 \ln K_i + \alpha_2 \ln L_i + \alpha_3 \ln N_i + \alpha_4 \ln LQ_i + \alpha_5 \ln F_i + \ln \varepsilon_i, i = 1,2,..., n \quad (3.13)$$

where

Q is the dependent variable

ε_i is the error term, which represents omitted or measurement error

F_i is the endogenous regressor, which is potentially correlated with ε_i

K_i, L_i, N_i, LQ_i are the included exogenous regressor, which are uncorrelated with ε_i

D is the dummy variable and $D = 1$ if $F = 0$ and $D=0$ if $F > 0$

$\beta_0, \alpha_0, \alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha 5$ are unknown parameters to be estimated

It is also important to note that the coefficients are over-identified if there are more instruments than endogenous regressor and the inverse is true. In addition, the coefficients will be exactly identified if the endogenous regressor is equal to the instruments. Therefore, the estimation of IV regression model requires exact identification or over-identification (Stock & Watson, 2007).Wu-Hausman test, Sargan and First stage F-statistic tests are undertaken to test for consistency, validity and strength of instruments used.

Sargan over-identification test is a test of the validity of instrumental variables. It is a statistical test used to check for over-identifying restrictions in a statistical model. It is also based on the observation that residuals should be uncorrelated with the set of exogenous variables if the instruments are truly exogenous. The hypothesis being tested with the Sargan test is that the instrumental variables are uncorrelated to some set of residuals, and therefore they are acceptable instruments. If the null hypothesis is confirmed statistically, the instruments pass the test and they are valid by this criterion. P-value should however not be significant. If significant, the null hypothesis is rejected and the alternative is accepted. In addition, the Sargan test tests the joint null hypothesis that the instruments are valid and correctly excluded from the estimated equations.

Wu-Hausman test on the other hand is used to test for endogeneity of a variable and the consistency of estimators. To understand the basic idea underlying the Hausman test, it will be assumed that H_O is the null hypothesis that the explanatory variables in a multiple regression model are uncorrelated with the error. Therefore if H_O is true, then both OLS and IV are consistent and may give roughly the same result. However, if H_O is rejected, then OLS will be inconsistent whereas IV will be consistent and the results can be quite different (Koop, 2008).

Lastly, First-Stage F-Statistic is used to test for weak instruments .It tests the hypothesis that the coefficients on the instruments is equal to zero in the first stage of two stage least squares. When there is a single endogenous regressor first-stage F-statistic less than 10, then it indicates that the instruments are weak, in which case the TSLS estimator is biased and TSLS t-statistic and confidence intervals are unacceptable (Stock & Watson, 2007).

3.5 Measuring efficiency

Efficiency is an important concept in the field of economics and the potential importance of efficiency as a means of fostering production has been recognized by many researchers. The concept is basically concerned with the economic use of the scarce resources available in the production process (Cullinane *et al.*, 2007).Researchers such as Dhungana *et al.* (2004) have pointed out that the absolute efficiency position of farmers is usually not known and this therefore implies that the main problem is measuring the efficiency of one farm relative to others. The main method suggested by Ellis (1988) for dealing with farm efficiency is the estimation of the production function and the two main competing approaches for estimating the relative efficiency of farms is the parametric and non-parametric approach. The parametric SFA and non-parametric

DEA used in measuring the contribution of fencing to the efficiency of farms will be discussed in the next sub-section. A CD stochastic frontier production function and constant returns to scale (CRS) and variable returns to scale (VRS) output-oriented DEA models are also discussed in this section.

3.5.1 Stochastic models

For a long time, econometricians have been estimating average production functions. It was not until the pioneering work of Farrell (1957) that serious considerations have been given the possibility of estimating the so-called frontier production functions in an effort to bridge the gap between theory and empirical work (Aigner, Lovell and Schmidt, 1977).

The stochastic production frontier was earlier introduced simultaneously by Aigner, Lovell and Schmidt (1977) and Meeusen and Van den Broeck (1977) and is defined by;

$$Y_i = f(x_i;\beta) + \varepsilon_i \qquad \boldsymbol{i = 1,2,\ldots,\ N} \tag{3.14}$$

where Y_i is the output of *i*th firm , x_i is the vector of all the inputs used by the producer, β is a vector of unknown parameters to be estimated, $f(x_i;\beta)$ denotes the production frontier. ε_i is an error term made up of two components, one normal and the other from a one-sided distribution and is written as ;

$$\varepsilon_i = v_i - u_{i,} \qquad \boldsymbol{i = 1,\ldots,\ N} \tag{3.15}$$

where v_i is the symmetric error component that accounts for random effects and exogenous shocks. It is associated with measurement errors of production or the effects of unspecified explanatory variables in the production frontier such as weather which the farmer does not have control over and it is assumed to be independently and identically distributed (iid) as $N(0,\sigma_V^2)$[7] random variables independent of u_i. Put simply, it is the "noise" component always considered as a two-sided normally distributed variable. It is assumed that these shocks affect the production process.

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[7] The error term v_i has zero mean and unknown variance.

Furthermore, as Kumbhakar and Lovell (2000) assert, the advantage of stochastic production frontier models is that the impact on output of shocks due to variation in labour and machinery performance, vagaries of the weather, and just plain luck can at least in principle be separated from the contribution of variation in technical efficiency.

On the other hand, u_i is a one sided error component that measures technical inefficiency and it is assumed to be non-negative truncations at zero of the $N(0, \sigma_u^2)$ distribution (i.e. half-normal distribution).It is also assumed to be iid as random variables associated with farm-specific factors, which leads to the *i*th firm not attaining maximum efficiency of production.

Several cross-sectional studies in which technical inefficiency effects have been assumed to be iid generally as half normal distributions have been carried out by many researchers and they include those of Aigner *et al.* (1977) who applied the stochastic frontier production function in the analysis of the US primary metals industry consisting of observations across 28 states. Also, Ojo (2003) in his study on productivity and technical efficiency of poultry egg production in Nigeria. Bravo-Ureta *et al* .(1991) in their study on dairy farm efficiency measurement using stochastic frontiers and neoclassical duality also assumed a half normal distribution and Ajibefun *et al.*(1999) in their study on investigation of technical inefficiency of farmers. Nchare (2007) also assumed a half-normal distribution in his cross sectional study on the analysis of factors affecting technical efficiency of Arabica Coffee producers in Cameroon.

Thus, the stochastic production frontier function is;

$$Y_i = f(x_i; \beta) + v_i - u_i \qquad i = 1, 2, \ldots, N \qquad (3.16)$$

Technical efficiency (TE) of an individual firm is defined in terms of the ratio of the observed output to the corresponding frontier output, conditional on the levels of inputs used by the firm (Battese, 1992). Thus the TE of firm *i* in the context of the stochastic frontier production is;

$$TE_i = \frac{Y_i}{Y_i^*}$$

$$= \frac{f(x_i;\beta) + v_i - u_i}{f(x_i;\beta) + v_i}$$

$$= -u_i \qquad (3.17)$$

where $u_i \geq 0$, since it is required that $TE_i \leq 1$

It is also important to note that even though the technical efficiency of a farm associated with the deterministic and frontier models are the same, the values are different. Battese (1992) argues that the TE is greater under the stochastic frontier than for the deterministic frontier. Furthermore, TE_i=1 is used to show that the ith producer attains the maximum feasible output while TE_i< 1 on the other hand provides a measure of the shortfall of the observed output from maximum feasible output.

If it is assumed that the production frontier, $Y_i = f(x_i;\beta)$ takes the log-linear Cobb-Douglas form, Equation 3.16 can be written as;

$$\ln Q = \alpha_0 + (\beta_0 - \alpha_0)D_i + \alpha_1 \ln K_i + \alpha_2 \ln L_i + \alpha_3 \ln N_i + \alpha_4 \ln LQ_i + \alpha_5 \ln F_i + V_i - U_i \qquad (3.18)$$

where: the subscripts *i* refer to the *i*-th farm

i=1,2,…, n

ln	denotes the natural logarithm
D	is a dummy variable equal to one if there is no fence and zero if the value of fence was positive(D=1 if F=0 and D=0 if F>0)
Q	represents the value of output (in Kshs)
K	represents the value of physical capital available for use in farming activity in Kshs
L	represents total work hours by family members and hired labourers in crop and livestock farming
N	represents the total area of land on which farming is carried out (in acres)
LQ	represents land quality proxied by price of land
F	represents the area of fenced homestead in square meters.

The two most frequently used packages for estimating stochastic production frontiers and inefficiency are FRONTIER 4.1 and LIMDEP. FRONTIER 4.1 is a single package specifically designed for the estimation of stochastic production frontiers and it also has an advantage for the reason that estimates of technical efficiency of each farm are produced as a direct output from the package. It also models half-normal distributions but not exponential distributions and this partly explains why the program was preferred because a half-normal distribution is assumed in the stochastic production frontier (Coelli, 1996). The Maximum Likelihood estimates (MLE) for the parameters can be obtained as well as the variance parameters γ and σ^2

Stochastic production frontier models have an advantage for the reason that the impact on output of shocks can at least in principle be separated from the contribution of variation in technical efficiency. On the other hand, deterministic models take no account of measurement errors and other sources of statistical noise and that all deviations from the frontiers are assumed to be the result of technical inefficiency (Coelli *et a.l*, 2005). Moreover, stochastic production frontier has the advantage that standard statistical test such as t-tests can be used to test the significance of variables included in the model, a feature the non-parametric models do not allow. Data on the input and output quantities used by a sample of firms is required. A frontier is then fitted over the top of the data points to measure technical inefficiency as the distance between each data point and the estimated frontier.

3.5.2 Data Envelopment Analysis (DEA)

DEA is typically concerned with the assessment of an individual firm .The firm is the central unit of analysis that, following aggregation, forms the sample for analysis and is defined as the *Unit of Assessment* or the *Decision Making Unit (DMU)* (Cullinane *et al* ., 2007 ; Charnes *et al* ., 1978). The evaluation of the DMU[8] performance is commonly based on economic efficiency and it is generally made up of two major components: technical efficiency (TE) and price or allocative efficiency. This research is however concerned with TE rather than allocative efficiency.

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[8] In this research the DMU will be the farm

In the microeconomics of production and as defined earlier, TE is defined as "the maximum attainable level of output for a given level of inputs, given the current range of alternative technologies available to the farmer" (Ellis, 1988) and it ranges between zero and one. A value of one indicates full efficiency and operations are on the production frontier. A value of less than one reflects operations below the frontier and the wedge between one and the value observed measures technical inefficiency. Moreover, Kumbhakar *et al.* (2000) defines TE as "the ability to minimize input use in the production of a given output vector, or the ability to obtain maximum output from a given input vector". Technical inefficiency can therefore be described as the amount by which the level of production for the farm is less than the frontier output. TE has further been defined as being equal to the ratio of what a firm is producing over what it could potentially produce given its current level of inputs (Coelli *et al* ., 2003). Another aspect of TE that is worth noting is that it is made up of two components: pure TE and scale efficiency (SE).When the scale effect is separated from the TE, pure TE is obtained. SE relates to the most efficient scale of operation in the sense of maximising average productivity. A SE farm has the same level of technical and pure TE. The basic principle of utilising DEA to measure the efficiency level of firms and to construct production frontiers within a given sample can be explained through the use of the example data presented in appendix 4

DEA also obtains technical efficiency estimators as optimal solutions to mathematical programming problems (Theodoridis *et al.*, 2008) and is the foundation of DEA, originally proposed by Charnes *et al.* (1978; 1981). Charnes *et al.* (1978) proposed a model that had an input orientation and assumed CRS and other subsequent papers such as that of Banker *et al.* (1984) proposed VRS model. The CRS assumption is appropriate when all DMUs are operating at an optimal scale (Coelli *et al.*, 2005). However this may not be true for the reason that large farms may be more productive than small farms because they can have labour teams that specialize in particular tasks. Also, vagaries of weather or lack of income may cause a DMU not to operate at optimal scale. Banker *et al.* (1984) was the first to propose that the CRS DEA model can be adjusted to account for VRS situations. Coelli *et al.* (2005) further argues that using CRS specification when all firms are not operating at the optimal scale results in measures of TE that are confounded by scale efficiencies (SE). Thus, using VRS specification allows the calculation of TE irrespective of these SE effects. The approach of VRS is also believed to envelope the data points more tightly than the CRS and thus provides technical efficiency scores that are greater than or equal to those obtained using the CRS model (Coelli *et al* ., 2005).Also, VRS frontier makes it possible to effect returns to scale evaluations (increasing, constant and decreasing). Likewise, it enables small farms to be benchmarked against small farms and big farms against big farms. On the other hand, CRS is a frontier that allows firms of any size to be benchmarked against each other, for example, small farms can be benchmarked against big farms and vice versa. The DEA mathematical programming model under the assumption of CRS and VRS that will be estimated latter in Chapter 6 is presented in the appendix 5

The scale efficiency (SE) measure for each DMU can be calculated by conducting both a CRS and a VRS DEA, and then separating the TE scores obtained from the CRS DEA into the components of scale inefficiency and "pure" technical inefficiency (i.e. VRS TE). If CRS and VRS TE scores for a particular firm are different, then this implies that the firm has scale inefficiency. This can be expressed in a ratio form as:

$$SE = \frac{TE^{CRS}}{TE^{VRS}} \qquad (3.19)$$

where SE =1 indicates scale efficiency or CRS and SE <1 indicates scale inefficiency. The nature of scale inefficiency can be of two types. First, a farm is too small and belongs to the section of the frontier where increasing returns to scale prevail, second a farm is too large and belongs to the section of the frontier where decreasing returns to scale prevail. Lothgren *et al.* (1996) further explains that the scale inefficiency may be due to a small output hence IRS or a too large output (DRS).

In order to determine the type of scale inefficiency, the sum of the weights is inspected, under the specification of CRS (Banker, 1984; Wadud *et al.*, 2000; Cullinane *et al.*, 2007). According to Banker and Thrall (1992), if the sum of the weights is greater than 1, there is decreasing returns to scale (Superoptimal scale) and if the sum of the weights is less than 1, there is increasing returns to scale (Suboptimal scale). CRS (Optimal scale) occur when the sum of weights equals one. Alternatively, if TE_{CRS}=$TE_{VRS,}$ then by definition the firm is operating under CRS (Coelli *et al.*, 2005).

Another method of determining whether a DMU is operating in an area of increasing or decreasing returns is by running an additional DEA problem with non-increasing returns to scale (NIRS) imposed (Nguyen, 2008; Coelli *et al.*, 2005; Wadud *et al.*, 2000; Banker *et al.*, 1984 and Löthgren *et al.*, 1996). The nature of the scale inefficiencies that is due to increasing or decreasing returns to scale for a particular firm can be obtained by seeing whether the NIRS TE score is equal to the VRS TE score. If they are not equal, then increasing returns to scale exist for that firm. If they are equal, then decreasing returns to scale apply (Coelli *et al.*, 2005).This is done by altering the DEA model by substituting the VRS constraint $\sum_{j} \lambda_{j} = 1$ presented in the appendix 5 with $\sum_{j} \lambda_{j} \leq 1$. λ_j is weight of the *j*-th DMU

Compared to the parametric stochastic frontier approach, DEA involves the use of linear programming methods to construct a non-parametric frontier over the data and one does not need to specify a functional form for the production frontier. Efficiency measures are then calculated relative to the frontier (Coelli *et al.*, 2005). In other words, DEA is a methodology directed to frontiers rather than central tendencies and that DEA can avoid parametric specification of technology for production. It will also not need the distribution assumption of the inefficiency term. Likewise, with a given set of finite samples, DEA efficiency estimates can indicate significant technical inefficiencies for the studied decision-making units-DMUs. DMUs are also directly compared against a peer or combination of peers. In addition, DEA assumes that the data are free of noise while the stochastic frontier approach uses methods similar to regression methods, but more complex. Coelli *et al.* (2003) further assert that standard production functions are usually fitted using regression methods and that these regression methods fit a line through the centre of the data, and hence measure average practice. Frontier methods, by contrast, fit a surface over the data, and hence measure best practice. Another advantage pointed out by other researchers is that DEA also allows for multiple outputs and inputs (Nguyen *et al.*, 2008; Wadud *et al.*, 2000). The inputs and the outputs can have very different units as well[9].

In this setting, standard statistical test such as t-tests cannot be used to test the significance of variables included in the model. This implies that DEA estimators do not offer any guidance about the statistical inference problem in that only point estimates of efficiency are obtained from the estimators (Nguyen, 2008). Besides, other researchers have pointed out that lack of allowance for statistical noise is generally considered as the most serious drawback of DEA, because this puts pressure on users of this technique to collect data on all relevant variables and to measure them correctly (Cullinane *et al.*, 2007; Wadud *et al* ., 2000).Another criticism pointed out by other authors is that DEA is deterministic rather than stochastic and it attributes all the deviations from the frontier to inefficiencies, so that a frontier estimated by DEA will probably be sensitive to measurement errors and outliers (Nguyen,2008; Dhungana *et al* ., 2004) .Also, since a standard formulation of DEA creates a separate linear program for each DMU, large problems can be computationally intensive. Andersen *et al.* (1993) further claims that in DEA, a substantial number of observations are characterized as efficient, unless the sum of the number of inputs and outputs is small relative to the number of observations. For example, specialized units may be regarded as efficient owing to a single input or output, although that input or output may be seen as relatively unimportant.

Moreover, it is important to note that DEA models can be distinguished according to whether they are output oriented and input oriented. Output-oriented asks by how much the firm could increase its output given its level of inputs. However, one can define input –oriented TE, which asks how much the firm could reduce its inputs given its level of output. Coelli *et al.* (2005) however argues that the two measures generally produce the same TE scores under CRS but are unequal when VRS is assumed. The input-oriented measure is also most often used in network industries, like water and electricity because the firm is usually required to supply a particular level of service to the community. Hence a request for an increase in output is not very sensible. This

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[9] For example, one input or output could be in units of quantities and another in monetary units without requiring an a priori trade-off between the two.

study will thus focus on output-oriented measure because it is looking at the agriculture industry where increase in output is of paramount importance.

3.6 Conclusion

This chapter provides an overview of the methodological aspects considered in this study. The main source of data is a survey of 251 farms in five semi-arid regions of Kenya. Primary data was collected because to the best of the researcher's knowledge, there is no data on fencing in Kenya. However, the sample size reduced to 249 in that the 2 questionnaires were incomplete. Fence along other inputs such as land, capital, labour and land quality are considered in the production function. Conventional regression techniques and non-parametric linear programming models (output oriented DEA) that will be used in determining the contribution of fence to agricultural production and efficiency of farms are derived. Besides discussing only a model that allows for a change in the intercept, another one that allows for a change in the slope is also discussed and both models will be compared in latter analysis in chapter 5 .The stochastic frontier analysis (SFA) is also discussed for the purpose of obtaining technical efficiency estimates that will be compared with those from DEA in order to find out the contribution of fence to farm efficiency. The study adopted the method proposed by Battese *et al.* (1996) of estimating Cobb-Douglas production functions when some explanatory variables have zero values. Instrumental variable technique to be used in testing for the endogeneity of variables in latter analysis is also discussed.

CHAPTER 4
SAMPLE STATISTICS

4.1 Preamble

As mentioned in the introductory chapter, data was collected from five semi-arid regions in Kenya and this chapter looks at the sample statistics from the data set at both the aggregate and regional level. In later analysis, we shall assume that at the aggregate level, there are no structural differences and that all the data is from one population. At the regional level, we shall later assume that each region is homogenous in itself. To confirm that these assumptions are valid, ANOVA analysis will be used. Here, sample characteristics of the households in relation to fencing, trees and shrubs, land and property ownership, farming activity, form of labour and all the inputs and output used by each household will be described and discussed.

4.2 Aggregate level

The sample statistics of fence characteristics, trees and shrubs, land and property ownership, farming activity and for all the other inputs considered in this study (labour, capital, land and land quality at the aggregate level) will be discussed from sub section 4.2.1 to 4.2.11

4.2.1 Fence characteristics

Table 4.1 shows fence and general farm characteristics. It is noted that 67 percent of the households interviewed have fenced their land and only 33 percent have not. During the interview process, 88 percent of households with fence reported that fencing actually increases production. Reasons given for the increase in production are that fence prevents intrusion from livestock and wild animals that tend to destroy crops and trees in the farms. Others said that they fenced for aesthetic reasons and that a fence generally creates comfort and it eradicates unwanted disturbance in the homestead. For example, those who reside near a main road said that fence inhibits intrusion from human beings and especially those who trespass and create unnecessary footpaths in the homestead. Preventing intrusion from human beings reduces soil erosion caused by strange paths that are formed by passers-by. Likewise, preventing intrusion of human beings reduces theft of crops, livestock and farming equipment and this can be explained by the fact that in normal practice a fenced homestead will only have one entrance and movement of people can be controlled.

Table 4.1: Fence characteristics

Fence characteristics	% Respondents	
	Yes	No
1. Land with fence	67	33
2. Fence worked	98	2
3. Effect of fencing on farm yields: gone up?	93	7
4. Perception that fencing increases productivity?	88	12
5. Other factors may have influenced total crop yield	59	41

Another important role of fence is that it helps in containing livestock within the homestead and in the event of disease outbreaks for example, the spread of the disease to other livestock is minimized or prevented. In addition, fence is used to demarcate farms and that it protects grass. Protecting grass reduces soil erosion in the long run. Others pointed out that it helps in maintaining security within the homestead. Aspects of security that were mentioned are that fence protects children from livestock and that it ensures the safety of buildings. Other respondents further reported that fence is used in separating grazing land from the homestead. Respondents next to game reserves said that fence reduces human-wildlife conflict.

About 98 percent of those who have a fence around their land reported that their fence had worked and 93 percent of all the households with fence reported that their farm yields had gone up since fencing the land. This observation may imply that fence may actually have a role to play in improving agricultural output. It is worth mentioning that those whose fence had worked reported that without fence they would not have managed to do all the activities they had done such as planting trees and crops because livestock would destroy them. Likewise, they would not have managed to get the litres of milk they had because the calves and cows would easily mix up and also controlling livestock diseases, land maintenance and security of the home could be impossible.

59 percent of those interviewed further reported that other factors may have influenced the total crop yield. This implies that even though other factors may have influenced yield, fence still had some role to play in production. Some of the reasons given by the respondents include improved weather, use of artificial fertilizer and manure from poultry and livestock, spraying insects by use of the appropriate pesticides and employing the services of a veterinary doctor to increase livestock yields, feeding and handling livestock and poultry effectively, safeguarding the farm daily to prevent animals and other intruders, proper farm preparation before planting as well as planting on time, introduction of different varieties of drought resistant plant breeds in the market, irrigation, and government subsidies.

Those who had no fence in their land gave reasons such as lack of funds. It was also observed that some homesteads were in between farms a reason that can be regarded as a positive spill over from neighbours. Others said they had leased the land and that they could not see the urgency of fencing someone else's land. Some respondents were just lazy, lacked knowledge on the usefulness of a fence or not interested at all but they hoped to put up a fence in future. Family disputes over land were another reason for not fencing. It was also observed that common land had no fence. In addition, lack and high cost of materials such as poles and barbed wire discouraged some homestead as well. Others had small parcels of land and could not realise the necessity of a fence.

4.2.2 Form, strength and height of fence

Table 4.2 shows the form, strength and height of fence. Out of the households who have a fence around their farm, 49 percent have an artificial fence, 37 percent have a pure natural fence and 15 percent have a mixed fence. The fact that the use of an artificial fence is slightly higher than natural and mixed fence could be attributed to the fact that the sampled areas of study are semi-arid and a natural fence may not be an option. Put another way, it could be because a natural fence could probably do well only in favourable climatic conditions. In addition, 63 percent of all the fences are moderate and only 13 percent have a strong fence (non-porous). About 24 percent however have a weak fence. This could be explained by the fact that most households in ASALS have low incomes and most ASAL areas suffer poverty rates above the national average (Barrett *et al.*, 2000). As far as height is concerned, 78 percent of all fences are between 1 to 2 meters which is a reasonable height of a fence. Only 18 percent are greater than 2 meters.

Table 4.2: Form, strength and height of fence (% of those with fencing)

Fence characteristics	**% Score**		
1. Form of fence	Natural	Artificial	Mixed
	37	49	15
2. Strength of fence	Porous[10] (weak)	Semi-porous (moderate)	Non-porous (strong)
	24	63	13
3. Height of fence	0-1 meters	1-2 meters	>2 meters
	4	78	18

4.2.3 Trees and shrubs

83 percent of all the households interviewed have trees in their farms and 89 percent of those with fence reported that their trees had increased since fencing land (Table 4.3). This implies that fencing may be a good way of preserving the environment in that a fenced area may help in regenerating plantation. About 71 percent of households with fence thought that trees increase crop and livestock production. Some of the reasons given during the interview were that trees provide shade as well as resting place for the animals, they prevent soil erosion by holding the soil particles together, are medicinal, they serve as wind breakers by for example preventing wind from interfering with young fruits, some tree leaves and shrubs are used as feeds for the animals, leaves drop down and when they decay it serves as manure, some trees fix nitrogen in the soil and that they help in preserving soil moisture and also prevent excessive evaporation of water from the soil. In fact, Harvey *et al* . (2005) show that "live" fences which can also be referred to as natural fences are common in Central America, delineating crop fields,

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[10] The word porous is used in this context to refer to a fence that can be said to be weak and is easily penetrable by human beings or wildlife.

pastures, and farm boundaries and that they are important in forming elaborate networks of tree cover across rural landscapes.

Table 4.3: Trees and shrubs

Trees and shrubs	**1.Trees in farm(% of all farms)**		**2. Increase in number of trees since fencing land (% of fenced farms)**		**3. Do trees increase crop and livestock production? (% of fenced farms)**	
Response	Yes	No	Yes	No	Yes	No
%	83	17	89	11	71	29

Figure 4.1: Fence and trees; Koibatek District.

Figure 4.1 is used to show a homestead with a mixed fence in one of the semi-arid areas studied, Koibatek district. It is mixed in the sense that both barbed wire and poles were used in constructing the fence. It is also clear from the figure that the fence has protected the trees that have been planted along the fence. This figure thus confirms the observation that fence may be useful in terms of preserving the environment as far as planting of trees is concerned.

4.2.4 Land and property ownership

As far as land ownership is concerned, 86 percent of all households interviewed reported that the land belonged to them and 74 percent had title deeds or an adjudication number (Table 4.4).

Table 4.4: Land and property ownership

Land and property ownership	**1.Land ownership (% of all the respondents)**		**2.Title deed or an adjudication number(% of those who owned land)**		**3.Would you rate your land as fertile(% of all the respondents)**	
Response	Yes	No	Yes	No	Yes	No
%	86	14	74	26	61	39

It was further observed that 26 percent of households who claimed that land belonged to them did not have title deeds as proof of ownership. The fact that most households reported that land belonged to them and that they also had proof of ownership may explain the high number of fenced homesteads in the study areas, 67 percent (Table 4.1). This shows that there is a relationship between property ownership and the desire to fence land and that land rights are key determinants in farm improvement. This assertion is supported by the cross-tabulation of fence against property ownership presented in Table 4.5.

The null hypothesis is that fence and property ownership are independent. Since the p-value is less than 0.05, the null hypothesis is rejected and it is concluded that there is an association between fence and property ownership. Also, since the computed chi-distribution (63.4126) is greater than critical value of 3.841 at significance level of 0.05, the null hypothesis of independence is also rejected. In fact, during data collection, some respondents reported that fence helped them to identify themselves with the land. Several economists have argued that individualizing land, which could be done by availing title deeds to owners of farms, increases investment (Barrows *et al.*, 1990; Pule *et al.*, 2004). Fencing could be such one investment.

Table 4.5: Cross-tabulation of fence (rows) against property ownership (columns)

		Property ownership		
		Yes	No	Total
Fence	Yes	150	18	168
	No	34	47	81
	Total	184	65	249

***Note**: Pearson chi-square test = 63.4126 (1 df, p-value = 1.67639e-015)*

A cross-tabulation to find out if there is any association between fencing and land fertility is also undertaken as shown in Table 4.6. The null hypothesis is that fence and land fertility are independent. Since the p-value is less than 0.05, the null hypothesis is rejected and it is concluded that there is an association between fencing and land fertility. Also, since the computed chi-distribution (6.04578) is greater than critical value of 3.841 at significance level of 0.05, the null hypothesis of independence is also rejected. However, the association between fencing and land fertility is weaker compared to that of fencing and property ownership for the reason that the latter is strongly significant compared to the former as shown in Table 4.6 and 4.5 respectively.

Table 4.6: Cross-tabulation of fence (rows) against land fertility (columns)

		Land fertility		
		Yes	No	Total
Fence	Yes	112	57	169
	No	40	40	80
	Total	152	97	249

***Note**: Pearson chi-square test = 6.04578 (1 df, p-value = 0.0139395)*

As shown in Table 4.4, 61 percent of all respondents reported that their land was fertile even though the sampled areas of study are classified by the Government of Kenya as being semi-arid. This finding could be supported by the cross-tabulation of fence against land fertility that shows that there is an association between fencing and land fertility. However, the fertility of land is not very convincing as the research concentrated on areas categorised by the Government of Kenya as being semi-arid. These areas have similar climatic conditions and data was collected from regions with similar altitude as discussed in the introductory chapter. Therefore, even though some respondents claimed that their land was fertile, this was not used in the analysis for the reason that the increased output may have been as a result of other factors such as increased use of fertilizer or rainfall. This also explains why land fertility was not used as a proxy for land quality. 39 percent of all respondents said their land was not fertile and that they reared livestock and poultry instead of practising crop farming. Those who practised crop farming did not get high yields in the less fertile land.

Table 4.7: Cross-tabulation of property ownership (rows) against land fertility (columns)

		Land fertility		
		Yes	No	Total
Property ownership	Yes	108	76	184
	No	44	21	65
	Total	152	97	249

***Note**: Pearson chi-square test = 1.63485 (1 df, p-value = 0.201034)*

Another cross-tabulation to find out the relationship between property ownership and land fertility was carried out as displayed in Table 4.7. The null hypothesis is that property ownership and land fertility are independent. Since the p-value is greater than 0.05, the null hypothesis is accepted and it is concluded that there is no association between property ownership and land fertility. Moreover, given that the computed chi-distribution (1.63485) is less than critical value of 3.841 at significance level of 0.05, the null hypothesis of independence is accepted. The implication of this finding is that people do not own land just because it is fertile. There could be other factors as discussed earlier in the text such as an increase in population. Increasing population may force people to settle somewhere else. In this study, it is assumed that people will settle in the semi-arid areas as the productive land in Kenya has already been put into use. This finding thus strongly supports the decision taken in this study of not using land fertility as a proxy for land quality. Instead an economic measure, price of land, is used as a proxy for land quality.

4.2.5 Farming activity

The households interviewed practiced various types of farming activities.39 percent of all households were involved in crop, livestock and poultry farming (Table 4.6). This could be attributed to the fact that the study areas are semi-arid and crop farming alone may not be sufficient. Indeed, we observe that only 18 percent were involved in pure crop farming and that only 11 percent kept livestock. Livestock keeping is mainly drawn from the pastoralists' communities, in particular the Masai of Kenya who highly value livestock. Barrett *et al.* (2000) show that the mainstay of most households in pastoralist's societies mostly found in arid and semi-arid areas is livestock farming. 20 percent of the households practiced crop and livestock farming. About 64 percent of all those who own livestock reported that livestock grazed in their own land. This percentage appears to be reasonable in that 86 percent of all those interviewed reported that land belonged to them.

4.2.6 Form of labour

49 percent of all households interviewed used family labour. 37 percent used hired labour and only 15 percent use both family and hired labour (Table 4.6). This could be attributed to the low level of education in the sense that six years in school as shown in Table 4.9 reduces the reward of white collar jobs. In addition, lack of mechanization could be reason for use of family labour. Families are also poor and they may not afford to hire workers. This finding is consistent with the view of Ellis (1988) who clearly states that most farmers rely on family labour. However, he further argues that hired labour could still be used during peak periods of harvesting.

Table 4.8: Farming activity and form of labour

Item	Type	Percentage
Farming Activity	Crop	18
	Livestock	11
	Poultry	1
	Others	1
	Crop+Livestock+Poultry	39
	Crop+Poultry	6
	Crop+Livestock	20
	Crop+Poultry+Others	0.4
	Livestock+Poultry	3.6
Animal grazing ground	Own land	64
	Common land	36
Form of Labour	Hired	37
	Hired+Family	15
	Family	49

4.2.7 Capital stock

To measure capital stock, the value of farm equipment used in various operations of farming activity is used (Sharma *et al.*, 2003). Besides, the traditional definition of capital as the tangible means of production is used as laid down in the United Nations document (2008). The calculated values of the individual farm equipment are aggregated to obtain the total for the full stock of farm equipment. In addition, capital stock was valued at historic prices. This is the prices at which the farm assets were originally acquired. The advantage of using historic prices is that they can be objectively verified by examining the invoices relating to purchases of the equipment (OECD, 2001).

Each household had an average of 7 items with an average age of 4 years (Table 4.9).However inequality is observed in as far as the cost of repair is concerned with an average cost of repair of Kshs 270.04 and standard deviation of 730.65. This could be because equipment is not homogenous. Some households also overuse the equipment and hence the high cost of repair. Another point of argument could also be that some households used hired tractors and costing is not included.

Table 4.9: Capital stock

Variable	Mean	Standard deviation	Min.	Max.
Number of equipment	6.81	7.32	0.00	90.00
Age of equipment (years)	4.32	2.79	0.00	20.00
Cost of repair (Kshs)	270.04	730.65	0.00	7200.00
Price of capital (Kshs)	87750.00	116980.00	35.00	1800000.00

4.2.8 Total work hours

It is noted from Table 4.10 that an average of 2 workers spend an average of 4 hours and 5 days ploughing land in readiness for planting. An average of 4 workers then spends about 4 days and 5 hours planting. When crops are ready for weeding, about 4 workers spend an average of 7 days and 6 hours weeding the planted crops. It is noted that farmers spend more time doing weeding and this could be attributed to the inability to hire labour hence the use of family labour which may not be adequate. Ideally, crops such as maize should be planted within 1 day and the aim is to attain plant uniformity and to cut down on labour cost. However, for the same reason of use of traditional technology that relies heavily on family labour, it tends to take more days. Harvesting time varies and descriptive statistics show that it takes longer days (9 days). This may also be attributed to scarce labour and the continuous harvest of some crops. However, for some crops such as maize, it was observed that harvesting is done within one day because of the fear of losing crops in the field. Statistics also show that an average of 4 workers is used in harvesting for 5 hours each day. As far as livestock rearing is concerned, 1 worker takes an average of 1 hour to do the milking each day. Spraying is done occasionally at least once per week and 2 workers are needed to do the spraying in one day for about 1 hour. It was observed that except for Narok North district predominantly a pastoralist community, farmers kept more livestock unlike in the other sampled districts of Mwala, Koibatek, Taita Taveta and Suba.

Table 4.10: Total work hours

Variable	Work hours		Work days		No. of workers	
	Mean	**Std dev**	**Mean**	**Std dev**	**Mean**	**Std dev**
Ploughing	4.12	3.17	4.98	5.47	2.39	2.07
Planting	5.19	2.97	3.66	3.98	3.61	2.96
Weeding	5.65	2.89	7.37	7.95	3.78	3.87
Harvesting	5.41	3.31	9.33	12.77	4.09	4.35
Milking	0.48	0.72	1.80	2.68	0.84	1.04
Spraying	0.74	0.84	0.72	0.66	1.69	2.12

4.2.9 Key household characteristics

The mean age is 44.92 years. The years in school are low with mean years being only 6.94 years (Table 4.11). This could be an indicator of the level of illiteracy in the sampled districts caused by high poverty levels and traditional cultural practices that may not value education. High levels of illiteracy may have a negative effect on the improvement of farming and the general community may not appreciate the usefulness of a fence. It may be generally argued that those with more years of schooling are more likely to invest in fence than those with less years in school and this could be perhaps because they are more aware of the benefits of own farm development and good farming practices. Besides, more years of education enables farmers to acquire and process relevant information more effectively which eventually lead to improved method of production. This result may also imply that education and training increases the efficiency and productivity of households. The fact that educated farmers are more likely to fence their land may be supported by the conventional theory on human capital which suggests that schooling raises labour productivity in that it increases the cognitive abilities to a worker (Becker, 1964). On the other hand, land ownership in the sampled districts is highly unequal with reported acreage owned yielding a mean of 19.05 acres (standard deviation of 39.05).

Table 4.11: Key household characteristics

Variable	**Mean**	**Std. dev.**	**Min.**	**Max.**
Age (years)	44.92	15.76	19.00	101.00
Education (years in school)	6.94	0.72	0.00	16.00
Total land (acres)	19.05	39.05	0.13	92.00

4.2.10 Actual and potential quantity of livestock

The descriptive statistics for data on actual and potential quantity of livestock are presented in Table 4.12. Actual output from the table show that households kept more sheep (mean number of 28.55) than cows, goats or chicken. A lot of inequality is also observed in livestock rearing. This could be attributed to the fact that sampled households practiced varied agricultural activities. For example, some specialized in crop farming, others in livestock farming while others practiced mixed farming. The fact that most households kept sheep could also be because some species of sheep thrive in semi-arid conditions. Milk is also very scarce in the sampled areas with a mean of only 4.25 kg. The potential output of the homestead without fences would increase and the highest would be sheep rearing with a mean of 30.39 if households who did not have a fence had one. Potential output as opposed to actual implies the output that would be achieved if households who did not have a fence had one and it is measured by looking at the expected output of only farms that did not have a fence. This was computed by asking those households who did not have a fence to state their expected output assuming they had a fence. This thus means that potential does not refer to farms that already have a fence. It is therefore expected that the potential and actual output of farms with fence will be the same and those without fence will be different as shown in Figures 4.2 and 4.4.

Figure 4.2 shows the actual and potential livestock output. As shown in the Figure 4.2, output would increase if households had a fence. As is shown in the diagram also, there is a low population of animals in unfenced households. This may be contributed by theft from outsiders, wild animals coming into the home and animals straying into the neighbours' farms.

Table 4.12: Descriptive statistics for actual and potential quantity of livestock

Variable	Actual		Potential		Prices(Kshs)	
	Mean	**Std dev.**	**Mean**	**Std dev.**	**Mean**	**Std dev.**
Cows(Units)	21.92	64.88	24.50	70.76	21463.00	7203.60
Goats(Units)	19.75	44.41	22.40	50.56	2266.70	626.86
Chicken(Units)	10.31	24.91	12.66	24.81	242.15	62.51
Sheep(Units)	28.55	96.40	30.39	99.78	2846.30	523.02

Note: *Price of livestock (Kshs/unit)*

When livestock stray, they are likely to pick up diseases and this reduces the quantities. This seems to be a very good result in that it implies that fencing land may actually improve agricultural productivity.

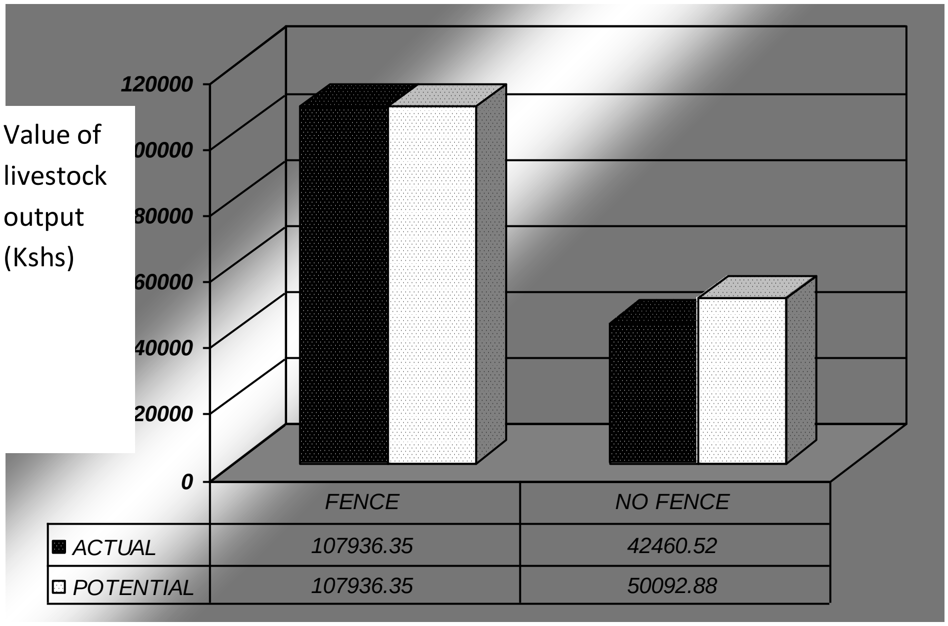

Figure 4.2: Actual and potential livestock output in fenced and unfenced Households

Figure 4.3 is used to show livestock in a fenced homestead in Mwala district. As discussed in the previous paragraphs, it was noted that households who had a fence had more livestock than those who did not have. The fence has hence helped the household to contain livestock within the homestead besides the increase in quantities. It is also clearly shown in the figure that the homestead has trees which serve as shade for the livestock as well.

Figure 4.3: Livestock and fence, Mwala District

4.2.11 Actual and potential crop output

In terms of crop production, we note from Table 4.13 that households grew more maize than any other crop. The mean quantity of maize was 1116 kilograms. The most likely reason for this is that maize is a staple food in most Kenyan communities and almost every home planted maize. Millet has a very low mean of 6.86 kilograms .This could be attributed to the fact that too much work goes into the production of millet and it takes an average of six months to harvest the crop and as a result only few households grew the crop.

Table 4.13: Descriptive statistics for actual and potential crop output

Variable	Actual		Potential		Prices(Kshs)	
	Mean	Std dev.	Mean	Std dev.	Mean	Std dev.
Milk (kg)	4.25	0.43	5.37	0.53	31.43	11.59
Maize (kg)	1115.80	3541.20	1138.20	3541.70	21.68	7.16
Millet (kg)	6.87	44.84	6.89	44.92	44.38	25.56
Beans (kg)	329.46	1501.60	328.79	1500.30	36.58	29.48
Sorghum (kg)	80.39	378.41	78.30	379.27	25.16	13.63
Peas (kg)	86.08	413.59	84.65	413.64	17.91	4.68
Vegetables(kg)	257.19	1155.20	269.68	1193.00	39.45	20.80

Note: *Price of crop/product (Kshs/kg)*

Figure 4.4 shows the actual and potential crop output and just as in livestock production; crop output would increase if households who did not have a fence had one. However, as earlier shown in Table 4.1, 59 percent of all respondents reported that other factors may have influenced their total crop yield besides fencing. Some of the reasons given by the respondents include improved weather, use of fertilizer and manure from poultry and livestock, irrigation, and government subsidies.

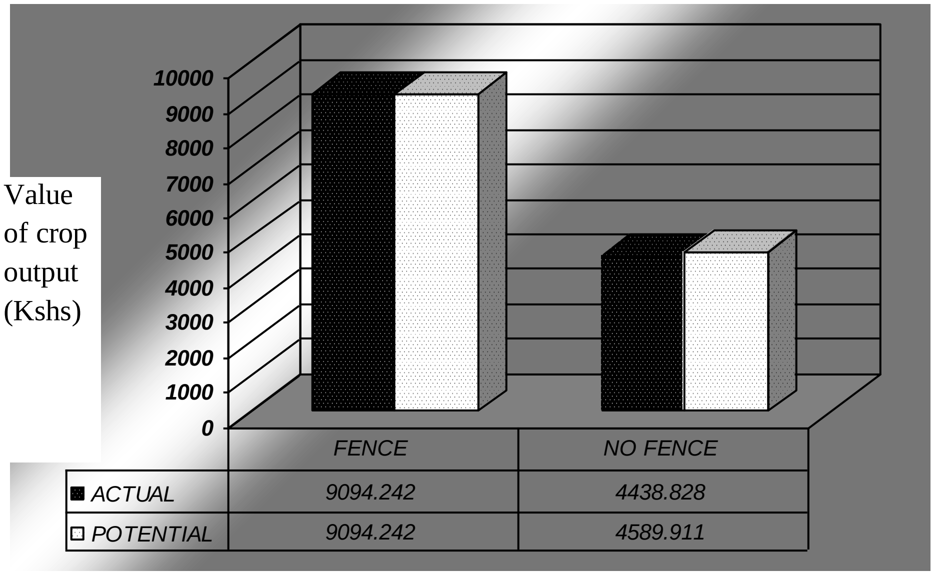

Figure 4.4*: Actual and potential crop output in fenced and unfenced households*

Figure 4.5*: Fence and crop output, Narok North district*

Figure 4.5 show a fenced home with maize. It can be concluded from the diagram that fencing farms improves crop production. The positive effect may spill over to those who do not have a fence and they may see the need to have one. The most used form of fence in Narok North district is artificial fence and this is because the area is quite arid and live fences would take longer to grow. The aridity of the area is depicted by the shrubs.

4.3 Test of Independence

A statistical test, chi square, test of independence was carried out to test for independence between fence and other variables of interest. The null hypothesis of independence and the significance level of 0.05 are assumed .The results are summarized in Table 4.14.

4.3.1 Fence and Output

Since the p-value is less than 0.05, the null hypothesis is rejected and it can be concluded that there is an association between fence and improvement in farm yields. It is in addition statistically significant. Since the computed test-statistic (200.413) is greater than critical value of 3.841, the null hypothesis of independence is rejected.

Table 4.14: Chi square test

Variable	**Output** **(FYIELDS)**	**Environmental changes** **(TREESI)**	**Education** **(EDUC-YEARS)**
$\chi 2$ **(p-value)**	200.41 (1.69752e-045)	184.98 (3.96328e-042)	4.20 (0.52)

4.3.2 Fence and changes in environment

The null hypothesis is that fence and trees in households are independent. Since the p-value is less than 0.05, the null hypothesis is rejected and it can be said that there is an association between fence and trees. It is also statistically significant. Since the computed statistic (184.981) is greater than critical value of 3.841, the null hypothesis of independence is also rejected.

4.3.3 Fence and education

The null hypothesis is that fence and education are independent. Since the p-value is greater than the threshold of 0.05, the null hypothesis is accepted. The computed chi square distribution is also less than the critical value of 11.070 .The null hypothesis is thus accepted as well. It can therefore be said that there is no association between fencing land and the level of education.

4.4 Test for difference in the Means

As already mentioned, the primary data used in this study was collected from five semi-arid regions of Kenya. Analysis is done at both the aggregate and latter, in the next section, at the regional level. At the aggregate level, it is assumed that there are no structural differences and that all the data is from one population. At the regional level, it is assumed that each region is homogenous in itself. To confirm that these assumptions are valid, ANOVA analysis based on the F distribution is used to test for differences among the means of the populations. This is done by examining the amount of variation within each of the samples, relative to the amount of variation between the samples. The hypothesis is tested by the F-ratio. The null and alternative hypothesis for the analysis is thus given as:

H_0:μ_1= μ_2= μ_3= μ_4= μ_5 (The population means are equal)

H_1: at least one mean is different from the others

μ_1 to μ_5 represent the means of all the five regions

ANOVA analysis in this study is useful in the sense that it will answer the question of any significant difference between the mean values of fenced and unfenced homesteads. Besides, it is a quick way of comparing the means without getting overwhelmed with many coefficient estimates. Moreover, it will enable a quick comparison of the means from the five data sets when the regional analysis is considered.

At the aggregate level, ANOVA results (Table 4.15) show that fence is significant in terms of livestock and crop output, trees representing environmental changes and title deed representing property ownership. Therefore, the null hypothesis of no difference in the means of the population is rejected since the test statistic exceeds the critical value and the F statistic is significant at the alpha=0.05 level. This implies that there is a difference in the means of fenced and unfenced households as far as the variables are concerned. Furthermore, in terms of education and age, fence appears to be insignificant and this implies that there is no difference between fenced and unfenced households when it comes to looking at the level of education and age of the household heads.

Table 4.15: ANOVA (aggregate data)

Variable	**Total livestock**	**Total amount of crops**	**Age**	**Education**	**Trees (Environ mental changes)**	**Title deed (Property ownership)**
F(F-crit)	6.54 (3.88)	3.91 (3.88)	1.44 (3.88)	0.15 (3.88)	18.54 (3.88)	78.81 (3.88)
(p-value)	0.01	0.05	0.23	0.70	0.00	0.00

4.5 Regional level

This section will endeavour to present a comparative analysis of the five ecological zones classified as semi-arid. Data was collected from each of the regions and each was chosen depending on differences in traditional and cultural practices amongst other factors. Sample characteristics from each region will be compared. Descriptive statistics for the market prices of each region is displayed in appendix 2.

4.5.1: Sample characteristics

A sample of 50 households was visited in each region except Voi where 49 households were visited. The divisions, locations and sub-locations in each region however had different climatic conditions even though the whole district was classified as semi-arid. Those areas that receive low rainfall within the administrative division were nevertheless chosen. In Mwala district for example, the sample was drawn mainly from the low plains of Yathui (Figure 1.3). In Narok North district, the sample was drawn mainly from lower midland zone, Suswa (Figure 1.4). Furthermore, in Koibatek district, the sample was mainly drawn from the low zone, Mogotio (Figure 1.5). In Suba, the sample was drawn mainly from Mbita (Figure 1.6).Finally, in Taita Taveta district, the sample was drawn from the low zone, Voi (Figure 1.7).

4.5.1.1: Fence characteristics

Table 4 .16 shows that all the regions at least had households with fence in their land. Compared to other regions however, Voi had the least percentage of fenced households (39 percent). This could be explained by the fact that in Voi most of the homesteads visited were squatters and this is supported by the fact that only 29 percent of all the households had a title deed or an adjudication number (Table 4.16). Besides, all those who had a fence around their land also said the fence had worked. As far as the form of fence is concerned, it was observed that in Mwala and Narok districts, most of the households had an artificial fence and this could be attributed to the fact that the area is quite dry and a natural fence may not be an option as it takes time for a natural fence to grow into a reasonable height. Narok is also next to a game reserve and it is assumed that an artificial fence is stronger. However, in Koibatek and Suba districts, the majority of the households had a natural fence and this could be because in Koibatek, most

Table 4.16: Fence characteristics

Fence characteristics		**% Regional Score**				
		Mwala	**Narok**	**Koibatek**	**Suba**	**Taita**
1. Land with fence?	Yes	74	60	98	66	39
	No	26	40	2	34	61
2. Fence worked?	Yes	74	62	88	100	100
	No	26	38	12	0	0
3. Fencing improved yields?	Yes	74	58	80	100	100
	No	26	42	20	0	0
4. Perception fencing improved productivity?	Yes	100	96	100	100	43
	No	0	4	0	0	57
5. Other factors influenced crop yield?	Yes	70	42	88	63	84
	No	30	58	12	37	16
6. Form of fence	Natural	11	3	51	96	5
	Artificial	76	94	45	6	5
	Mixed	14	3	4	0	90
7. Strength of fence	Porous	0	13	76	0	0
	Semi-porous	89	48	24	82	100
	Non-porous	11	39	0	18	0
8. Height of the fence	0-1 meters	0	16	0	3	0
	1-2 meters	97	77	69	88	47
	>2 meters	3	7	31	9	53

households use sisal in fencing land and it also serves another role of being a cash crop. Generally, most households used available material to fence their homesteads. Voi however had more of mixed fence (90 percent) and the homesteads interviewed claimed that a mixed fence could be stronger for the reason that it protects the homestead from intrusion by human beings and wild animals. In addition, in all the regions, the fence was observed to be semi-porous (moderate) except in Koibatek where the fence was observed to be porous (weak). This could be blamed on the low income of the respondents. It was also noted that few households had a strong fence. During the interview however, most respondents reported that they would wish to have a strong fence but they could not afford. An expected observation also was that in all the regions, most of the fences had a height of between 1 to 2 meters which is a reasonable height of a fence. It is only in Voi where households had a fence that was greater than 2 meters.

In Voi (in Taita Taveta), this is not an unreasonable observation in that one of the challenges in the study area is wildlife-human conflict. It therefore appears that most households have put up a high fence of more than 2 metres to prevent wildlife from jumping over into their homes. No household in Voi also had a low fence of between 0 and 1 meter. Majority of the households in all the regions also reported that their farm yields had gone up since fencing the land and that other factors may have influenced their total crop yield besides fencing.

4.5.1.2: Trees and shrubs

Table 4.17 exhibits that most of the households with fence had trees in their farms and that their trees had increased since they fenced their land. This implies that fencing may be a very good way of preserving the environment in that a fenced area may help in regenerating plantation. Majority also said trees increase crop and livestock production.

Table 4.17: Trees and shrubs

Tree characteristics		**% Regional Score**				
		Mwala	**Narok**	**Koibatek**	**Suba**	**Taita**
1. Trees in farm?	Yes	100	58	100	72	86
	No	0	42	0	28	14
2. Trees increased since fencing land?	Yes	74	50	98	67	100
	No	26	50	2	33	0
3. Trees increase crop/ livestock production?	Yes	98	58	98	72	100
	No	2	42	2	28	0

4.5.1.3: Land ownership

As far as land ownership is concerned (Table 4.18), all households interviewed reported that the land belonged to them and that they had title deeds or adjudication number. This may explain the high number of fenced homesteads in the study area except in Voi where the majority (55 percent) reported that land did not belong to them. This further confirms the relationship between property ownership and the desire to fence land and that land rights are key determinants in farm improvement as earlier shown in the aggregated data in Table 4.5. Land fertility also varied in the different regions and this is explained by the observation that the respondents in Mwala and Narok reported that their land was not fertile while households in Koibatek, Suba and Voi reported that their land was fertile. Mbita is also described as an ASAL pocket and a large area of land may be fertile. Interestingly, the perception of all households on the idea of fencing land is that they all believed fencing increases productivity.

Table 4.18: Land ownership

Land ownership		**% Regional Score**				
		Mwala	**Narok**	**Koibatek**	**Suba**	**Taita**
1. Land ownership	Yes	100	100	98	84	45
	No	0	0	2	16	55
2. Would you rate your land fertile?	Yes	10	32	94	90	80
	No	90	68	6	10	20
3. Title deed or an adjudication no?	Yes	94	88	98	60	29
	No	6	12	2	40	71

4.5.1.4: Farming activity

76 percent of all households in Mwala were involved in crop, livestock and poultry farming (Table 4.19) .Only 4 percent were involved in pure crop farming. This could be attributed to dry climate and crop farming alone may not be sufficient. 98 percent of all those who own livestock reported that livestock grazed in their own land. This seems true in that 100 percent of all interviewed households reported that land belonged to them. In Narok, most homesteads kept livestock and this confirms the fact that this is a pastoralist community. None reared chicken purely and this is not a surprising result in that traditionally, the Masai community referred to chicken as birds and they believed that it was not fit for human consumption. It is only recently that they have come to realise the monetary and nutritional value of chicken. In Koibatek, 58 percent of all households interviewed were involved in crop, livestock and poultry farming .None was involved in pure crop and poultry farming.

This could be attributed to the dry climate and the fact that poultry farming alone may not meet all the needs of the households unless it is done large scale. Most households are basically subsistence farmers. However, most of the farmers reported that they had planted crops in the last three years but they did not have any harvest and this was due to poor weather conditions. In Suba, 50 percent of all households interviewed were involved in only crop farming. 10 percent kept livestock and 4 percent poultry farming. 10 percent of all households practiced crop, livestock and poultry farming.16 percent however practiced crop and livestock farming. In Voi, 39 percent of all households interviewed were involved in only crop farming and 35 percent practiced crop, livestock and poultry farming. None was involved in pure poultry farming .This could be attributed to the dry climate and the fact that poultry farming alone may not meet all the needs of the households unless it is done large scale. Other farming activities therefore have to be practiced for the households to be more food secure.

Table 4.19: Farming activity in percentage

Farming activity	Mwala	Narok	Koibatek	Suba	Voi
Crop	4	0	0	50	39
Livestock	0	38	4	10	2
Poultry	0	0	0	4	0
Others	0	0	0	0	0
Crop+Livestock+Poultry	76	18	58	10	35
Crop+Poultry	10	0	2	8	10
Crop+Livestock	10	44	18	16	14
Crop+poultry+others	0	0	0	2	0
Livestock+poultry	0	0	18	0	0

4.5.1.5: Form of labour

Family labour is the most used form of labour in Mwala district, 60 percent (Table 4.20). Only 10 percent of all households interviewed used hired labour and 30 percent use both hired and family labour. This could be attributed to the low level of education in the sense that six years in school reduces the chances of white collar jobs. In addition, lack of mechanization could be reason for use of family labour. Families are also poor and they may not afford to hire workers. In Narok however, hired and family labour is the most used form of labour, 80 percent. Only 14 percent of all households interviewed used only family labour and 4 percent hired labour. 2 percent combine both family and reciprocality is used to refer to a form of exchanging labour. People work and they are fed or given part of the harvest in return as form of payment and the owner of the farm is expected to go and assist when there time for harvesting come.

Table 4.20: Form of labour

Form of labour	Mwala	Narok	Koibatek	Suba	Taita
1. Hired Labour	10	4	17	0	20
2. Family Labour	60	14	23	70	57
3. Hired and Family	30	80	60	0	43
4. Family and reciprocality	0	2	0	30	0

In Koibatek district, combined hired and family labour is the most used form of labour, 60 percent. Only 23 percent of all households interviewed used only family labour and 17 percent hired labour. On the other hand, family labour is the most used form of labour in Suba district, 70 percent. No household interviewed hired labour and 30 percent practised reciprocality. Finally in Voi, family labour is the most used form, 57 percent. Only 23 percent of all households interviewed used hired labour and 43 percent combined both family and hired labour.

4.5.1.6: Key household characteristics

The key household characteristics as shown in Table 4.21 show that the mean age for the sampled household heads in the regions range from 38 to 60 years. The years in school in all the regions is also low with mean number of years in school in all the regions ranging between 5 and 8.This is quite low and this could be an indicator of the level of illiteracy in the district as it means that the head of the household never went beyond primary school level. However, 98 percent of all the respondents were household heads. Land ownership in Mwala district is highly unequal with reported acreage owned yielding a mean of 27 acres (standard deviation of 75). Inequality is also observed in Koibatek and Taita Taveta.

In Taita Taveta also, the average acreage of land of each household is 4.82 acres and this concurs with the estimates of the Districts Development Plan (2009). It is only in Narok and Suba district where no inequality is observed in terms of land ownership.

Table 4.21: Descriptive statistics for key household characteristics of all the regions

	Mwala		**Narok**		**Koibatek**		**Suba**		**Taita**	
Key characteristics	**Mean**	**Std dev**	**Mean**	**Std dev**	**Mean**	**Std dev**	**Mean**	**Std dev**	**Mean**	**Std dev**
Age (yrs)	59.7	19.2	42.0	12.1	38.5	12.7	40.7	10.6	44.5	15.1
Education (yrs in school)	6.35	5.47	4.7	5.45	7.52	4.22	7.84	5.02	8.18	4.22
Head of h'hold	0.98	0.11	0.98	0.14	1.00	0.00	1.00	0.00	1.00	0.00
Total land (acres)	26.65	74.95	37.26	22.90	23.48	26.18	2.90	1.44	4.82	9.40

4.6: ANOVA (Regional data)

Each region is assumed to be homogenous in itself and ANOVA is used to confirm that this is the case. The null and alternative hypothesis for the analysis is as:

H_0:$\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$(The population means are equal)

H_1: at least one mean is different from the others

μ_1 to μ_5 represent the means of all the five regions.

4.6.1 Fence and livestock output

It is noted from Table 4.22 that fence is significant in terms of livestock output in Narok and Taita districts. In Mwala district, it is significant at the alpha level 0.10. This implies that there is a difference in the value of livestock between those who fence and those who do not. However, in Suba and Koibatek districts, fence is insignificant implying that there is no difference between fenced and unfenced homesteads.

Table 4.22: ANOVA (Regional data): Fence and variables of interest.

	Mwala		Narok		Suba		Taita		Koibatek	
Variable	**F**	**p-value**	**F**	**p-value**	**F**	**p-value**	**F**	**p-value**	**F**	**p-value**
Livestock	2.92	0.09	11.90	0.00	1.47	0.23	6.56	0.01	0.05	0.82
Crops	2.10	0.15	3.03	0.09	0.10	0.76	1.35	0.25	0.02	0.88
Age	4.52	0.04	7.79	0.01	0.03	0.87	0.91	0.34	0.07	0.79
Education	0.66	0.42	0.08	0.78	0.14	0.71	2.30	0.14	0.01	0.94
Trees	65534	0.00	25.11	0.00	1.35	0.25	5.55	0.02	65535	-
Title deed	10.66	0.00	2.40	0.13	7.24	0.01	17.11	0.00	65535	-

Note: *The significance level used is 0.05 and in case 0.10 is used, it is stated in the text.*

4.6.2 Fence and crop output

Fence is significant in terms of crop output only in Narok district at the alpha level 0.10. All other districts show an insignificant result implying that there is no difference in terms of crop output between those who fence and those who do not in Mwala, Suba, Taita and Koibatek districts.

4.6.3 Fence and age

It also appears that there is a difference in age for those who fence and those who do not in Mwala and Narok district. Age however does not matter in Suba, Taita and Koibatek districts as ANOVA analysis depicts insignificant results.

4.6.4 Fence and education

ANOVA analysis shows that there is no difference in terms of education with those who have a fence or not in all the districts.

4.6.5 Fence and environmental changes

The relationship between fence and trees is statistically significant in all the districts implying that there is a difference between fenced and unfenced homesteads in terms of trees. This observation further strengthens the point that fence plays a big role in regenerating plantation.

4.6.6 Fence and title deed

Likewise, fence and title deed is also statistically significant in Mwala, Suba, Taita and Koibatek except Narok district. As discussed at the aggregate level in section 4.2, the relationship that the right to own land may increase the need of fence can further be deduced from the ANOVA analysis. The insignificance of title deed in Narok district may be explained by the fact that land ownership may not be important in that as discussed earlier, this is a predominantly pastoralist community and they are also traditionally nomads .

4.7 Conclusion

This chapter herein looks at the sample statistics from the data set at both the aggregate and regional level in relation to fencing, trees and shrubs, land and property ownership, farming activity, form of labour and all the inputs and output used by each household. Thus, the general conclusion to be drawn from the chapter is that most households appreciate the fact that fence is a useful investment in that those who had a fence said their fence had worked and that it had improved productivity though other factors such as improved weather amongst others already discussed may have contributed to the high yields. Also, fence has an impact on plant cover in that those who had a fence reported that their trees and shrubs had increased since fencing land and that trees do also improve crop and livestock production. The null hypothesis of independence was also rejected. In addition, there is an association between fence and right to own property and this is supported by the fact that the null hypothesis of independence was rejected in the chi-square test statistic. Furthermore, those who had title deeds also had a fence around the land and those who did not have a title deed had most likely not fenced the homestead. It is also noted that the most used form of labour is family labour and this could be as a result of absence of other employment opportunities for farm areas, and small size of typical farms. The use of family labour could also be related to the low level of education observed in the sampled households. ANOVA analysis shows that at the aggregate level, fence is significant in terms of crop and livestock output, trees representing environmental changes, title deed representing property ownership but not education and age. Likewise, at the regional level, fence is significant in all the regions in terms of trees. Title deed is also significant in all districts except Narok. The significance of fence in terms of livestock and crop output, age and education is inconsistent. Therefore, it can be concluded that the only consistent variable in terms of significance at both the regional and aggregate level is trees.

CHAPTER 5
MODELLING AND STATISTICAL INFERENCES

5.1 Preamble

This chapter will initially endeavour to present the regression results in general from the use of both OLS and IV estimation at both the aggregate and regional level of the sampled households. This is because there is a possibility that fencing is endogenous and a consistent estimator is not known. Theoretically, for OLS to be chosen as the best estimator there are various requirements and one of them is exogeneity of regressors. On the other hand, the IV technique does allow for endogeneity of regressors but it involves the selection of appropriate valid instruments. A concern on the validity of instruments may then arise. If the instruments are not valid, then there is no sound basis on which to choose between OLS and IV. Likewise, if the instruments are valid, then a Wu-Hausman test is carried out to check for the exogeneity of regressors. In later analysis therefore, if the regressors are exogenous, OLS estimates shall be reported and if there is endogeneity of regressors, IV estimates will be reported. The analysis in this chapter also distinguishes between fence as a binary dummy variable and as a variable which measures area. Distinction is also made between models with and without land quality variable and each is regressed separately. At the aggregate level, the regressions of when fence is used as a variable which measures area is shown in Tables 5.2 to 5.5. Likewise, Tables 5.6 to 5.9 shows the regressions when fence is used as a binary dummy variable. At the regional level, fence is used as a variable which measures area and not as a dummy variable. Finally in this chapter, a general conclusion on the impact of fence on agricultural output will be drawn depending on the regression results at both the aggregate and regional levels.

5.2 Empirical analysis and results at the aggregate level

Table 5.1 is used to show the definition of variables and their sample means and standard deviations. It is noted from the table that there is no much variation in the natural logarithms of livestock production, fence, capital, and labour, land and land quality from the fact that the standard deviation is less than the mean except for crop production. Moreover, as explained earlier in chapter 3, the variable fence is suspected to be endogenous in that it may be affected by other omitted factors that determine output. This therefore implies that fence may be correlated with the error term in the regression. The method of instrumental variables is used to remove the correlation between fence and the error term. It is not easy to find suitable instruments but in this research, instrumental variables for fence are given as age of the household head, cost of fencing land, education level of household head and the farming activity practiced. The variables are also used as conditioning variables in that they may influence the choice of a fence. It is also clear from Table 5.1 that there is no much variation in the chosen instruments for the same reason that the standard deviation is less than the mean. Labour, capital, land and land quality are assumed to be exogenous.

5.2.1. OLS and TSLS results

As discussed in chapter 3, the explanatory variable fence has a significant proportion of zero values. This is because data on fence is made up of households with and without fence. Owing to these, the study adopted the method proposed by Battese (1996a) of estimating Cobb-Douglas production functions when some explanatory variables have zero values. Battese (1996a) used dummy variables associated with the incidence of the zero observations such that efficient estimators are obtained using the full data set but no bias is introduced. Therefore, the regression coefficients presented in Table 5.2 treats fence as a variable for measuring area.

The parameters of the production function are estimated by using the OLS and TSLS regression of the model specified by Equation 3.11.Furthermore, the estimates were obtained using GRETL. The instrumental variables and the relevant tests of consistency of OLS estimates, weak instrument test and over identification test are presented in Table 5.3. OLS estimates will be discussed first and thereafter TSLS estimates.

Table 5.1: Definition of variables and descriptive statistics-Input, output and instruments

Variable Production function	Description	Mean	SD
ln (livestock)	Natural log of the value of Livestock production (Kshs)	3.47	3.58
ln (crop)	Natural log of the value of Crop production (Kshs)	1.60	2.80
ln (fence)	Natural log of the fenced area(m^2)	4.19	0.56
ln (capital)	Natural log of the value of capital at current Prices used in farming activity(Kshs)	3.97	1.39
ln (labour)	Natural log of the total labour used(Total work hours)	5.14	2.62
ln (land) ln(land	Natural log of the total land size(acres)	2.00	1.43
quality)	Natural log of land quality(Proxied by price of land)	5.71	0.58
ln (age)	Age of household head (Years)	3.75	0.33
ln (cfm)	Cost of fencing square meters of land(Kshs)	1.07	0.93
ln (edu)	Education of household head(Years)	1.59	1.05
ln (farming activity)	Farming activity practiced	1.31	0.72

***Notes**: (i) SD-Standard Deviation, (ii) Kshs- Kenya shillings*

From the regression results (Table 5.2), OLS estimates indicate the importance of factor inputs in agricultural production. For example, the coefficients of all the variables have the expected positive signs and magnitudes except for the input land quality in terms of crop production.

Fence variable which is the variable of interest in this study had a positive and statistically significant coefficient on output except for the OLS estimate in terms of livestock production which was positive but statistically insignificant. This finding implies that households with a larger area of fence report higher production than those without and hence the affirmation of the hypothesis that fencing enhances output. It is also noted that the coefficients of the natural logarithm of fence are not very different. For example, in terms of livestock production, it is estimated to be 0.27 and in terms of crop production it is 0.39 and when output is aggregated, it is 0.35. In addition, the coefficients of crop production and total output all round up to 0.4 except the coefficient of livestock production which rounds up to 0.3, a difference that is not very significant. The coefficients of the other variables considered along fence are discussed in the next four paragraphs.

Capital showed a positive but insignificant coefficient in terms of crop and livestock production. Aggregated output however presented a positive and statistically significant coefficient. The general observation thus from this result is that households who invest in a lot of physical capital are likely to get more output than those who do not invest, as expected.

Table 5.2: Regression of natural log of crops, livestock and total output -TSLS and OLS regressions

	Dependent variable					
	CROPS		**LIVESTOCK**		**TOTAL OUTPUT**	
Regressors:	**OLS**	**TSLS**	**OLS**	**TSLS**	**OLS**	**TSLS**
Labour	0.42***	0.40***	0.01	-0.04	0.08**	0.06
(Total work hrs)	(0.05)	(0.05)	(0.07)	(0.08)	(0.04)	(0.04)
Capital	0.08	0.05	0.19	0.09	0.15**	0.10
(‘000’kshs)	(0.09)	(0.10)	(0.13)	(0.15)	(0.07)	(0.07)
Land	0.08	0.10	0.15	0.21	0.06	0.09
(Acres)	(0.12)	(0.12)	(0.17)	(0.18)	(0.08)	(0.09)
Land quality	-2.38***	-2.30***	3.21***	3.48***	1.57***	1.69***
(Price)	(0.30)	(0.31)	(0.42)	(0.46)	(0.21)	(0.22)
Fence	0.39**	0.81**	0.27	1.59***	0.35***	0.92***
(Area)	(0.16)	(0.32)	(0.23)	(0.48)	(0.11)	(0.23)
Dummy	1.08	2.74**	-0.43	4.68**	0.52	2.74***
	(0.69)	(1.29)	(0.98)	(1.92)	(0.48)	(0.93)
Number of observation	249	249	249	249	249	249
R-squared	0.51	0.50	0.39	0.33	0.41	0.36

***Notes**: (1) Dependent variable is total value of crops, total value of livestock and total output (2)* Significant at 10% ** Significant at 5% and *** significant at 1 %(3) Standard errors in parentheses.*

Labour posted a positive but significant coefficient in terms of crop production and total output. This result implies that labour has an impact on crop production and generally total output and that farming households are more likely to gain if they invest in more labour in crop production. This result is consistent with that of Chirwa (2007) who found a statistically significant relationship between labour and production of maize in Malawi. This result is expected since most of crop production in Kenya uses traditional technology that relies heavily on family labour. However, in terms of livestock production, labour has a positive coefficient but it is statistically insignificant. This result is not very surprising because the elasticity coefficients are quite small and it can be concluded that the contribution of labour to livestock production is small. The positive coefficient of the OLS estimate in terms of livestock production may also imply that practically, more workers may improve livestock production.

Land showed a positive but statistically insignificant coefficient in crop, livestock and aggregated output. The coefficient is also not significantly different in that it is about 0.1 for crops, livestock and total output. It can be argued for example in the case of livestock production that large farms provide enough grazing ground for livestock rearing i.e. farm size and livestock production appear to be positively correlated. The general observation therefore is that land is important in production and this as expected is consistent with economic theory.

Land quality proxied by price of land, demonstrates interesting results that are against conventional economic theory. In terms of livestock production for example, land quality is positive and statistically significant whereas in terms of crop production, land quality is negative and also statistically significant. However, the overall aggregated output show a positive and statistically significant coefficient. Theoretically, it is expected that high quality land should improve crop production. However, the results presented here may imply that price of land may not be a good proxy for land quality and that an agronomic measure should have been used. This is because land may have a high value for other reasons such as proximity to the road or a shopping centre. The fact that land is expensive may not necessarily mean that land is fertile agriculturally. Also, it can be argued that theoretically fertile land is expected to produce more crop output. On the other hand, animals can still do well in infertile land because other practices of livestock rearing such as zero grazing can still be practised. Hence, land fertility may not be a pre-requisite for livestock production but it could be for crop production. This finding may therefore imply that price of land is not a good proxy for land quality. In later analysis, land quality variable will be omitted from the model so that results from the two models can be compared.

To ensure the robustness of the OLS results, a test for the endogeneity of factor inputs was conducted. This is because it was suspected that the variable fence may be affected by other omitted factors that determine the decision or the need to fence. To verify the endogeneity problem, instruments such as cost of fencing an area per meter square, socio-economic characteristics such as age and education and the farming activity carried out by each household were used as instruments. Cost of fencing an area was considered as an important instrument in that as pointed out by Twyman *et al*. (2001), the people of Okonyoka in Eastern Namibia needed to put up a fence around the community but cost was a challenge. The government did not give them any support either and money was raised by contributions per head of cattle from all residents in the settlement. However, fencing was a good thing despite the financial cost borne by all. The researcher points out that it appeared that there was an improved sense of community derived from the successful organization of this fencing program and people felt that they had greater control over their rangeland resources .This therefore implies that determining whether to put up a fence or not may depend on cost amongst other factors .

The relevant tests for the exogeneity of the preferred instruments is undertaken (Table 5.3) and it is found that all the chosen instruments pass the first stage F statistics for weak instruments. As for the Wu-Hausman test for consistency of OLS estimates, the results show that the null hypothesis of consistency of OLS estimates is rejected when livestock and total output is treated as the dependent variable for all sets of instruments. However, when the dependent variable is crop output, the OLS estimate is weakly consistent[11] .Furthermore, except for when livestock output is treated as the dependent variable, all the instruments pass the Sargan test for over identification and validity of instruments when the dependent variable is crop output and total output. Therefore, based on this results, it can be concluded that the preferred instruments generally illustrate that fence may be affected by the cost of fencing an area of land, the number

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[11] In this research ,OLS estimates with a p-value of about 0.10 and a chi-square test statistic of between 2 and 3 are referred to as being weakly consistent.

of years of schooling and age of the household head and the farming activity though not significantly. This conclusion is reached at from the fact that the dependent variable, total output, an aggregate of both crop and livestock output do pass all the tests of weak instruments, OLS estimate consistency and validity of instruments but not when livestock and crop output are considered as dependent variables.

Table 5.3: Instrumental variables and tests

Instrument	**Tests**	**Dependent variable**		
		CROPS	**LIVESTOCK**	**TOTAL OUTPUT**
Cost of fencing	-First stage F statistic	84.00	84.00	84.00
	-Hausman specification, $X^2(1)$	2.51	12.25	9.45
Cost of fencing + Age	-First stage F statistic	42.66	42.66	42.66
	-Hausman specification, $X^2(1)$	2.48	9.22	8.13
	-Sargan test (p-value)	0.02 (0.87)	10.10 (0.00)	2.70 (0.10)
Cost of fencing + Age + Education	-First stage F statistic	28.73	28.73	28.73
	-Hausman specification, $X^2(1)$	2.60	7.99	7.82
	-Sargan test (p-value)	0.07 (0.97)	13.27 (0.00)	3.03 (0.22)
Cost of fencing + Age + Education + Farming activity	-First stage F statistic	21.69	21.69	21.69
	-Hausman specification, $X^2(1)$	2.92	4.02	6.90
	-Sargan test (p-value)	0.72 (0.87)	72.67 (0.07)	5.82 (0.12)

Notes *:(1) An F statistic below 10 indicates weak instruments. (2) Hausman test- Null hypothesis: OLS estimates are consistent (3) Sargan over-identification test: All instruments are valid*

The TSLS regression estimates presented in Table 5.2 do not differ significantly from the corresponding OLS estimates. The estimates of fence for example continue to exhibit a positive statistically significant coefficient. Some differences nevertheless are observed in a few cases such as labour in terms of livestock production which presents itself with a negative sign. The negative insignificant coefficient in terms of livestock production is also not very surprising because the elasticity coefficient of 0.01 as per the OLS estimate is quite small. The negative sign may also imply that labour may not be important in livestock production because in most farming households and as observed during data collection, few workers ranging from one to three are needed to take care of any number of livestock. Another possible explanation for the negative relationship may be attributed to the fact that 49 percent of households in rural Kenya depend on family labour rather than hired labour (37 percent) as shown in Table 4.6 and hence may have a lower propensity to invest in it. Furthermore, another difference observed is that the labour variable when total output is the dependent variable maintains the positive coefficient but it now becomes statistically insignificant.

The dummy variable as discussed earlier is used so that efficient estimators are obtained using the full data set without introducing any bias. This is due to the fact that the explanatory variable fence has a significant proportion of zero values. The dummy variable also allows for changes in the regression intercept and in slopes of associated variables. A test of the hypothesis that the intercepts are equal is obtained by a t-test on the coefficient of the dummy variable. As expected from the nature of the test, the intercept may be equal but the slopes are not equal. Therefore, from the dummy coefficient in Table 5.2, OLS estimates show that the null hypothesis of equal intercepts is not rejected in terms of crop, livestock and total output. On the other hand, TSLS estimates show that the null hypothesis of equal intercepts is rejected in terms of crop, livestock and total output.

It is also worth mentioning that the coefficients of the natural logarithm of capital in the TSLS regression are positive and are estimated to be about 0.1 for the outputs crops, livestock and total output. Also, something else to note is that by definition, the OLS R-squared will always be larger than that of TSLS because OLS minimises the sum of squared residuals .This definition is confirmed in all the R-squared reported for both OLS and TSLS regression in Table 5.2. The OLS estimate of the intercept in the regression model can be interpreted as the predicted value of the dependent variable when the explanatory variable equals zero.

Therefore, even though the TSLS estimates do not differ significantly from the OLS estimates, a possible implication that there may be no bias in using either IV or OLS. The fact that there is inconsistency in the validity and reliability of instruments suggests that OLS could be the best estimator when all variables land quality inclusive is considered in the production function.

5.2.1.1 Regression model without land quality variable

As observed in the earlier results (Table 5.2), land quality estimates gave results that are against economic theory. This is because a positive coefficient was expected for land quality variable. The reason for this assumption is that high quality land is expected to increase crop production. This research thus will attempt to omit land quality variable from the regression model when fence is used as a variable that measures area. The results are as shown in Table 5.4 and Table 5.5. From Table 5.4, it can be deduced that the specification without the variable land quality appears to be more robust in that all the variables especially fence the variable of interest continues to have the expected signs.

Specifically, the OLS regression estimate (Table 5.4) for fence exhibits the expected positive sign and it is statistically significant in terms of crop production and total output. However, the OLS estimate in the case of livestock production is positive but not statistically significant. Looking at it carefully, this result is not different from the OLS estimates when land quality is included in the regression model.

Table 5.4: Regression of natural log of crops, livestock and total output -TSLS and OLS regressions (Without land quality)

	Dependent variable					
	CROPS		**LIVESTOCK**		**TOTAL OUTPUT**	
Regressors:	**OLS**	**TSLS**	**OLS**	**TSLS**	**OLS**	**TSLS**
Labour	0.53***	0.51***	-0.14*	-0.20**	0.01	-0.02
(Total work hrs)	(0.06)	(0.06)	(0.08)	(0.08)	(0.04)	(0.04)
Capital	0.14	0.10	0.11	0.01	0.10	0.06
(‘000’kshs)	(0.11)	(0.11)	(0.15)	(0.16)	(0.07)	(0.08)
Land	-0.51***	-0.47***	0.95***	1.06***	0.45***	0.50***
(Acres)	(0.10)	(0.11)	(0.14)	(0.16)	(0.07)	(0.08)
Fence	0.53***	1.01***	0.08	1.29**	0.26**	0.78***
(Area)	(0.18)	(0.36)	(0.25)	(0.52)	(0.12)	(0.25)
Dummy	2.04***	3.90***	-1.72	2.92	-0.11	1.89*
	(0.76)	(1.41)	(1.07)	(2.05)	(0.53)	(0.99)
Number of observation	249	249	249	249	249	249
R-squared	0.38	0.36	0.25	0.19	0.27	0.23

Notes: *(1) Dependent variable is total value of crops, total value of livestock and total output (2)* Significant at 10% ** Significant at 5% and *** significant at 1 %(3) Standard errors in parentheses.*

This may therefore imply that it does not really matter if land quality is included in the model because the coefficients of our variable of interest, fence, obtained from the two regressions are similar.

The coefficient of labour in terms of crop production is positive and statistically significant, a result similar to that presented in Table 5.2 where land quality variable is included in the model. However, in terms of livestock production, the results change in that it exhibits a negative statistically significant coefficient. In terms of total output, the labour coefficient is positive but it is now not statistically significant.

Capital maintains the same positive coefficients a result similar to that presented in Table 5.2 except that the OLS estimate in terms of total output loses its statistical significance.

The coefficient of land now changes for the reason that as noted in Table 5.2, it is consistently positive but not significant. In this case however, the coefficients in terms of livestock and total output are positive and statistically significant implying that land has an impact on livestock production and total output. This result may also mean that farmers are likely to keep more livestock given a large area of land a result that appears to be theoretically correct. On the other hand, in terms of crop production, the coefficient of land variable is negative and statistically significant implying that land area has no impact in crop production.

From the results shown in Table 5.2 and 5.4, it can be concluded that it is better to keep the land quality variable in the regression because removing it changes the land variable in terms of crop production to a negative coefficient a result that is not theoretically correct. The resulting negative coefficient could be attributed to the poor measure of land quality. Future research should therefore consider using an agronomic measure. In Latter analysis, the land quality variable will be maintained in the regression. The instrumental variables when land quality is excluded from the model and the relevant tests are presented in Table 5.5.

Table 5.5: Instrumental variables and tests

Instrument	**Tests**	**Dependent variable**		
		CROPS	**LIVESTOCK**	**TOTAL OUTPUT**
Cost of fencing	-First stage F statistic	86.29	86.29	86.29
	-Hausman specification, $X^2(1)$	2.64	8.50	6.47
Cost of fencing + Age	-First stage F statistic	43.48	43.48	43.48
	-Hausman specification, $X^2(1)$	2.18	7.57	6.44
	-Sargan test (p-value)	1.93 (0.16)	2.36 (0.12)	0.03 (0.86)
Cost of fencing + Age + Education	-First stage F statistic	29.02	29.02	29.02
	-Hausman specification, $X^2(1)$	1.88	7.76	7.01
	-Sargan test (p-value)	4.21 (0.12)	2.48 (0.29)	1.74 (0.42)
Cost of fencing + Age + Education + Farming activity	-First stage F statistic	22.12	22.12	22.12
	-Hausman specification, $X^2(1)$	2.84	2.43	4.95
	-Sargan test (p-value)	8.32 (0.04)	73.30 (0.00)	10.50 (0.01)

***Notes:** (1) An F statistic below 10 indicates weak instruments. (2) Hausman test- Null hypothesis: OLS estimates are consistent (3) Sargan over-identification test: All instruments are valid*

From Table 5.5, the reliability and validity of instruments is similar to those observed in Table 5.3 when land quality is treated as a variable. A critical analysis of the estimates in the table reveals that all the chosen instruments also pass the first stage F statistics for weak instruments. Besides, the Wu-Hausman test for consistency of OLS estimates show that the null hypothesis of consistency of OLS estimates is rejected when livestock and total output is treated as the dependent variable but not when the dependent variable is crop output. In addition, all the sets of instruments do not clearly pass the Sargan test for over identification and validity of instruments. This is therefore another reason as to why the TSLS estimator will be rejected in favour of the OLS estimator.

The TSLS coefficient estimates are also not significantly different from OLS estimates (Table 5.4). Apart from labour in terms of total output where the TSLS coefficient changes to negative from positive, and fence variable in terms of livestock production where the TSLS estimate becomes significant, all the other estimates maintain the same coefficients and statistical significance as those of OLS. The OLS estimate of the dummy variable in terms of crop production in Table 5.4 show that the null hypothesis of equal intercepts is rejected implying that the intercepts are not equal. That of livestock and total output is not rejected implying that the intercepts are equal. On the other hand, TSLS estimates in terms of crop and total output rejects the null hypothesis of equal intercepts but that of livestock output is not rejected. Therefore, since the coefficient of fence, the variable of interest does not change in the two regressions when land quality as a variable is included and omitted in the regression (Table 5.2 and 5.4) and as mentioned earlier that omitting the land quality variable changes the sign of land coefficient, it is only reasonable to include land quality in the rest of the regressions to be undertaken in this research.

5.2.1.2 Fence as a dummy variable

It is also important to mention that Tables 5.2 and 5.4 shows the results of the specification that treats fence as a standard variable like capital and labour. Fence is also used as a variable that measures the area (Equation 3.11).It is however imperative to also consider a model that allows for a change in the slopes of associated variables. This is done by using fence as a binary dummy variable. The model is estimated by multiplying the fence dummy by the natural log of all inputs and what this implies is that other variables that take on a multiplicative effect (Equation 3.12) are introduced into the model. The results are as shown in Table 5.6

From Table 5.6, it is noted from the estimates that the slope actually changes and so it is a specification that is worth considering too. In addition, compared to the results from Table 5.2 and 5.4, OLS estimates exhibit fence, the variable of interest, as consistently having a positive coefficient. Capital also consistently presents itself with a positive coefficient. However, land quality is stubbornly giving a negative coefficient in terms of crop production and a positive coefficient in terms of livestock production but a positive significant coefficient in terms of total output except for the first regression (Table 5.2) where land quality is included in the model and fence is treated as a variable that measures area. This result implies that the two specifications, Equations 3.11 and 3.12 are not significantly different.

Table 5.6: Regression of natural log of crops, livestock and total output with multiplicative effect variables -TSLS and OLS regressions

	Dependent variable					
	CROPS		**LIVESTOCK**		**TOTAL OUTPUT**	
Regressors:	**OLS**	**TSLS**	**OLS**	**TSLS**	**OLS**	**TSLS**
Labour	0.50*** (0.06)	0.49*** (0.07)	0.10 (0.09)	0.06 (0.09)	0.12*** (0.05)	0.10** (0.05)
Capital	0.09 (0.12)	0.07 (0.13)	0.42** (0.18)	0.32* (0.18)	0.19** (0.09)	0.16* (0.09)
Land	-0.08 (0.13)	-0.06 (0.13)	0.24 (0.19)	0.30 (0.19)	0.04 (0.09)	0.06 (0.09)
Land quality	-2.49*** (0.29)	-2.48*** (0.29)	3.14*** (0.42)	3.16*** (0.42)	1.52*** (0.21)	1.53*** (0.21)
Fence	0.38 (0.24)	0.59** (0.30)	0.41 (0.34)	1.31*** (0.43)	0.46*** (0.17)	0.80*** (0.21)
Dummy*labor	-0.18* (0.10)	-0.16 (0.10)	-0.19 (0.14)	-0.10 (0.14)	-0.08 (0.07)	-0.04 (0.07)
Dummy*capital	-0.03 (0.19)	-0.00 (0.19)	-0.52* (0.27)	-0.40 (0.27)	-0.12 (0.13)	-0.08 (0.13)
Dummy*land	0.45** (0.21)	0.41* (0.22)	-0.40 (0.30)	-0.61* (0.31)	0.03 (0.15)	-0.05 (0.15)
Dummy*land quality	0.22 (0.22)	0.35 (0.25)	0.69** (0.32)	1.27*** (0.36)	0.32** (0.16)	0.54*** (0.18)
Dummy*fence	-0.05 (0.32)	-0.26 (0.36)	-0.22 (0.45)	-1.12** (0.53)	-0.19 (0.22)	-0.53** (0.26)
No. of observation	249	249	249	249	249	249
R-squared	0.53	0.53	0.41	0.40	0.42	0.41

***Notes**: (1) Dependent variable is total value of crops, total value of livestock and total output (2)* Significant at 10% ** Significant at 5% and *** significant at 1 %(3) Standard errors in parentheses.*

Even though the TSLS estimates are not significantly different from the OLS estimates in Table 5.6, the estimates in Table 5.7 nevertheless continue to confirm the decision that OLS is the best estimator for the same reasons that the reliability and validity of the instruments is not clear. For example, from Table 5.7, even though all the instruments pass the test of weak instruments, the test of consistency of OLS estimate and Sargan test is not consistent.

Table 5.7: Instrumental variables and tests

Instrument	Tests	Dependent variable		
		CROPS	**LIVESTOCK**	**TOTAL OUTPUT**
Cost of fencing	-First stage F statistic	414.68	414.68	414.68
	-Hausman specification, $X^2(1)$	1.42	13.44	7.70
Cost of fencing + Age	-First stage F statistic	209.98	209.98	209.98
	-Hausman specification, $X^2(1)$	1.43	11.02	6.81
	-Sargan test (p-value)	0.00	7.13	1.90
		(0.98)	(0.01)	(0.17)
Cost of fencing + Age + Education	-First stage F statistic	143.75	143.75	143.75
	-Hausman specification, $X^2(1)$	1.59	9.11	6.43
	-Sargan test (p-value)	0.08	10.68	2.30
		(0.97)	(0.00)	(0.32)
Cost of fencing + Age + Education + Farming activity	-First stage F statistic	107.81	107.81	107.81
	-Hausman specification, $X^2(1)$	1.75	6.10	5.88
	-Sargan test (p-value)	107.81	75.46	5.14
		(0.81)	(0.00)	(0.16)

***Notes** (1) An F statistic below 10 indicates weak instruments. (2) Hausman test- Null hypothesis: OLS estimates are consistent (3) Sargan over-identification test: All instruments are valid*

5.2.1.3 Fence as a dummy variable without land quality

Land quality is also omitted from the specification of the model that allows for a change in the slope for the reason that, as explained earlier, it is still giving theoretically incorrect results as far as the variable land quality is concerned. Table 5.8 is used to show the results.

Compared to estimates from Table 5.6 where land quality is included as a variable in the specification that allows for a change in the slope, it is noted that estimates in Table 5.8 when land quality is omitted from the specification differ in some aspects. For example, for the fence variable, the only difference from the estimates in Table 5.6 is that OLS estimates (Table 5.8) in terms of livestock production show a negative statistically insignificant coefficient. The negative sign is not a surprising result for the reasons that in real life situations, fence is supposed to keep livestock away. It can also be argued that it may prevent the movement of livestock freely, in some cases animals can be trapped in the fences and can even lead to electrocution if it is an electric fence thus leading to a reduction in quantities.

Table 5.8: Regression of natural log of crops, livestock and total output with multiplicative effect variables except land quality -TSLS and OLS regressions

	Dependent variable					
	CROPS		**LIVESTOCK**		**TOTAL OUTPUT**	
Regressors:	**OLS**	**TSLS**	**OLS**	**TSLS**	**OLS**	**TSLS**
Labour	0.57*** (0.07)	0.53*** (0.08)	-0.01 (0.10)	-0.13 (0.11)	0.06 (0.05)	0.02 (0.05)
Capital	0.13 (0.14)	0.01 (0.16)	0.25 (0.19)	-0.09 (0.22)	0.12 (0.10)	-0.02 (0.11)
Land	-0.74*** (0.12)	-0.75*** (0.12)	0.95*** (0.17)	0.94*** (0.17)	0.39*** (0.08)	0.38*** (0.08)
Fence	0.27 (0.20)	0.62** (0.29)	-0.15 (0.28)	0.81** (0.41)	0.20 (0.14)	0.58*** (0.20)
Dummy*labour	-0.07 (0.11)	0.00 (0.12)	-0.30* (0.16)	-0.10 (0.17)	-0.13* (0.08)	-0.05 (0.08)
Dummy*capital	0.02 (0.20)	0.24 (0.24)	-0.27 (0.28)	0.31 (0.34)	-0.01 (0.14)	0.23 (0.16)
Dummy*land	0.60*** (0.20)	0.66*** (0.21)	-0.08 (0.28)	0.10 (0.30)	0.18 (0.14)	0.24* (0.15)
Dummy*fence	0.09 (0.31)	-0.26 (0.37)	0.31 (0.43)	-0.63 (0.53)	0.06 (0.21)	-0.31 (0.26)
Number of observation	249	249	249	249	249	249
R-squared	0.39	0.38	0.26	0.23	0.28	0.26

Notes : *(1) Dependent variable is total value of crops, total value of livestock and total output (2)* Significant at 10% ** Significant at 5% and *** significant at 1 %(3) Standard errors in parentheses.*

The positive sign in terms of crop production depicted in both the specifications (Table 5.6 and 5.8) is a sensible result in that as already mentioned, a fence is supposed to keep intruders away and if this objective is attained, it is expected that quantities will increase. Otherwise generally, the variable of interest fence continues to exhibit a positive relationship in terms of total output as expected.

Labour exhibits a negative coefficient a complete opposite of the result observed when land quality is included in the model that changes the slope .Capital consistently maintains a positive coefficient. Land maintains the same coefficients as those presented in Table 5.6 except that in this setting where land quality is omitted; all the coefficients turn out to be statistically significant.

The TSLS estimates are not very different from the OLS estimates except for capital where the TSLS estimate becomes negative in terms of livestock production and total output. Also, the TSLS estimate for fence coefficient in terms of livestock production becomes positive and statistically significant.

Table 5.9: Instrumental variables and tests

Instrument	**Tests**	**Dependent variable**		
		CROPS	**LIVESTOCK**	**TOTAL OUTPUT**
Cost of fencing	-First stage F statistic	222.35	222.35	222.35
	-Hausman specification, $X^2(1)$	3.14	11.90	7.50
Cost of fencing + Age	-First stage F statistic	124.37	124.37	124.37
	-Hausman specification, $X^2(1)$	1.47	9.21	7.40
	-Sargan test (p-value)	3.46 (0.06)	2.73 (0.10)	0.25 (0.61)
Cost of fencing + Age + Education	-First stage F statistic	82.65	82.65	82.65
	-Hausman specification, $X^2(1)$	1.37	9.32	7.67
	-Sargan test (p-value)	5.51 (0.06)	2.98 (0.23)	2.35 (0.31)
Cost of fencing + Age + Education + Farming activity	-First stage F statistic	62.21	62.21	62.21
	-Hausman specification, $X^2(1)$	0.89	14.80	9.14
	-Sargan test (p-value)	12.15 (0.01)	67.27 (0.00)	8.98 (0.03)

Notes : *(1) An F statistic below 10 indicates weak instruments. (2) Hausman test- Null hypothesis: OLS estimates are consistent (3) Sargan over-identification test: All instruments are valid*

Just like in earlier analysis, it is noted in Table 5.9 that even though all the instruments appear to be strong, almost all of them do not pass the Sargan test of validity of instruments a result that further confirms our conclusion that OLS is the best estimator. Thus, all the analysis in the next sub-sections will be purely based on OLS estimates given the finding that all the models earlier discussed have confirmed that OLS is the best estimator.

5.2.2 Fence and various sets of regressors

It is also important to observe the behaviour of fence coefficient given various sets of regressors. Table 5.10-5.12 summarises the results of OLS regressions in terms of livestock production, crop production and total output on various sets of regressors. Each column summarises a separate regression. Each regression has the same dependent variable, total value of livestock output, total value of crop output and total output respectively. The entries in the first six rows are the estimated regression coefficients with their standard errors below them in parentheses. Regressions that include the control variables are reported in columns (2)-(5). An F-test with the null hypothesis that all coefficients are equal to zero was done on all specifications and this was rejected implying that the model chosen does not perform poorly.

Table 5.10: Results of OLS regression of total value of livestock on fence and control variables

Regressor	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Fence	-0.23	-0.17	-0.21	0.08	0.27
	(0.27)	(0.28)	(0.27)	(0.25)	(0.23)
Dummy	-3.28***	-3.12***	-3.16***	-1.72	-0.43
	(1.13)	(1.14)	(1.14)	(1.07)	(0.98)
Labour		-0.11	-0.12	-0.14*	0.01
		(0.08)	(0.08)	(0.08)	(0.07)
Capital			0.16	0.11	0.19
			(0.16)	(0.15)	(0.13)
Land				0.95***	0.15
				(0.14)	(0.17)
Land quality					3.21***
					(0.42)
Intercept	5.19***	5.53***	5.05***	2.19*	-16.60***
	(1.14)	(1.16)	(1.26)	(1.24)	(2.73)
R-squared	0.10	0.11	0.11	0.26	0.39
No. of observations	249	249	249	249	249
F-statistics and p-values	28.82 (0.00)	37.62 (0.00)	55.71 (0.00)	57.11 (0.00)	25.78 (0.00)

***Notes**: (1) Dependent variable is total value of livestock (2)* Significant at 10% ** Significant at 5% and *** significant at 1 %(3) Standard errors in parentheses.*

It is noted from Table 5.10 that controlling for the other inputs fundamentally changes the effect of fence on output in terms of livestock production in that for model (4) and (5) for example, when control variables land and land quality are included in the regression, the coefficient of fence changes the sign to positive from negative. We can thus conclude that land and land quality variable play a big role in determining the positive coefficient of fence. The fact that land and land quality changes the fence coefficient from negative to positive also means that the estimated effect is sensitive to which specific control variables are included in the regression even though in all cases they remain statistically insignificant. Specification (1) to (3) may however be deemed to be incredible. Fencing land however only explains a small fraction of the variation in output. The R-squared jumps, however, when the other inputs in production are added.

For example, the R-squared in model (1) is 0.10 but 0.39 in model (5). This is the same also as shown in Table 5.11 and 5.12. Table 5.11 shows that controlling for the other inputs reduces the effect of fence on crop production by a small magnitude. In addition, this estimated effect is not very sensitive to which specific control variables are included in the regression. In all cases, the coefficient on fence remains statistically significant at 1 percent and 5 percent level. In all the specifications, it appears that fence has an impact on crop production.

Table 5.11: Results of regression of total value of crops on fence and control variables

Regressor	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Fence	0.98** (0.21)	0.71*** (0.19)	0.69*** (0.19)	0.53*** (0.06)	0.39** (0.16)
Dummy	3.64*** (0.89)	2.85*** (0.78)	2.82*** (0.78)	2.04*** (0.76)	1.08 (0.69)
Labour		0.52*** (0.06)	0.52*** (0.06)	0.53*** (0.06)	0.42*** (0.05)
Capital			0.11 (0.11)	0.14 (0.11)	0.08 (0.09)
Land				-0.51*** (0.10)	0.08 (0.12)
Land quality					-2.38*** (0.30)
Intercept	-2.44*** (0.90)	-4.07*** (0.80)	-4.39*** (0.86)	-2.85*** (0.88)	11.10*** (1.91)
R-squared	0.08	0.31	0.31	0.26	0.51
No. of observations	249	249	249	249	249
F-statistics and p-values	52.57 (0.00)	32.44 (0.00)	47.97 (0.00)	63.84 (0.00)	41.81 (0.00)

***Notes**: (1) Dependent variable is total value of crops (2)* Significant at 10% ** Significant at 5% and *** significant at 1 %(3) Standard errors in parentheses.*

It is also shown in Table 5.12 that controlling for the other inputs maintains the same positive effect of fence on total output. An important difference however is that in models (4) and (5), the effect is statistically significant at 5 percent and 1 percent respectively. In all cases nevertheless, it appears that fence has an impact on total output.

It can therefore be concluded in this section that fence consistently exhibited a positive coefficient in three out of the four regressions attempted. From this evidence therefore, it can be said that fence improves agricultural production. Capital also consistently presented itself with a positive coefficient and thus the conclusion that capital is important in agricultural production. Labour gave inconsistent results in that it presented different coefficients in the different models. One model in which land quality was included as a variable and fence was used as a variable which measures fence (Table 5.2) gave positive statistically insignificant coefficients for fence. The other regressions consistently showed a negative coefficient in terms of crop production but positive coefficient in terms of livestock production and total output.

Table 5.12: Results of regression of total output on fence and control variables

Regressor	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Fence	0.16 (0.13)	0.15 (0.13)	0.12 (0.13)	0.26** (0.12)	0.35*** (0.11)
Dummy	-0.73 (0.55)	-0.77 (0.56)	-0.80 (0.56)	-0.11 (0.53)	0.52 (0.48)
Labour		0.03 (0.04)	0.02 (0.04)	0.01 (0.06)	0.08** (0.04)
Capital			0.13* (0.08)	0.11 (0.07)	0.15** (0.07)
Land				0.45** (0.07)	0.06 (0.08)
Land quality					1.57*** (0.21)
Intercept	4.73*** (0.56)	4.65*** (0.57)	4.26*** (0.62)	2.89*** (0.61)	-6.31*** (1.34)
R-squared	0.13	0.13	0.14	0.27	0.41
No. of observations	249	249	249	249	249
F-statistics and p-values	28.15 (0.00)	37.35 (0.00)	54.05 (0.00)	56.54 (0.00)	27.56 (0.00)

***Notes**: (1) Dependent variable is aggregated total output (2)* Significant at 10% ** Significant at 5% and *** significant at 1 %(3) Standard errors in parentheses.*

5.3 Empirical analysis and results at the regional level

One specification, the Equation 3.11 earlier written in chapter 3 as:

$$\ln Q = \alpha_0 + (\beta_0 - \alpha_0)D_i + \alpha_1 \ln K_i + \alpha_2 \ln L_i + \alpha_3 \ln N_i + \alpha_4 \ln LQ_i + \alpha_5 \ln F_i + \ln \varepsilon_i, i = 1,2,..., n$$

is chosen in analysing the regional results. This is because the coefficient on the variable of interest fence does not change given the different specifications and it is consistently positive when the whole sample is considered. This result implies that the specification chosen may not matter. However, the model with land quality variable as shown in the equation is the most preferred because omitting it as shown in the results in Table 5.4 changes the coefficient of land to negative. It is expected that a larger land area will increase agricultural production. Table 5.13 is used to show the OLS results of Mwala District

5.3.1-Mwala District

Estimates of the impacts of variable of interest in this research, fence, suggest a consistently statistically significant positive association in terms of livestock production, crop production and even when data is aggregated. This result implies that fence has a significant impact on output in Mwala district (Table 5.13).

Other independent variables labour, capital, land and land quality are also useful in both crop and livestock production. There is however a negative statistically insignificant association between labour and output in terms of crop production, livestock production and also when output is aggregated. This finding implies that labour has no impact in Mwala and that hiring more labour may lead to diminishing returns. This negative relationship could also be explained by the fact that the most used form of labour is family labour (Table 4.18). In Mwala district family labour accounts for about 60 percent as shown in Table 4.18.Land quality in terms of crop production is positive but statistically insignificant.

However, the coefficient of land quality in terms of livestock production is negative. This result is sensible in that some types of livestock thrive in low quality land. Mwala is generally a semi-arid land and it was observed during data collection that households do not keep large numbers of livestock.

The aggregated output however shows that generally, land quality has a negative association with output in Mwala. However, land area exhibit a negative statistically insignificant relationship in terms of output. Capital exhibits a positive association in terms of crop production but a negative relationship in terms of livestock production. The aggregated output however exhibits a positive coefficient. Moreover, the dummy variable coefficient in terms of crop and total output in Mwala district shows that the null hypothesis of equal intercepts is rejected unlike that of livestock which is not rejected.

Table 5.13: OLS results for the regression on total value of livestock, total value of crop output and aggregated output – Mwala District

	Dependent variable		
Regressors:	**CROPS**	**LIVESTOCK**	**TOTAL OUTPUT**
Labour	-0.03	-0.31	-0.06
(Total work hours)	(0.12)	(0.22)	(0.10)
Capital	0.03	-0.07	0.05
(‘000’kshs)	(0.14)	(0.26)	(0.11)
Land	-0.23	-0.01	-0.10
(Acres)	(0.14)	(0.26)	(0.11)
Land quality	1.27	-8.58**	-1.49
(Price)	(2.36)	(4.22)	(1.85)
Fence	1.12***	1.62**	1.16***
(area)	(0 .39)	(0.70)	(0.30)
Dummy	3.76**	3.74	3.58***
	(1.68)	(3.00)	(1.31)
Number of observation	50	50	50
R-squared	0.37	0.42	0.53

***Notes**: (1)Dependent variable is total value of crops, total value of livestock and total output. (2)* Significant at 10% ** Significant at 5% and *** significant at 1 %(3) Standard errors in parentheses*

5.3.2-Narok North district

The OLS estimates in Table 5.14 suggest a negative and statistically insignificant association between fence and crop production but a positive insignificant relationship in terms of livestock production and when data is aggregated.

Table5.14: OLS results for the regression on total value of livestock, total value of crop output and aggregated output – Narok North District

	Dependent variable		
Regressors:	**CROPS**	**LIVESTOCK**	**TOTAL OUTPUT**
Labour (Total work hours)	0.45*** (0.16)	-0.06 (0.09)	-0.04 (0.09)
Capital ('000'kshs)	-0.26 (0.32)	-0.12 (0.18)	-0.12 (0.18)
Land (Acres)	-0.68 (0.52)	-0.02 (0.30)	-0.04 (0.30)
Land quality (Price)	0.08 (2.52)	-1.03 (1.45)	-1.05 (1.44)
Fence (Area)	-1.21 (1.13)	0.14 (0.65)	0.08 (0.65)
Dummy	-6.29** (4.92)	-1.51** (2.84)	-1.79 (2.82)
Number of observation R-squared	50 0.32	50 0.31	50 0.32

***Notes**: (1) Dependent variable is total value of crops, total value of livestock and total output. (2)* Significant at 10% ** Significant at 5% and *** significant at 1 %(3) Standard errors in parentheses*

This appears to be a sensible result in that Narok district is predominantly occupied by a pastoralist community the Masai who move from one place to the other in search of pasture. A household in Narok for example keeps an average of about 89 cows, 71 goats and 142 sheep. Moreover, the fact that fence has no impact in terms of crop production could be because during data collection, farmers reported that they had experienced drought in the last harvest season and it was observed that most of them either did not harvest or if they did, it was in very small quantities.

As far as labour is concerned, the estimates exhibit a positive and statistically significant association between labour and output in terms of crop production but a negative statistically insignificant relationship in terms of livestock production. Capital as a factor of production also exhibit negative signs in terms of crop, livestock and aggregated output. Land size exhibits an insignificant negative association in terms of crop, livestock and aggregated output as well. The estimates also suggest a positive association between land quality and crop output a result that makes sense theoretically and from the assumptions considered in this study that high value land proxied by price improves output unlike land of low value. However land quality in terms of livestock production exhibit a negative sign a result that may also make sense theoretically. The dummy variable coefficient in terms of crop and livestock output in Narok district shows that the null hypothesis of equal intercepts is rejected but that of total output is not rejected.

5.3.3 Koibatek district

OLS estimates (Table 5.15) show a positive insignificant association between fence and output in Koibatek district. The coefficient in terms of livestock is larger than that of crops and aggregate output. The regression estimates also show a statistically insignificant relationship between labour and livestock production but a statistically significant positive association in terms of crop production and when data is aggregated.

Table 5.15: OLS results for the regression on total value of livestock, total value of crop output and aggregated output – Koibatek District

	Dependent variable		
Regressors:	**CROPS**	**LIVESTOCK**	**TOTAL OUTPUT**
Labour (Total work hours)	0.05 (0.12)	0.15** (0.07)	0.18*** (0.06)
Capital (‘000’kshs)	0.15 (0.15)	0.02 (0.08)	0.04 (0.08)
Land (Acres)	-0.14 (0.19)	0.08 (0.11)	0.04 (0.10)
Land quality (Price)	1.43 (4.59)	0.13 (2.57)	-0.12 (2.43)
Fence (Area)	0.00 (0.80)	0.76 (0.45)	0.66 (0.43)
Dummy	-0.67 (3.30)	3.13* (1.85)	2.68 (1.75)
Number of observation	50	50	50
R-squared	0.04	0.18	0.20

***Notes**: (1) Dependent variable is total value of crops, total value of livestock and total output (2)* Significant at 10% ** Significant at 5% and *** significant at 1 % (3) Standard errors in parentheses*

Capital also exhibits a positive association in terms of crop, livestock production and aggregated output. The estimates also suggest a negative relationship between land size and output in terms of crop production but a positive association in terms of livestock production and when data is aggregated. Land quality presents itself with a positive sign in terms of crop and livestock production but it is statistically insignificant. The result implies that land quality is important in determining crop and livestock output in Koibatek district. Furthermore, the dummy variable coefficient in terms of crop and total output indicates that the null hypothesis of equal intercepts is not rejected while that of livestock output is rejected.

5.3.4 Suba district

The variable of interest fence exhibit a statistically insignificant negative association between fence and livestock output in Suba district (Table 5.16).This may be because in Mbita, households do not own huge pieces of land and population has been growing. Evidence from Mbita also shows that the mean number of cows and goats is 5 and 9 respectively as compared to other semi-arid areas such as Koibatek. In Koibatek, each household owns an average of about 8 and 13 cows and goats respectively. Also in this part of the country, livestock are enclosed in a house rather than a fenced area and this may explain the negative relationship. It could also be argued that households do not practice much of livestock farming in that it is a predominantly fishing community. However, in terms of crop output, OLS estimates suggest a positive association between fence and crop output and this is because fence helps in preventing intrusion from livestock and human beings.

Moreover, the estimates further suggest a statistically negative relationship between labour and output in terms of both crop and livestock production. Capital exhibits a statistically insignificant positive association. Land size and land quality exhibits a negative coefficient in terms of both crop and livestock production. Also, the dummy variable coefficient in terms of crop output indicates that the null hypothesis of equal intercepts is rejected while that of livestock and total output is not rejected.

Table 5.16: OLS results for the regression on total value of livestock, total value of crop output and aggregated output – Suba District

	Dependent variable		
Regressors:	**Crops OLS**	**Livestock OLS**	**Total output OLS**
Labour	-0.55**	-0.51**	-0.09
(Total work hours)	(0.23)	(0.21)	(0.07)
Capital	0.43	0.51	0.06
(‘000’kshs)	(0.38)	(0.35)	(0.11)
Land	-0.63	-0.50	-0.18
(Acres)	(0.87)	(0.86)	(0.26)
Land quality	-4.79	-16.19*	-6.53**
(Price)	(3.66)	(9.27)	(2.87)
Fence	0.09	-0.28**	0.01
(Area)	(0.17)	(0.43)	(0.13)
Dummy	-0.59**	0.11	-0.46
	(0.68)	(1.73)	(0.54)
Number of observation	50	50	50
R-squared	0.66	0.24	0.23

Notes : *(1) Dependent variable is total value of crops, total value of livestock and total output. (2)* Significant at 10% ** Significant at 5% and *** significant at 1 % (3) Standard errors in parentheses*

5.3.5-Taita Taveta district

Fence exhibit a statistically insignificant negative relationship in terms of crop production but a positive relationship in terms of livestock production (Table 5.17). The descriptive statistics in Table 4.15 show that only 29 percent of all the households interviewed had title deeds as compared to 94, 88, 98 and 60 percent in Mwala, Narok, Koibatek and Suba respectively. In Taita Taveta, it was noted that most households interviewed were squatters and this may explain the low percentage of households with title deeds.

Labour exhibits a statistically insignificant positive sign and this may be because family labour is the most used form of labour. Capital exhibits a positive relationship in terms of crop production but a negative relationship in terms of livestock production a result that appears to be theoretically correct. Land size exhibits a positive relationship in terms of crop production but a negative relationship in terms of livestock production.

Table 5.17: OLS results for the regression on total value of livestock, total value of crop output and aggregated output – Taita Taveta District

	Dependent variable		
Regressors:	**Crops**	**Livestock**	**Total output**
Labour (Total work hours)	0.13 (0.09)	0.23 (0.16)	0.19** (0.09)
Capital (‘000’kshs)	0.44* (0.25)	-0.12 (0.42)	0.28 (0.23)
Land (Acres)	0.11 (0.26)	-0.64 (0.42)	-0.14 (0.23)
Land quality (Price)	1.88 (3.82)	1.81 (6.31)	0.05 (3.46)
Fence (Area)	-0.09 (0.69)	0.36 (1.14)	0.22 (0.62)
Dummy	-1.36 (3.42)	-1.43 (5.66)	-0.13 (3.11)
Number of observation	49	49	49
R-squared	0.26	0.31	0.31

Notes : *(1) Dependent variable is total value of crops, total value of livestock and total output. (2)* Significant at 10% ** Significant at 5% and *** significant at 1 %(3) Standard errors in parentheses*

Land quality suggests a positive relationship in terms of livestock and crop output and also when data is aggregated.

The dummy variable coefficient in terms of crop, livestock and total output show that the null hypothesis of equal intercepts is not rejected.

5.4 Conclusion

In this chapter, at the aggregate level, OLS estimates show that fence has got an impact in improving output when the dependent variable is either crop or total output. However, it could be argued that the owners of more fertile or productive land use more fencing. This assumption of reverse causality is not considered in this study for the reason that as discussed in the introductory chapter, Kenya’s population just like in many other parts of the world is increasing exponentially. Therefore, due to scarcity of land in the productive areas which is only 20 percent of the total land area, people are now moving into semi arid lands that were initially meant for government activities such as wildlife conservation. Besides, most cultural practices require that a man must move out of his father’s home and settle elsewhere. Moreover, communities such as the Masai predominantly known for pastoralism are now shifting into agriculture in the same semi-arid lands. Therefore, from this background, it is true that people are settling here due to increasing population and changing traditional and cultural practices and not necessarily because the land is fertile.

The coefficient of livestock output is positive but it is not statistically significant. All the other inputs also have the expected positive signs in terms of total output. To investigate whether there is an endogeneity problem, IV technique is used and at the aggregate level, TSLS results show that cost of fencing land, age and education level of household head and the farming activity undertaken by households all may influence the decision by households to fence especially when the dependent variable is total output. The validity and reliability of instruments is not clear when the dependent variable is either crop or livestock production. At the regional level, only OLS estimates are used .A further observation is that when other inputs such as land, labour, capital and land quality are controlled for, fence is highly significant and hence the general conclusion of a positive relationship between fence and agricultural output. On the other hand, at the regional level, it is concluded that all the regions attested to the fact that since fencing land, output and plant cover in terms of trees and shrubs improved. Just like in the whole sample results, those who had a title deed in the different regions had also fenced their land. Moreover, OLS estimates show that the impact of fence in the different regions studied does not differ significantly. The difference observed however could be attributed to changes in traditional and cultural practices and different ecological conditions in that the data was collected from 5 different regions as shown in figures 1.3, 1.4, 1.5, 1.6 and 1.7.

Therefore, despite the complexity of the results, it can generally be concluded from the various regressions undertaken in this chapter that fencing enhances agricultural output.

CHAPTER 6
STOCHASTIC FRONTIER AND DATA ENVELOPMENT ANALYSIS

6.1 Preamble

The two main approaches for estimating technical efficiency are the parametric stochastic frontier analysis (SFA) and non-parametric data envelopment analysis (DEA)[12]. The two approaches have been extensively discussed in the methodology chapter of this thesis. Parametric methods involve specification of a particular functional form and the estimation criteria have the common statistical properties if the models are correctly specified. These properties however depend on the assumed model specification. Non-parametric methods on the other hand do not have this requirement and for this reason, researchers have explored mathematical programming procedures like DEA to avoid model specification problems (Miller, 2007). DEA and SFA techniques are thus used in this chapter and the major aim is to show the extent to which fencing improves the efficiency of farms. SFA gives the maximum likelihood estimates (MLE) and again, because it is not really known what the best model is, both OLS and MLE results obtained from the program FRONTIER 4.1 will be reported for comparison purposes with those obtained and discussed earlier in chapter 5 obtained from the program GRETL. Of course one can argue that technical efficiency estimates can also be obtained from the residuals of OLS estimates. However, SFA is chosen because besides it being a widely used method of measuring frontiers and that the efficiency estimates obtained are comparable to those obtained from DEA (Theodoridis *et al.,* 2008), it also has an advantage for the reason that stochastic estimations incorporate a measure of random error and therefore the output of a firm will be a function of a set of inputs, inefficiency and random error a characteristic that OLS does not have. Also, the choice of using the stochastic frontiers method on the one hand is made on the basis of the variability of agricultural production which is attributed to

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[12] See chapter 3, section 3.5.1 and 3.52 for a detailed explanation of the theoretical aspects of both SFA and DEA.

weather and insect pests. On the other hand, sometimes information gathered on production is usually inaccurate since small farmers do not have updated data on their farm operations (Nchare,2007).In addition in this chapter, measures of technical efficiency obtained from the two techniques with the use of data from 249 farms from semi-arid Kenya are compared. Besides, various statistical tests are carried out to ascertain if there are any significant differences in the estimates of efficiency when the two techniques are used. Analysis of data using DEA and SFA in this chapter makes a significant contribution to the existing literature on farm efficiency. The parametric model is estimated under the specification of the Cobb-Douglas (CD) stochastic frontier production model. In the DEA analysis, the output-oriented frontiers are estimated under the specifications of constant returns to scale (CRS) and variable returns to scale (VRS).

6.2 Stochastic frontier analytical framework

The stochastic frontier production function has received prominence in econometrics and applied economic analysis over the years (Ojo, 2003). It has been applied in a large number of empirical studies to account for the existence of technical inefficiencies of production (Battese *et al.*, 1996b). Early applications of stochastic frontier production to economic analysis include those of Aigner *et al.* (1977), Meeusen et *al.* (1977) and Battese *et al.* (1977). The original specification of the stochastic frontier production involved a production function specified for cross-sectional data which had an error term which had two components, one to account for random effects and another to account for technical inefficiency (Coelli, 1996). Other researchers such as Battese *et al*. (1993; 1996), Ahmad *et al.* (2002), Ajibefun *et al.* (1999) and Ojo (2003) have recently reported empirical applications of the technique in efficiency analysis. The stochastic frontier production function to be estimated is written as;

$$\ln Q = \alpha_0 + (\beta_0 - \alpha_0)D_i + \alpha_1 \ln K_i + \alpha_2 \ln L_i + \alpha_3 \ln N_i + \alpha_4 \ln LQ_i + \alpha_5 \ln F_i + V_i - U_i$$

i=1,2,…, n

(6.1)

where: the subscripts *i* refer to the *i*-th farm

ln	denotes the natural logarithm
D	is a dummy variable equal to one if there is no fence and zero if the value of fence was positive(D=1 if F=0 and D=0 if F>0)
Q	represents the value of output (in Kshs)
K	represents the value of physical capital available for use in farming activity in Kshs
L	represents total work hours by family members and hired labourers in crop and livestock farming
N	represents the total area of land on which farming is carried out (in acres)
LQ	represents land quality proxied by price of land
F	represents the area of fenced homestead in square meters.

$V_i s$ are assumed to be independent and identically distributed normal random variables with mean zero and variance σ_v^2, independently distributed of U_i. $U_i s$ are non-negative technical inefficiency effects, which are assumed to be independently distributed with variance, σ^2, and mean, μ (Battese *et al.*,1996b). It is important to note here again that the dummy variable, D is used to solve the zero problem observed in farms without fence as discussed in the methodology, chapter 3.

The stochastic frontier production function model is therefore estimated using the maximum likelihood estimation procedure (Ojo, 2003; Ajibefun *et al.*, 1999). The MLE for the parameters are obtained by using FRONTIER 4.1 a computer program written by Tim Coelli of University of New England, Australia. It has been used extensively by various authors in estimating technical efficiency among farmers. FRONTIER 4.1 obtains the variance parameters γ and σ^2 besides the technical efficiencies of each farm.

6.3 Stochastic frontier results

The estimation of the Cobb-Douglas stochastic production function, Equation 6.1, generates the maximum likelihood estimates reported in Tables 6.1 to 6.3. Specifically, in these tables, the coefficients of the estimated variables, their t-ratios and the variance of the parameters are presented. OLS estimates are also presented for comparison purposes and it is worth noting that the estimates are similar to those obtained using the program GRETL under the OLS estimator in chapter 5 section 5.2.1.The technical efficiency estimates of each farm will be compared in the next section 6.4 with those obtained from DEA.

Finding out whether any form of stochastic frontier production is required at all can be done by testing the significance of the **γ** parameter (Coelli, 1994).The variance parameter $\gamma = \sigma_u^2 / \sigma_\varepsilon^2$ must lie between 0 and 1 with a value equal to zero implying that technical inefficiency is not present and the ordinary least square estimation would be an adequate representation and a value close or equal to one implying that the frontier model is appropriate [13](Chirwa, 2007; Piesse and Thirtle, 2000). A value equal or close to one also implies that the traditional average production function is not an adequate representation of the data and hence, technical inefficiency effects have significant impact on output.

Table 6.1 is used to show the MLE and OLS estimates of the total output in terms of crop and livestock production taken together. It is clear from the table that the estimate of **γ**=0.607 is statistically significant at the 1 percent level. Therefore, the null hypothesis of no technical inefficiency is rejected. This implies that about 61 percent of the residual variation is due to the inefficiency effect a clear indication that there is statistically significant inefficiency in the data. This result is consistent with that of Wadud, *et al.* (2000), Sharma *et al.* (1997) and Ajibefun *et al.* (1996). The value of, γ, also indicates the portion of the one-sided error component in the total variance and that about 61 percent of variation in the data between farms can be attributed to inefficiency and the remaining 39 percent is pure noise (Theodoridis *et al.*, 2010). This result also implies that technical inefficiency is likely to have an important effect in explaining output variability among farmers in the sample. Moreover, the results are consistent with the conclusion that the true **γ** value must be greater than zero and hence the stochastic frontier model is different from the deterministic frontier, in which there are random errors in the production function (Serrao, 2003). Sigma square (σ^2) from the

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[13] If the null hypothesis that **γ** equals zero, is accepted, this would indicate that σ_u^2 is zero and hence U_i should be removed from the model, leaving a specification with parameters that can be consistently estimated using ordinary least squares(Coelli,1994).

MLE is also statistically significant and different from zero at the alpha level 0.01. This indicates a good fit and the correctness of the specified distributed assumption of the composite error term (Udoh, 2005).

All the coefficients of the inputs in the production function are positive and statistically significant as expected except land which has a positive coefficient but is statistically insignificant**.** Labour and capital are significant at the 5 percent level and land quality and fence the variable of interest are significant at the 1 percent level. Fence elasticity in terms of crop and livestock production (total output) is also estimated to be 0.35. Therefore, the positive coefficient and statistical significance of fence variable implies that fence has an impact in total output. This result also can be interpreted to mean as fenced area increases, output in terms of crop and livestock improves as well.

The elasticity of output for labour, capital, land, land quality and fence and returns to scale elasticity of the CD production function model are presented in Table 6.1.The elasticity of output for land quality, among all the other output elasticity, is the highest which shows that land quality as an input has major influence on output followed by fence. A returns to scale elasticity, which is found to be statistically significantly different from unity is 2.23, implying that the farms operate under increasing returns to scale (IRS), a finding which is similar to that of many other researchers such as Theodoridis *et al.* (2010).

Table 6.1: Ordinary least squares (OLS) and maximum- likelihood estimates (MLE) of the Cobb-Douglas stochastic production frontier model (Total output)

		OLS		**MLE**	
Name of Variables	**Parameters**	**Coefficients**	**t-ratios**	**Coefficients**	**t-ratios**
Constant	β_0	-6.376 (1.344)	-4.745***	-5.319 (1.323)	-4.022***
Labour	β_1	0.080 (0.036)	2.224**	0.065 (0.036)	1.814**
Capital	β_2	0.145 (0.066)	2.188**	0.135 (0.063)	2.133**
Land	β_3	0.061 (0.082)	0.749	0 .051 (0.081)	0.630
Land Quality	β_4	1.584 (0.210)	7.557***	1.608 (0.206)	7.789***
Dummy	β_5	0.521 (0.482)	1.081	0.607 (0.471)	1.289
Fence	β_6	0.353 (0.113)	3.113***	0.355 (0.110)	3.239***
Sigma-squared	$\sigma_\varepsilon^2 = \sigma_u^2 + \sigma_v^2$	1.936		3.071 (0.730)	4.209***
Gamma	$\gamma = \sigma_u^2 / \sigma_\varepsilon^2$			0.607 (0.197)	3.090***
Sigma-squared of u	σ_u^2			1.864	
Sigma-squared of v	σ_v^2			1.207	
log likelihood		-431.985		-431.148	
Returns to scale (RTS)		2.22		2.23	
Number of farms		249		249	

***Note** :(i) ***Statistically significant at the 1% level (ii)** Statistically significant at the 5% level (iii)* Statistically significant at the 10% level (iv)Figures in parentheses indicate standard errors*

Table 6.2 is used to show the OLS and MLE estimates of livestock production. The estimate of γ=0.982 is statistically significant at the 1 percent level and this implies that about 98 percent of the residual variation is due to the inefficiency effect. The value of, γ, also indicates the portion of the one-sided error component in the total variance and that about 98 percent of variation in the data between farms can be attributed to inefficiency and the remaining 2 percent is pure noise.

Table 6.2: Ordinary least squares (OLS) and maximum- likelihood estimates (MLE) of the Cobb-Douglas stochastic production frontier model (livestock production)

		OLS		MLE	
Name of Variables	**Parameters**	**Coefficients**	**t-ratios**	**Coefficients**	**t-ratios**
Constant	β_0	-16.704 (2.732)	-6.114***	-8.338 (1.866)	-4.469***
Labour	β_1	0.009 (0.073)	0.117	0.006 (0.040)	0.152
Capital	β_2	0.189 (0.135)	1.401	0.155 (0.080)	1.943**
Land	β_3	0.146 (0.166)	0.878	-0 .076 (0.134)	-0.570
Land Quality	β_4	3.229 (0.426)	7.578***	2.496 (0.317)	7.872***
Dummy	β_5	-0.430 (0.980)	-0.439	0.167 (0.553)	0.301
Fence	β_6	0.275 (0.230)	1.194	0.200 (0.122)	1.634
Sigma-squared	$\sigma_\varepsilon^2 = \sigma_u^2 + \sigma_v^2$	7.998		21.184 (2.185)	9.693***
Gamma	$\gamma = \sigma_u^2 / \sigma_\varepsilon^2$			0.982 (0.009)	112.327***
Sigma-squared of u	σ_u^2			20.802	
Sigma-squared of v	σ_v^2			0.381	
log likelihood		-608.626		-584.689	
Returns to scale (RTS)		3.86		2.79	
Number of farms		249		249	

***Note** (i) *** Statistically significant at the 1% level (ii)** Statistically significant at the 5% level (iii)*statistically significant at the 10% level (iv)Figures in parentheses indicate standard errors*

This result also implies that technical inefficiency is likely to have an important effect in explaining livestock output variability among farmers in the sample. The estimated parameter γ is also found to be statistically significant at the 1 percent level and this suggests that a conventional production function is not an adequate representation of the data. This result which is consistent with those of many researchers such as Theodoridis *et al*. (2008), Wadud *et al.* (2000) and Sharma *et al.* (1997) suggests that a conventional production function is not an adequate representation of the data. σ_{ε}^{2} (21.184) from the

MLE is also statistically significant and different from zero at the alpha level 0.01 indicating a good fit and the correctness of the specified distributed assumption of the composite error term as that in total output in terms of crop and livestock production.

Only capital and land quality are statistically significant at 5 percent and 1 percent respectively. Land, labour and fence have the expected signs but they are not statistically significant. However, the sign of the land variable changes to negative. Compared to the corresponding OLS estimates, it can be said that the MLE model is better from the fact that the parameter γ is statistically significant at the 1 percent level suggesting that a conventional production function that only presents OLS estimates is not an adequate representation of the data. Moreover, the value of the elasticity of scale, which is found to be statistically significantly different from unity is 2.79, implying that livestock farms operate under IRS.

Table 6.3 is likewise used to show the OLS and MLE estimates of crop production. The estimate of $\boldsymbol{\gamma}$=0.000 is not statistically significant and this implies that the crop farms are efficient and that technical inefficiency is likely not to have an important effect in explaining crop output variability among farmers in the sample. This result is contrary to what was expected. However, the paradox could be explained by Schultz's hypothesis of "efficient but poor" as widely revisited and discussed by various researchers in trying to understand developing country agriculture. Shultz as per the authors argued that farmers in developing countries are "efficient but poor" meaning that they make efficient use of their resources (Ball *et al.*, 1996; Abler *et al.*, 2006).Ball *et al.* 1996 however challenged the hypothesis but Abler *et al.* (2006) accepted it. The finding in this research that crop farms appear to be efficient strongly agrees with Schultz hypothesis and the arguments by Abler *et al.* (2006) that farmers in the developing world are experts within their own domain and that they learn how to allocate the resources at their disposal in a market that is consistent with their own interests. For example, the farmer before making any purchases calculates with care what he needs and acts accordingly (Ball *et al.*, 1996).However, as Ball *et al.* (1996) asserts, this is only possible if it is assumed that the physical and economic environment and also preferences have been stable for long enough such that farmers have arrived at an equilibrium in which they optimise at the margins in their resource allocation and investment decisions.

Other studies that have supported Shultz's hypothesis include that of Okon *et al*. (2010) who looked at technical efficiency and its determinants in garden egg production in Nigeria. Arindam *et al*. (2011) on the other hand in a study based on data envelopment analysis found that farmers are moderately efficient in the choice of inputs in rural India. Others such as Ogundari *et al*. (2006) in their study on small scale maize production used a stochastic frontier cost function and their results support the hypothesis that even though farmers are relatively poor, they are relatively efficient in their allocation of resources. Earlier researchers such as Nerlove (1956) claimed that farmers predict the price they expect to prevail in the coming year in proportion to the error they made in predicting price this period. This statement supports an earlier statement in the text that farmers in the developing world are experts within their own domain and that they learn how to allocate the resources with care.

Moreover, the finding of efficient crop farms can further be supported by the fact that most households fence their land to keep away livestock from crop farms and hence they end up producing on the frontier. Therefore, in terms of crop production, most fenced farms would likely produce on the frontier than unfenced farms. This explanation could further be supported by the finding that the OLS and MLE estimates show that the coefficient of fence variable in terms of crop production is positive and statistically significant at the 5 percent level.

The estimated parameter σ_{ε}^{2} (3.842) is also found to be statistically significant at the alpha level 0.01 and this suggests that a conventional production function is not an adequate representation of the data and that the specified distributed assumption of the composite error term has a good fit and is correct.

All the inputs are statistically significant except capital and land area. Again, the variable of interest fence has a positive and statistically significant coefficient implying that fence has an impact in crop production. Besides, the value of the elasticity of scale, which is found not to be statistically significantly different from unity, is 0.34, implying that crop farms operate under constant returns to scale (CRS).

6.4 DEA frontier results

Table 6.3: Ordinary least squares (OLS) and maximum- likelihood estimates (MLE) of the Cobb-Douglas stochastic production frontier model (crop production)

		OLS		**MLE**	
Name of Variables	**Parameters**	**Coefficients**	**t-ratios**	**Coefficients**	**t-ratios**
Constant	β_0	11.14 (1.920)	5.799***	11.15 (2.698)	4.132***
Labour	β_1	0.416 (0.051)	8.095***	0.416 (0.051)	8.199***
Capital	β_2	0.080 (0.095)	0.847	0.080 (0.094)	0.851
Land	β_3	0.081 (0.117)	0.689	0.081 (0.117)	0.691
Land Quality	β_4	-2.399 (0.300)	-7.979***	-2.399 (0.291)	-8.196***
Dummy	β_5	1.085 (0.689)	1.574	1.085 (0.662)	1.640
Fence	β_6	0.386 (0.162)	2.38**	0.386 (0.157)	2.462**
Sigma-squared	$\sigma_\varepsilon^2 = \sigma_u^2 + \sigma_v^2$	3.953		3.842 (0.366)	11.44***
Gamma	$\gamma = \sigma_u^2 / \sigma_\varepsilon^2$			0.000 (0.015)	0.003
Sigma-squared of u	σ_u^2			0.000	
Sigma-squared of v	σ_v^2			3.842	
log likelihood		-520.876		-520.876	
Returns to scale (RTS)		0.34		0.34	
Number of farms		249		249	

***Note** (i) *** Statistically significant at the 1% level (ii) ** statistically significant at the 5% level (iii)*statistically significant at the 10% level (iv) figures in parentheses indicate standard errors*

DEA is a non-parametric method that does not require a specification of a statistical model like the stochastic frontier production function. In the following section, a DEA model consisting of the same output and input variables like those of the stochastic frontier model is estimated. The constant returns to scale (CRS) and variable returns to scale (VRS) output-oriented DEA models are estimated.[14] A number of software for solving the efficiency problem in DEA exists but GAMS and specialised software DEA PIMX are used and it is found that the specialised software DEA PIMX gives the same result as GAMS. The method has been applied to the same sample (same number of farms). The output orientation has been selected because the technical efficiency scores obtained from the DEA method are comparable with those of the stochastic frontier production function (Theodoridis *et al.*, 2008; Wadud *et al.*, 2000).

Frequency distribution and summary statistics of technical efficiency estimates from different orientations with regard to crop, livestock and total output are presented in Table 6.4 to 6.9. Specifically, technical efficiencies of DEA models with fence and those without fence variable are obtained and compared with the estimates from SFA. Scale efficiency scores are also obtained and conclusions are drawn on the percentages of farms operating under CRS, IRS and DRS.

The mean technical efficiencies estimated for the CRS and VRS DEA approaches for the total output in terms of crop and livestock production (Table 6.4) are 0.31 and 0.42 respectively. The mean technical efficiencies of the DEA models indicate that the farms are producing 31 and 42 percent respectively of its potential output. This further implies that there is substantial inefficiency of 0.69 and 0.58 respectively for the farms in the sample, which confirms the expectations. This may also be interpreted to mean that farmers are more technically efficient under the assumption of VRS DEA than CRS. This finding is also consistent with the theory that the VRS frontier is more flexible and envelopes the data in a tighter way than the CRS frontier (Nguyen *et al.*, 2008; Wadud *et al.*, 2000; Cullinane *et al* 2007). This result is not surprising since a DEA model with an assumption of CRS provides information on pure technical and scale efficiency taken together, while a DEA model with the assumption of VRS identifies technical efficiency alone (Cullinane *et al.*, 2007). Also, this same result of the technical efficiency scores estimated under the CRS DEA frontier being equal to, or less than those calculated under the VRS DEA model is supported by Figure 6.1. As shown in the

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[14] See chapter 3, section 3.5.2.1 for a detailed discussion of VRS and CRS.

diagram, the efficiency score for fenced farms under VRS is higher than under the assumption of CRS. This result is similar to what was found under the stochastic frontier analysis.

In addition, 62 farms are fully technically efficient in terms of the VRS model and 33 farms are fully technically efficient under the CRS model. The stochastic frontier analysis estimates show that no farm is fully technically efficient.

Table 6.4: Frequency distribution and summary statistics of technical efficiency estimates from both the stochastic frontier (SF) and technical and scale efficiency from the DEA models- Total output with fence variable

Efficiency Score	**SF**		**CRS**		**VRS**		**SE**	
	No. of farms	**%**	**No. of farms**	**%**	**No. of farms**	**%**	**No. of farms**	**%**
< 0.3	50	20.01	169	67.87	134	53.82	25	10.04
0.3-0.4	45	18.07	14	5.62	16	6.43	5	2.01
0.4-0.5	59	23.69	9	3.61	9	3.61	8	3.21
0.5-0.6	58	23.29	2	0.80	10	4.02	14	5.62
0.6-0.7	34	13.65	4	1.61	5	2.01	21	8.43
0.7-0.8	3	1.2	4	1.61	4	1.61	16	6.43
0.8-0.9	0	0	10	4.02	6	2.41	33	13.25
0.9-1.0	0	0	4	1.61	3	1.20	60	24.10
1	0	0	33	13.25	62	24.90	67	26.91
TOTAL	249	100	249	100	249	100	249	100
Mean	0.44		0.31		0.42		0.79	
Minimum	0.11		0.00		0.00		0.00	
Maximum	0.72		1.00		1.00		1.00	
Std dev	0.14		0.35		0.39		0.27	
Skewness	-0.24		1.13		0.56		-1.31	

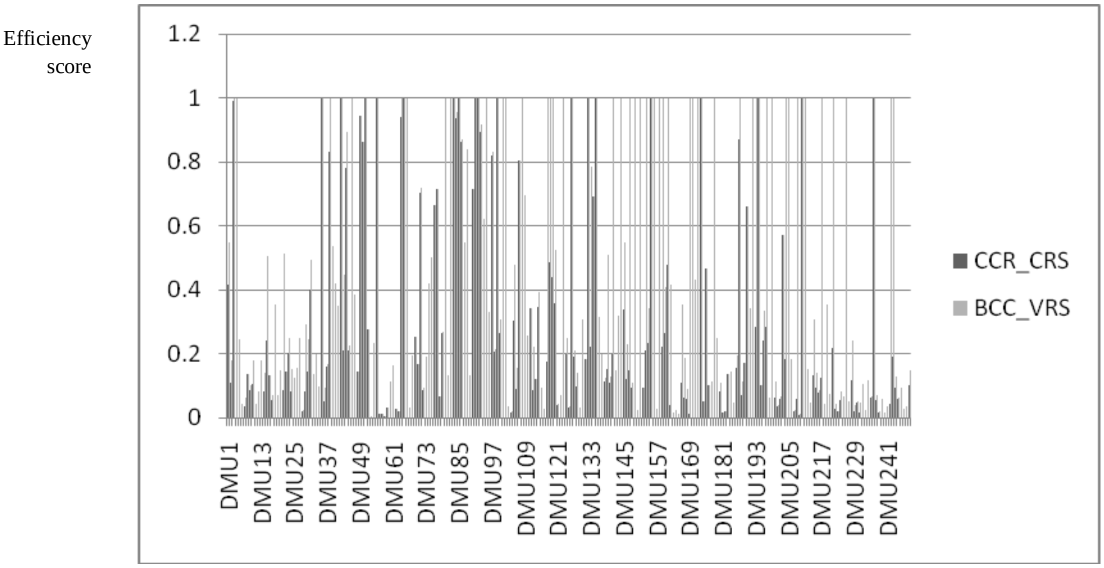

Figure 6.1: Efficiency plot of total output with fence variable

The scale efficiency index for the sample is estimated using the Equation $SE_i = \frac{TE_i^{CRS}}{TE_i^{VRS}}$ and it ranges from 0.00 to 1.000 with a sample mean and standard deviation of 0.79 and 0.27 respectively. The average scale efficiency of 0.79 implies that the inefficiency from the minimum efficient scale is 21 percent on average. Furthermore, the scale efficiency scores for 170 fenced farms show that 21 (12 percent) exhibited CRS, 110 (65 percent) exhibited increasing returns to scale (IRS) and lastly 39 (23 percent) exhibited decreasing returns to scale (DRS) (Appendix 8). This implies that most households with fence (110) are operating with IRS. This result conforms to that of Sharma *et al*. (1997) in which they found that most farms were operating under IRS in their study on productive efficiency of the swine industry in Hawaii. They also compared SFA and DEA technical efficiency estimates.

Table 6.5 exhibits that in terms of livestock production, when fence is introduced as a variable, 20 and 51 farms are fully technically efficient under the assumption of CRS and VRS respectively and the mean of VRS is also higher than that under CRS a finding that is consistent with all the other outputs considered. Just like in terms of total output, the efficiency scores under the assumption of VRS is also higher than under CRS as shown in Figure 6.3.

The scale efficiency in terms of livestock production shows that 20 out of 79 (25 percent) of unfenced farms exhibited IRS while 44 out of 79 (56 percent) showed DRS. 15 out of the 79 (19 percent) presented CRS. On the other hand, 70 (41 percent) farms with a fence out of 170 showed IRS and 85 (50 percent) exhibited DRS. 15 (9 percent) exhibited CRS. (Appendix 9)

Table 6.5: Frequency distribution and summary statistics of technical efficiency estimates from both the stochastic frontier (SF) and technical and scale efficiency from the DEA models- Livestock production with fence variable

Efficiency Score	**SF**		**CRS**		**VRS**		**SE**	
	No. of farms	**%**	**No. of farms**	**%**	**No. of farms**	**%**	**No. of farms**	**%**
< 0.3	183	73.49	206	82.73	168	67.47	47	18.89
0.3-0.4	27	10.84	6	2.41	7	2.81	51	20.48
0.4-0.5	13	5.22	3	1.21	5	2.01	25	10.04
0.5-0.6	10	4.02	1	0.40	5	2.01	10	4.02
0.6-0.7	8	3.21	2	0.80	4	1.61	17	6.83
0.7-0.8	7	2.81	3	1.21	3	1.21	9	3.61
0.8-0.9	1	0.4	6	2.41	3	1.21	17	6.83
0.9-1.0	0	0	2	0.8	3	1.21	42	16.87
1	0	0	20	8.03	51	20.48	31	12.45
TOTAL	249	100	249	100	249	100	249	100
Mean	0.27		0.18		0.32		0.56	
Minimum	0.00		0.00		0.00		0.00	
Maximum	0.81		1.00		1.00		1.00	
Std dev	0.21		0.31		0.39		0.33	
Skewness	1.21		1.93		0.94		-0.05	

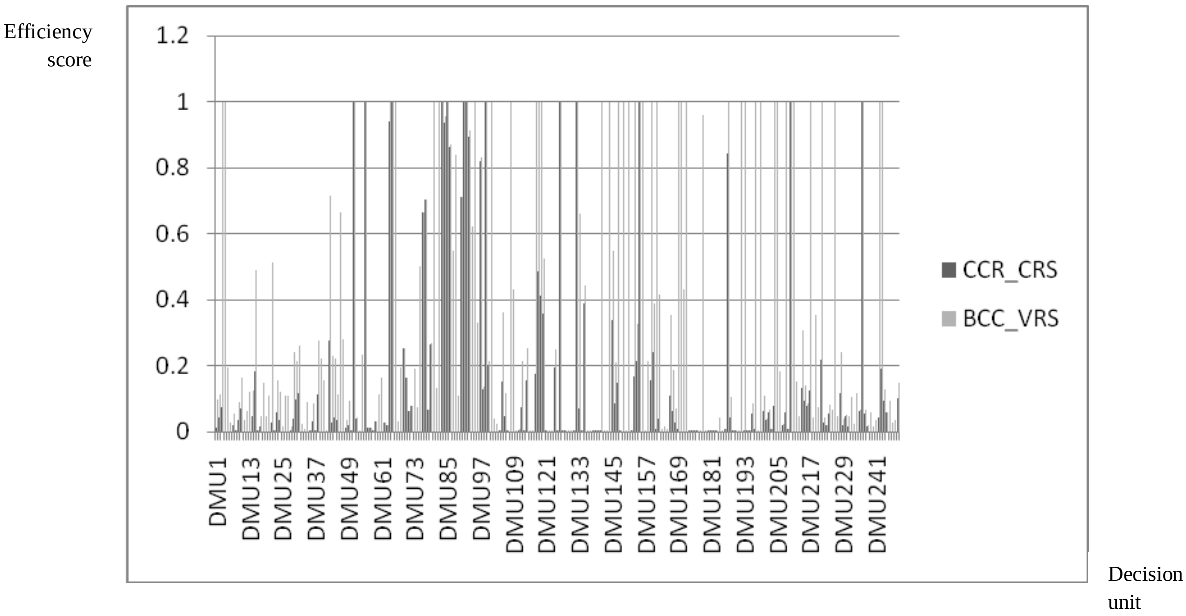

Figure 6.2: Efficiency plot of livestock production with fence variable

Table 6.6: Frequency distribution and summary statistics of technical efficiency estimates from both the stochastic frontier (SF) and technical and scale efficiency from the DEA models- Crop production with fence variable

Efficiency Score	**SF**		**CRS**		**VRS**		**SE**	
	No. of farms	**%**	**No. of farms**	**%**	**No. of farms**	**%**	**No. of farms**	**%**
< 0.3	0	0	208	83.53	178	71.49	28	11.24
0.3-0.4	0	0	10	4.02	14	5.62	6	2.41
0.4-0.5	0	0	4	1.61	2	0.80	10	4.02
0.5-0.6	0	0	1	0.40	3	1.20	9	3.61
0.6-0.7	0	0	3	1.20	3	1.20	9	3.61
0.7-0.8	0	0	3	1.20	1	0.40	15	6.02
0.8-0.9	0	0	2	0.80	3	1.20	19	7.63
0.9-1.0	249	100	3	1.20	3	1.20	88	35.34
1	0	0	15	6.02	42	16.87	65	26.10
TOTAL	249	100	249	100	249	100	249	100
Mean	0.989		0.16		0.27		0.79	
Minimum	0.989		0.00		0.00		0.00	
Maximum	0.989		1.00		1.00		1.00	
Std dev	0.000		0.28		0.37		0.31	
Skewness	-1.01		2.15		1.24		-1.52	

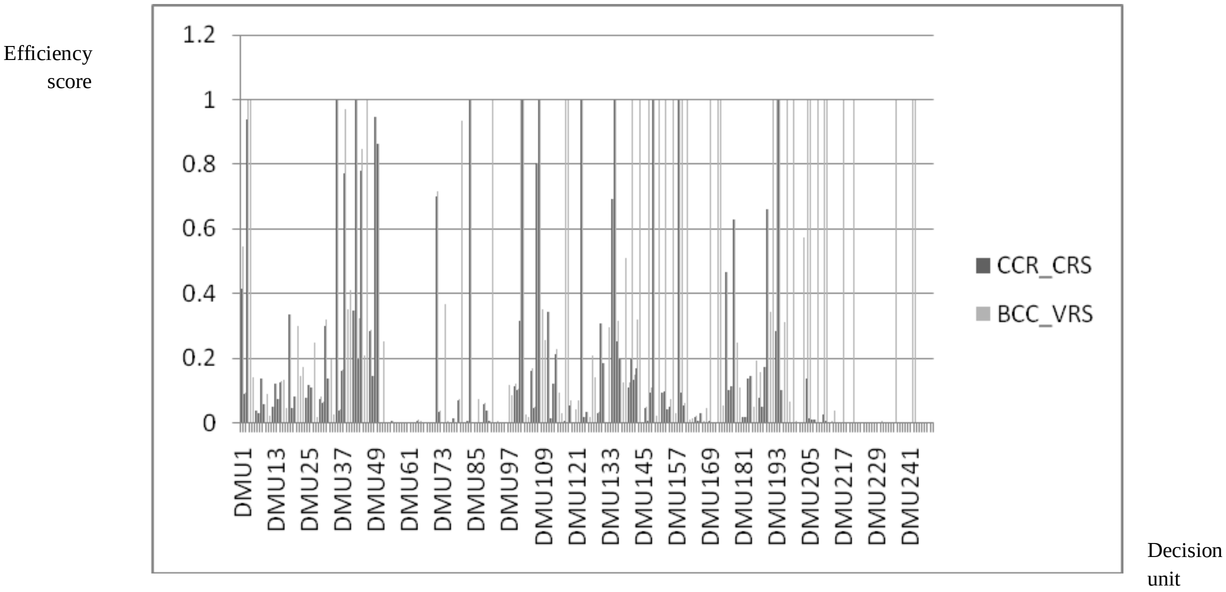

Figure 6.3: Efficiency plot of crop production with fence variable

In terms of crop production (Table 6.6), the same result also applies in that the number of fully technically efficient farms when fence is treated as a variable is high, 15 and 42 under the assumption of CRS and VRS respectively. Also, the average mean is 0.16 and 0.27 under CRS and VRS respectively (Table 6.6). Figure 6.5 shows the efficiency plot under the assumption of VRS and CRS. This diagram also supports the fact that VRS envelopes the data in a tighter way than CRS. Moreover, for crop production, 5 farms out of 79(6 percent) farms without fence showed IRS while 22(28 percent) showed DRS and 52(66 percent) exhibited CRS. 29 out of 170(17 percent) crop farms exhibited IRS and 128(75 percent) DRS while 13(7 percent) showed CRS (Appendix 10)

6.5 Analysis of Variance (ANOVA) –Aggregate analysis

ANOVA analysis was undertaken in order to determine whether fencing has any effect on farm efficiency in semi-arid regions of Kenya. Generally, in the computation of ANOVA, it is possible to use two methods. The first method involves ranking the technical efficiency estimates obtained from the SFA and DEA for both fenced and unfenced homesteads. A spread sheet software EXCEL is used in this study in computing ANOVA. The second method entails the regression of technical efficiency estimates on an intercept term. Theoretically, the two methods should give the same results. In the second method where the technical efficiency estimates are regressed on an intercept term, the coefficient of the fence variable should be equal to the difference between the two sample means of households with fence and those without. This was confirmed to be true. Therefore, ANOVA mean estimates for aggregated data when total output, livestock and crop production is considered is as shown in Tables 6.7 to 6.9.

Table 6.7: ANOVA mean estimates-Total output

	Stochastic frontier	**Data Envelopment Analysis Model**	
		TE_{CRS}	**TE_{VRS}**
Fence	0.43	0.28	0.40
No fence	0.47	0.40	0.48
P-value	0.10	0.01	0.17

DEA and SFA ANOVA estimates in terms of total output as shown in Table 6.7 show that fencing is insignificant in that the mean without fence is greater than the mean with fence. This result thus implies that fencing does not improve the efficiency of farms. Moreover, the F statistic for the SFA and TE_{VRS} is not significant but that of TE_{CRS} is significant at the alpha=0.05 level.

Table 6.8: ANOVA mean estimates-Livestock production

	Stochastic frontier	**Data Envelopment Analysis Model**	
		TE_{CRS}	**TE_{VRS}**
Fence	0.18	0.18	0.33
No fence	0.17	0.19	0.29
P-value	0.70	0.79	0.43

On the other hand, ANOVA estimates (Table 6.8) in terms of livestock production for both SFA and DEA under the assumption of VRS show that the mean with fencing is greater than without fencing. The difference in the means under SFA and DEA VRS is

0.01 and 0.04 respectively implying that fencing improves the efficiency of livestock production by 0.01 and 0.04. However, ANOVA estimates with regard to DEA CRS show otherwise in that it depicts that the mean of farms with no fence is greater than that of farms with fence. This means that fence does not improve the efficiency of farms a result that is inconsistent with that obtained under SFA and DEA VRS. It is also shown in the Table 6.8 that the F statistic for the SFA and DEA is not significant.

Table 6.9: ANOVA mean estimates-Crop production

	Stochastic frontier	**Data Envelopment Analysis Model**	
		TE_{CRS}	**TE_{VRS}**
Fence	0.99	0.12	0.24
No fence	0.99	0.26	0.33
P-value	0.73	0.00	0.11

In terms of crop production (Table 6.9), DEA estimates show that the mean of farms without fence is greater than the mean of farms with fence. The implication here is that fence does not improve the efficiency of farms. The SFA estimates however show that the mean of farms with fence is equal to the mean of farms without implying that efficiency of fenced and unfenced farms is the same. The F statistic for SFA and DEA VRS is not significant while that of DEA under the assumption of CRS is significant at the alpha=0.05 level.

6.6 Analysis of Variance (ANOVA) –Regional analysis

Regional ANOVA analysis is also undertaken and the estimates for all the regions are presented in Table 6.10 and 6.11. Table 6.10 is used to present estimates of total output while Table 6.11 is used to present estimates of livestock and crop production. In these tables, the difference between the two sample means of households with fence and those without are presented. An estimate with a positive sign implies that the mean of farms with fencing is greater than that without fencing. Likewise, an estimate with a negative sign implies that the mean of those farms without fencing is greater than the mean of farms with fencing.

Table 6.10: Regional analysis of ANOVA estimates-Total output

Regions	**Total output**		
	SFA	**DEA**	
		TE_{CRS}	**TE_{VRS}**
Mwala	-0.07**	-0.27***	-0.25**
Narok North	0.14***	0.13	0.14
Suba	-0.01	-0.12	0.04
Voi	0.01	-0.01	0.06
Koibatek	0.02	0.08	0.24

Notes *(i) ***, ** shows the F-statistic at the 1% level and at the 5% level respectively. (ii) Number of farms: Mwala=50; Narok=50; Mbita=50; Voi=49; Koibatek=50*

From Table 6.10, it is noted that both ANOVA DEA and SFA results of Mwala district show that farms without fencing have a greater mean than those with fencing. This means that fencing does not improve efficiency of farms in Mwala district as far as total output is concerned. The F statistic for the SFA and DEA VRS estimate is significant at the alpha=0.05 level while that of the DEA CRS is significant at the alpha=0.01 level.

In Narok North district however, fencing seems to have an effect in farm efficiency. This is because the mean of both SFA and DEA estimates is greater in farms with fencing than in those without. In fact, the F statistic as per the SFA estimate is significant at the alpha=0.01 level.

Suba district on the other hand presents inconsistent results because it is only in the DEA under the assumption of VRS that the mean of those farms with fencing is greater than the mean of those without fencing. On the other hand, the mean of SFA and DEA CRS estimates show that the mean of those farms without fencing is greater than the mean of those farms with fencing and hence the inconsistency.

Voi district SFA and DEA VRS ANOVA estimates show that fencing has an effect on farm efficiency for the same reason that the mean of those farms with fencing is greater than that of farms without. However, DEA estimates under the assumption of CRS show otherwise. The F statistics is also not significant in both SFA and DEA.

Koibatek district moreover presents consistent SFA and DEA estimates. The mean of those farms with fencing is greater than the means of those farms without fencing implying that fencing may have an effect on technical efficiency. The F statistics is however not significant.

Therefore, from the regional analysis in terms of total output and the accompanying interpretation of results from Table 6.10, it can generally be concluded that fencing has an effect on farm efficiency. This deduction is reached at because the mean of fenced farms for three districts out of five is greater than the mean of those farms without fencing. ANOVA estimates for livestock and crop output are combined in Table 6.11 and just like in Table 6.10, only the difference in the means of farms with and without fence are presented. ANOVA estimates of the livestock and crop output will be discussed concurrently.

Table 6.11: Regional analysis of ANOVA estimates-Livestock and crop output

Regions	**Livestock output**			**Crop output**		
	SFA	**DEA**		**SFA**	**DEA**	
		TE$_{CRS}$	**TE$_{VRS}$**		**TE$_{CRS}$**	**TE$_{VRS}$**
Mwala	-0.10	0.02	-0.02	-4.75289e-07	-0.29***	-0.29***
Narok North	0.09	0.14	0.14	6.76202e-06	0.02	0.02
Suba	-0.03	0.02	0.20	5.06368e-06	-0.14	0.04
Voi	-0.14**	0.01	0.19	1.20621e-06	0.01	0.02
Koibatek	0.01	0.07	0.23	1.15271e-05	0.02	0.22

***Notes** (i) ***, ** shows the F-statistic at the 1% level and at the 5% level respectively. (ii) Number of farms: Mwala=50; Narok=50; Mbita=50; Voi=49; Koibatek=50*

Mwala district DEA ANOVA estimates under the assumption of CRS from livestock output show that the mean of farms with fencing is greater than the mean of farms without fencing. However, SFA and DEA ANOVA estimates under the assumption of VRS illustrate that the mean of the farms without fence is greater than that of farms with fence and hence it can be concluded that fencing has no impact on farm efficiency as far as livestock production is concerned. The F statistic is also not significant. It is also worth noting that the stochastic frontier estimates are comparable to those presented in Table 6.10.

As far as crop production is concerned in Mwala, it appears that the mean of farms with fencing is less than the mean of farms without fencing. The F statistic for DEA ANOVA estimates is also significant at the alpha=0.01 level. These estimates imply that fencing does not have an effect on farm efficiency as far as crop production is concerned. This may however be attributed to the fact that the district had experienced drought and not many households practiced crop farming. Most of them kept poultry and during the interview, most households attested to the fact that most of their poultry had gone up since fencing land. The results are also comparable to those presented in Table 6.10 when total output is taken into consideration.

SFA and DEA ANOVA estimates from Narok North district on the other hand show that in terms of livestock production, the mean of farms with fencing is higher than the mean of farms without fencing. This thus implies that fencing has an effect on efficiency of livestock production. These results are comparable to those observed in Table 6.10.This result is not surprising from the fact that Narok is predominantly a pastoralist community and given the fact that it is situated next to the largest game park in Kenya, the Masai Mara, it is inevitable that fence is important so that livestock is protected from wildlife especially at night.

Likewise, as far as crop production is concerned, it is clearly shown in Table 6.11 that the mean of farms with fencing is greater than the mean of farms without fencing. This means that fencing has an effect on farm efficiency as far as crop production is concerned. It can further be deduced that these estimates are sensible because fencing is supposed to keep away livestock from destroying crops. The results are also similar to those presented in Table 6.10.

DEA ANOVA estimates of Suba district in terms of livestock production show that fence has an effect on farm efficiency under both assumptions of CRS and VRS for the reason that the mean of fenced farms is larger than the mean of unfenced farms. However, SFA estimate shows otherwise and as shown, the mean of farms without fencing is greater than the mean of farms with fence an observation that is comparable to that shown in Table 6.10. The F statistic is also not significant for both SFA and DEA ANOVA estimates.

The mean of fencing as per the SFA and DEA VRS estimates in terms of crop production show that the mean is greater in fenced farms than in farms without fence. However, DEA estimate under the assumption of CRS shows otherwise and that the mean of farms with fencing is less than the mean of farms with fence. The F statistic is also not significant.

ANOVA DEA livestock output estimates of Voi district show that fencing improves farm efficiency under both assumptions of CRS and VRS. This result makes sense because Voi is located near one of the largest national parks in Kenya, the Tsavo(Figure 1.7) and so fence is important in protecting livestock from wildlife that are likely to stray. However, SFA estimate shows that the mean of farms without fencing is greater than the mean of farms with fencing and the F statistic is also significant at the alpha=0.05 level.

In addition, as noted in Table 6.11, both SFA and DEA ANOVA estimate shows that fence contributes to the efficiency of crop production because the mean of fenced farms is greater than the mean of farms without fence. The F statistic is however not significant.

ANOVA results of Koibatek district also exhibit that fence improves efficiency of livestock production as well as that of crop production as shown by both SFA and DEA estimates .This is for the same reason that the mean of farms with fencing is greater than the mean of farms without fencing. These estimates are also comparable to those observed in Table 6.11 because in this district, when both livestock and crop output is aggregated, ANOVA estimates showed that fencing has an effect on farm efficiency.

Therefore, from the regional ANOVA results, we can conclude that fence generally improves the efficiency of farms for the reason that besides Mwala district where fence seems not to have an effect on farm efficiency, all the other regions, Narok, Mbita, Voi and Koibatek seem to show some effect.

6.7: Spearman rank correlation coefficient

To examine the agreement between the two approaches of SFA and DEA, Spearman rank correlation coefficients between the technical efficiency rankings from the stochastic frontier and the DEA models of the sampled farmers are computed and reported in Table 6.12. All the correlation coefficients are positive and highly significant. Since the calculated value is greater than the critical value, the H_0 must be rejected i.e. the correlation value is much higher than the critical value of 0.1244 at 0.05 confidence level. The correlation is therefore very highly significant. From Table 6.13, the strongest correlation is achieved between the rankings from the CRS and VRS DEA model.

Table 6.12: Spearman rank correlation matrix of technical efficiency rankings of sample farmers obtained from different methods (Total output-whole sample)

	TE_{SF}	**TE_{VRS}**	**TE_{CRS}**
TE_{SF}	1.0000		
TE_{VRS}	0.6050	1.0000	
TE_{CRS}	0.7018	0.7942	1.0000

***Note**: 5% critical value (two-tailed) = 0.1244 for n = 249*

Regional spearman rank correlation coefficients for the total output are also presented in Tables 6.12 to 6.17. It is noted from the different regions that the strongest correlation is also achieved between the rankings from the CRS and VRS DEA model just as in the whole sample. However all the regions are highly correlated except Koibatek where the correlation between the stochastic frontier and VRS DEA is not significant. In Mwala district, the strongest correlation is achieved between the rankings from the CRS and VRS DEA model

Table 6.13: Spearman rank correlation matrix of technical efficiency rankings of sample farmers obtained from different methods (Total output-Mwala district)

	TE_{SF}	**TE_{VRS}**	**TE_{CRS}**
TE_{SF}	1.0000		
TE_{VRS}	0.7486	1.0000	
TE_{CRS}	0.6789	0.9169	1.0000

***Note**: 5% critical value (two-tailed) = 0.2787 for n = 50*

Table 6.14: Spearman rank correlation matrix of technical efficiency rankings of sample farmers obtained from different methods (Total output-Narok North district)

	TE_{SF}	TE_{VRS}	TE_{CRS}
TE_{SF}	1.0000		
TE_{VRS}	0.8328	1.0000	
TE_{CRS}	0.8316	0.9995	1.0000

***Note**: 5% critical value (two-tailed) = 0.2787 for n = 50*

In Narok North district also, the strongest correlation is achieved between the rankings from the CRS and VRS DEA model just as in Mwala District

Table 6.15: Spearman rank correlation matrix of technical efficiency rankings of sample farmers obtained from different methods (Total output-Suba District)

	TE_{SF}	TE_{VRS}	TE_{CRS}
TE_{SF}	1.0000		
TE_{VRS}	0.7002	1.0000	
TE_{CRS}	0.7221	0.7503	1.0000

***Note**: 5% critical value (two-tailed) = 0.2787 for n = 50*

Likewise in Suba district the strongest correlation is achieved between the rankings from the CRS and VRS DEA model just as in Mwala and Narok North district.

Table 6.16: Spearman rank correlation matrix of technical efficiency rankings of sample farmers obtained from different methods (Total output-Voi district)

	TE_{SF}	TE_{VRS}	TE_{CRS}
TE_{SF}	1.0000		
TE_{VRS}	0.6545	1.0000	
TE_{CRS}	0.6620	0.7131	1.0000

***Note**: 5% critical value (two-tailed) = 0.2816 for n = 49*

Similarly, in Voi district, the strongest correlation is achieved between the rankings from the CRS and VRS DEA model

Table 6.17: Spearman rank correlation matrix of technical efficiency rankings of sample farmers obtained from different methods (Total output-Koibatek district)

	TE_{SF}	TE_{VRS}	TE_{CRS}
TE_{SF}	1.0000		
TE_{VRS}	0.1041	1.0000	
TE_{CRS}	0.3785	0.5875	1.0000

***Note**: 5% critical value (two-tailed) =0.2787 for n = 50*

However, in Koibatek district, the correlation between the stochastic frontier and VRS DEA is not significant even though the strongest correlation is still achieved between the rankings from the CRS and VRS DEA model just as in the other regions

6.8 Conclusion

Two different approaches, SFA and DEA have been applied to measure the technical efficiency of farms. The variance parameters obtained from the stochastic frontier MLE show that technical efficiency has significant impact on output implying that the frontier model is appropriate. In addition, the MLE show that fence has an impact in improving production. The mean efficiency for each of the methods is reported in Table 6.4 to 6.6. The mean efficiency measures of the total output obtained from the stochastic frontier model is greater than that obtained from the VRS and CRS DEA model a result similar to those of researchers such as Theodoridis *et al.* (2008) but opposite to that of Serrao (2003) and Wadud *et al.* (2000) who found that the mean productivity scores obtained by DEA are higher than those obtained by SFA. However, the DEA mean efficiency measure in terms of livestock and crop production taken separately are higher under the assumption of VRS than those of SFA. DEA efficiency scores was expected to be less than those obtained under the specifications of stochastic frontier because the DEA approach attributes any deviation of the data from the frontier to inefficiency, while stochastic frontier analysis acknowledges the fact that random shocks beyond the control of the farmers can affect output. Both the CRS and VRS DEA measures exhibit greater variability than the stochastic frontier efficiency measure as shown in the tables a result similar to that of Wadud *et al.* (2000).

ANOVA analysis showed that there is a difference in the means of fenced and unfenced homesteads as far as technical efficiency is concerned. In the aggregate analysis for instance, DEA and SFA ANOVA estimates in terms of total output show that fencing is insignificant in that the mean without fence is greater than with fence. In terms of livestock production, SFA and DEA estimates under the assumption of VRS show that the mean with fencing is greater than without fencing implying that fencing is significant. However, ANOVA estimates with regard to DEA CRS show otherwise in that it depicts that the mean of farms with no fence is greater than that of farms with fence. This implies that fence does not improve the efficiency of farms an inconsistent result. In terms of crop production, DEA estimates show that the mean of farms without fence is greater than the mean of those farms with fence. The implication here again is that fence does not improve the efficiency of crop farms. DEA estimates on the other hand in terms of crop output show that the mean of farms without fence is greater than the mean of those farms with fence. Therefore, the aggregate ANOVA analysis of the technical efficiency of farms with and without fence shows inconsistent estimates and hence inconclusive results. Nevertheless, the general observation from aggregate analysis is that fencing does not show a significant positive contribution to the efficiency of firms.

However in the regional analysis, ANOVA estimates in terms of total output show that fencing has an effect on farm efficiency. This deduction is reached at because the mean of fenced farms for three districts out of five is greater than the mean of those farms without fencing. It can thus be concluded on this basis that fencing generally improves the efficiency of farms for the reason that besides Mwala district where fence seems not to have an effect on farm efficiency, all the other regions, Narok, Mbita, Voi and Koibatek seem to show some effect.

Spearman rank correlation coefficients between the technical efficiency rankings obtained from the stochastic frontier and the DEA are reported in Table 6.12 to 6.17. The general impression here is that all correlation coefficients are positive and highly significant at the 5 percent level. The strongest correlation is obtained between the efficiency rankings estimated from the VRS and CRS DEA model. The weakest correlation is achieved between the rankings from the stochastic production frontier and the VRS DEA model a finding that is also similar to that of Wadud *et al.* (2000).

Studies that have compared the technical efficiency estimates derived from the stochastic parametric frontier and deterministic nonparametric frontier have mixed results. Sharma *et al.* (1997) reported similar results with this research while Wadud *et al*. (2000) reported a greater mean technical efficiency (0.858) obtained from the VRS DEA model than those of both CRS DEA and stochastic frontier model (0.789 and 0.791 respectively). However, Wadud *et al.* (2000) did not find a greater variability of technical efficiencies from the DEA models than from the stochastic frontier efficiency measures. Moreover, results from both econometric and programming frontier indicate that there are substantial production inefficiencies among the sample farmers. The sample farmers, given the existing technology, fence could, on average, enhance their production and improve their competitive position if they could operate efficiently.

It is worth mentioning also that results from the classical regression model and the stochastic frontier analysis reinforce each other in that the variable of interest fence continued to exhibit a positive coefficient.

CHAPTER 7
CONCLUSIONS & RECOMMENDATIONS

7.1 Conclusion

The general objective of this work was to find out if fencing improves agricultural production and the efficiency of farms in semi-arid regions of Kenya. An important feature of the analysis and also the main contribution of the study is that fence is included in the conventional production function to examine its effect on agricultural production and efficiency alongside traditional inputs such as capital, labour, land and land quality. However, measuring positive benefits of fence is a necessary but not sufficient condition because there are costs involved. Cross-sectional primary data was used to achieve the objectives of the study through parametric and non-parametric estimation methods. Parametric estimation methods involved the use of the Cobb-Douglas (CD) classical regression model of production based on ordinary least square estimation and the stochastic estimation method.

In the classical regression model, fence was measured in two ways, as a variable which measures area and as a binary dummy variable. Using fence as a variable that measures area allowed for fence to be treated as a standard variable like capital or labour .On the other hand, treating fence as a binary dummy variable allowed for changes in the regression intercept and in slopes of associated variables. The changes in slopes were estimated by multiplying the fence dummy by the natural log of all inputs. Each regression was further categorized into two; with and without land quality variable and the results obtained were then compared. This decision was reached at because land quality variable presented sensitive results and it was therefore sensible to try out another model without land quality variable. It was found that the variable of interest fence continued to exhibit a positive coefficient and that it did not really matter whether the model had the land quality variable or not in respect to fence.

Instrumental variable (IV) technique was also applied in the classical regression model and the aim was to test for endogeneity of the fence variable. This is because it was suspected that fence variable might be correlated with the regression error (ε).The suspected correlation between fence and ε may be as a result of various reasons such as that of omitted variables, measurement errors in the regressor, functional form mis-specification and sample selection. IV technique was thus used to remove the correlation between fence and ε. However for OLS to be efficient, the chosen instrument must satisfy two conditions. The conditions are that the instruments must be correlated with F (instrument relevance) and uncorrelated with ε (Instrument exogeneity). The diagnostic tests revealed that all the preferred instruments passed the first stage F statistics for weak instruments. Regarding the Wu-Hausman test for consistency of OLS estimates, the null hypothesis of consistency of OLS estimates was rejected when livestock and total output was treated as the dependent variable for all sets of instruments. However, when the dependent variable was crop output, the OLS estimate was weakly consistent. Furthermore, all the instruments passed the Sargan test for over identification and validity of instruments when the dependent variable was crop output and total output but not for livestock output.

Theoretically, for OLS to be chosen as the best estimator there are various requirements and one of them is exogeneity of regressors. The Wu-Hausman test for exogeneity and the Sargan test for validity of instruments were carried out and it was found as discussed in the previous paragraph that OLS was consistent. Also, it was only when total output was used as the dependent variable that OLS was inconsistent, it was therefore decided that OLS is the best estimator. Thus, all other results that followed thereafter were entirely based on OLS estimates.

Results from OLS estimates in the model that measured fence as an area and with land quality in it showed a positive coefficient for fence implying that fence actually improves agricultural production. Specifically, fence was statistically significant when the dependent variable was crop and total output implying that fence has an impact in crop and aggregate production. Livestock production presented a positive but statistically insignificant coefficient.

The coefficients of all the other inputs in the model with land quality in terms of total output and livestock production had the expected positive signs. However, in terms of crop production, all the inputs too had a positive sign except land quality. OLS estimates in terms of total output showed that land quality is the most important input followed by fence, the next important inputs are capital, labour and finally land size in that order. Similarly, when fence was treated as a fence variable which measures area and land quality was excluded from the model, all the OLS estimates in terms of total output exhibited a positive coefficient. Likewise, in terms of livestock production all showed a positive coefficient except labour and in terms of crop production, all variables showed a positive coefficient except land area. This evidence therefore supports the hypothesis that fence which was the variable of interest in this study actually improves agricultural production.

Furthermore, when fence was measured as a binary dummy variable in the model that allowed for a change in slope of associated variables and with land quality included in the model, fence also continued to exhibit a positive coefficient. However, when land quality was removed from the model, the OLS estimates presented a negative coefficient on fence in terms of livestock production and it is in fact the only model which presented a negative coefficient a result that implies that fence may not have a positive impact in terms of livestock production. This however makes sense for the reason that practically, fence is supposed to keep livestock away from crop farms. This finding is also consistent with that of Boone *et al.* (2004) who in their study of effect of fencing on large herbivores found out that when 10km^2 of land was fenced, 19 percent fewer cattle could be supported compared to the land being unfenced.

To further support the finding that OLS estimates show that fence has an impact in agricultural production, the behaviour of fence was observed with different sets of regressors. It was found that controlling for the other inputs maintained the same positive statistically significant effect of fence on total output another confirmation that fence improves agricultural production. In terms of crop production, all the sets of regressors maintained a positive statistically significant coefficient implying that fence is important in crop production. For livestock production, the regressors gave negative and positive statistically insignificant coefficients implying that fence has no impact on livestock production a result that makes sense theoretically.

Another form of parametric estimation method used in this research was the stochastic parametric estimation method. The CD production frontier was estimated by maximum likelihood estimation (MLE) to obtain maximum likelihood estimates of the CD stochastic production frontier model and technical efficiency scores of each firm. The test statistics confirmed that the traditional average production function is not an adequate representation of the data. As mentioned earlier in the text, it is important to note that this does not render all results above invalid. This is because the variable of interest fence continued to exhibit a positive coefficient in both the classical and stochastic regression model. Also, as Battese (1977) asserts, unless there are strong reasons for assuming one particular model, it is better if empirical data can be used to determine the model that fits best.

From the stochastic frontier analysis (SFA), maximum likelihood estimates indicate that the coefficient for fence is positive and statistically significant in terms of total output and crop production. In terms of livestock production, the coefficient is positive but not statistically significant. This result also supports the hypothesis that fencing improves agricultural production and this agrees with the conclusion reached when the classical regression model is used. Also, the fact that fence has a significant impact on crop production and not livestock production is supported by theory in that fence is supposed to keep livestock away from crop farms as mentioned earlier. MLE from the SFA also show that there are substantial inefficiencies in farms which may probably be attributed to lack of means of improving efficiency.

The non-parametric estimation on the other hand involved the use of data envelopment analysis (DEA), a linear programming approach that does not require the specification of a statistical model. The output-oriented frontier was estimated under the specifications of constant and variable returns to scale. Technical efficiency estimates were obtained from DEA analysis and they were compared with those from the SFA.

Findings on farm efficiency showed that efficiency measures obtained from the stochastic frontier model are greater than those obtained from the VRS and CRS DEA model a result similar to other researchers. ANOVA analysis showed that there is a difference in the means of fenced and unfenced households but the results were mixed. For example, on one hand, ANOVA analysis for aggregated data showed that fenced farms are more efficient than unfenced farms from the SFA and VRS DEA but not total and crop output. On the other hand, when regions were analysed separately, the results were that fencing improves efficiency of farms in that three out of the five sampled regions showed that fenced farms were more efficient than unfenced farms though insignificantly. Spearman rank correlation coefficients between the technical efficiency rankings were also obtained. It was found that the strongest correlation is obtained between the efficiency rankings estimated from the VRS and CRS DEA model. The weakest correlation is achieved between the rankings from the stochastic production frontier and the VRS DEA model and hence the general conclusion that all correlation coefficients were positive and significant at the 5 percent level.

The study also attempted to find out the role of socio-economic and demographic characteristics in relation to fencing. IV technique was used and it was found that the decision to fence may be affected by other factors such as cost of putting up a fence, age and education level of household head and the farming activity such as crop farming, livestock or mixed farming undertaken by households though not significantly . This deduction was reached at because it was only when total output, which is an aggregate of both crop and livestock output was used as a dependent variable that all the instruments passed all the tests of first stage F-statistics, test for weak instruments and the Sargan test of validity of instruments and over identification .When livestock and crop output were treated as dependent variables, the validity and reliability of the instruments was inconsistent and hence the conclusion that cost ,age, education and farming activity may affect the decision to fence but insignificantly (Table 5.3).

Regions were also compared given their traditional, cultural and economic differences. The regression results show that the impact of fence does not differ significantly between the different regions and hence the conclusion that fence is important in improving agricultural production. The small differences observed in the different regions are as a result of different traditional and cultural practices.

As well as seeking to find out the role of fencing in improving agricultural production, this study also attempted to examine the relationship between fencing and the land policy in Kenya. Traditionally, in Kenya, land was held communally and the coming of imperial powers in the 1920s almost ended the customary land tenure in Kenya for the reason that most land was transformed from communal land into individual land. This led to increase in fence structures as individuals used fence to claim ownership of the land. Also, as discussed earlier in chapter 1, Kenya has different land tenure systems and cultural norms relating to land. Besides, as discussed earlier in the text, Kenya had not had a clear Land Policy until August 2010 when Kenya approved a new constitution. In addition, Land in Kenya has always been a very sensitive issue and this is mainly attributed to the importance of land in human life. This point strongly explains the reason for the struggle for Kenya's independence from British colonial rule. Therefore, the complexity of laws governing land ownership in Kenya, the abuse of those laws in the sense that state powers allowed the irregular allocation of public land to a favoured few led to ethnic tension. Ethnic tension on the other hand led to land clashes in the 90s and the post election violence of 2007 .The recent land clashes of 2007 created a class of landless people (Internally Displaced Persons) .Likewise, IDPs have greatly destabilised the implementation of planned programs. Therefore resettling these IDPs will go a long way in improving agricultural production in Kenya. This is for the reason that they will go back to their farms. Given the benefits of fencing, it is recommended that the government should help in fencing their farms so that each can have exclusive ownership of their property besides other benefits of fencing measured earlier in the text. It is also hoped that the new Land Policy will help in reducing ethnic tension in Kenya as far as land issues are concerned.

Therefore, from the descriptive statistics in this study on land ownership, it can be concluded that the presence of a clear land policy has led to an increase in the individualisation of land and hence an increase in fence structures. This is supported by the fact that households who owned the land had fences and title deeds unlike those who leased or hired the land. In addition, cross tabulation was used and from the chi-square tests, the null hypothesis of independence between fence and property ownership was rejected an indication that there is a relationship between fencing and property ownership. It is important to also point out here that, even though there is a high correlation between fencing and private property, this study has strictly captured the overall effect of fencing that goes beyond the property issue.

Therefore, even though other factors such as the high food prices is a potential threat to attainment of Millennium Development Goals (MDG's) and other national targets, mainly poverty and hunger reduction, farms especially in the ASALs need to be expanded through adoption of modern production methods, including effective fencing. Researchers such as Tywan (2001) in a study in Namibia noted that due to the positive impacts of fencing such as extending the sense of community control over livelihoods and the improvement in their natural resource base, many other communities wished to fence their land. It also appears that fence gave a positive environmental and societal result in Eastern Namibia.

It is therefore very evident from this study that fencing can improve agricultural production of farms in semi-arid areas. In fact, during data collection, an important finding was that the respondents from the various regions verbally expressed the significance of fence and some of the statements from the respondents were that since they fenced land, output had really increased and some wished they had fenced their farms much earlier. This has been confirmed empirically.

7.2 Limitations of the study

It is worth noting that there are no empirical studies on fencing in Kenya. It therefore makes it difficult to compare the results with other Kenyan studies on fencing. It was also the wish of the researcher to collect data from as many regions as possible but this was not possible due to financial and security reasons. Theory states that an increase in sample size leads to an increase in the precision of the sample statistic as an estimator of the population characteristic even though a sample that is too large could be a waste of resources and a sample that is too small could produce an estimator of inadequate precision (Barnet,1974). This is why the enquiry was restricted into five semi-arid districts with different traditional and cultural practices. Other limitations noted are that production functions assume that all inputs have been taken into consideration.

Also lack of data on fencing from the Central Bureau of Statistic (CBS), Kenya, is one of the major limitations. The researcher therefore had to collect primary data from five different regions which was time consuming and expensive besides other problems experienced during the data collection.

During the process of collecting data, as much as most farmers interviewed were willing to cooperate, others however were reluctant and they were not willing to volunteer information. In some instances for example, the respondents deviated from the main issue. In addition, some communities were superstitious and their beliefs could not allow them to count the livestock in that some may die. It was also difficult to get into some homesteads in that they kept dogs for security reasons.

Another expected limitation was that farmers were suspicious of talking about their output which had just been harvested. This was due to traditions, cultural practices and limited education of the diverse communities found in the study areas. Attempts were made to overcome the problem by explaining to the farmers the usefulness of the research and that confidentiality was to be kept up to the latter.

Data collection also coincided with the Kenya’s constitutional review process. Land was a contentious issue in the constitution and most respondents were not willing to give information on land. Language was also a barrier and some respondents could not understand English or the national language, Kiswahili. Besides, for future records and reference, the researcher needed to take pictures occasionally but some respondents were refusing to have their pictures taken. Also, due to the high poverty level in the study areas, some respondents were demanding money in return for information.

Most of these problems later showed up during checking for internal consistency and coding. Since coding was done after returning from Kenya, it was not possible to make corrections by re-asking the respondents. Discarding inconsistent, incomplete and outlying responses therefore reduced the final sample size to 249 from 251.

Nevertheless, these limitations do not subtract from the validity of the research, since it has allowed for the contribution of fence to agricultural production and efficiency in semi-arid areas in Kenya to be determined for the first time.

7.3 Recommendations

The conclusions and policy implications presented in this thesis rests upon the quality of the data used in the empirical analysis. Therefore, it would be a useful avenue for future research to expand the current data set to include other regions not included in this research. Kenya has 13 semi-arid districts and only 5 were sampled due to shortage of time, effort and finances. It would therefore be good if more than 5 regions were sampled.

Of particular interest in further work is to critically find out how fence may impact on the environment. This is because this study concentrated more on agricultural output. This recommendation of the extension is supported by the fact that from the findings in this study, it is clear that fence improves plant cover and that fenced homes also had trees and shrubs within the homestead. It is therefore worthwhile to find the impact of fence on the environment by using a good measure of the environment such as the biomass.

Additionally, price of land was used in this research as a proxy of land quality. It appears that it may not be a very good proxy because of the sensitive results it gives. Further research should therefore use a better measure of land quality.

This study also only measures the impact of fence on specific households and no attempt has been made to estimate the spill over effects of a household's fence on the neighbours. It would therefore be interesting to find out if there are any positive externalities a neighbours fence may have on a neighbours homestead.

Also, as mentioned earlier in the chapter, measuring benefits is important but then there is the cost factor involved. Future research should therefore attempt to carry out a cost benefit analysis to find out if the benefits exceed the cost of fence.

7.4 Policy implication

Given the constraints and challenges that the agricultural sector in Kenya faces, various policy issues need to be considered for the country as a whole. Therefore, looking for appropriate development strategies for agricultural production, including efficiency improvement is a necessity. Thus, the policy gap in this study is that at the household level in Kenya, fencing has led to a series of positive benefits as concluded in this research. There is therefore a need for the government to recognize the positive impact of fence and empower those communities who would wish to fence their land. Helping and encouraging farmers by educating them on the importance of fence would go a long way in helping to reduce food insecurity in the country besides improving the efficiency of farms. During data collection, most farmers wished to reinforce their fence to prevent intrusion with stronger materials such as barbed wire and poles. “Live” fences do not do well in the semi-arid areas due to limited rainfall. Unfortunately, as it stands currently, it is far too expensive for the common man to afford. The Government should therefore consider subsidising so that the households can afford.

This study will also be policy relevant for the reason that it will add in helping to find ways to simultaneously increase agricultural production while greatly reducing their environmental impacts and consequently improving food security in semi-arid regions. It will also help farmers manage the land resource well. Besides, strengthening fences in semi-arid areas can set in motion a wide range of social and economic benefits including empowerment of households and other marginalised people and poverty reduction.

To improve production in semi-arid areas, the following policy interventions are proposed. Public funding on fencing crop farms in semi-arid-areas should be availed. This is because the results show that cost of fencing may affect the decision to fence. This is supported by the fact that the IV technique (Table 5.3) showed that cost of fencing an area of land passed all the reliability and validity tests and hence the deduction that cost may affect the decision to fence. Also, from the field survey undertaken, those farmers who did not have a fence and expressed the need of having one said cost was the inhibiting factor and they could be happy if the government helped in a way. Most proposed that the constituency development funds would be a good kitty to draw funds from and thus at the local level, this would be a good way of covering the cost of fencing. Accelerated fencing would thus promote food production. In addition, supporting agriculture, including dairy production and crop farming in semi-arid areas would also help in improving production in semi-arid areas. Moreover, if fencing costs fall sufficiently, farmers will be able to build fences and produce at efficient levels. The Government can also help by educating people on the benefits of fencing thus encouraging fencing to reduce intrusion by human beings or wildlife would increase agricultural production. This study thus is a strong argument for government subsidy of fencing as well as a key element of overseas aid.

A further policy implication of this research is that efficiency estimates indicate that there is inefficiency in farms and fencing could improve efficiency even though the improvement is not significant. Finally, if two diverse approaches to estimating efficiency, namely DEA and SFA, gave similar results as far as contribution of fence is concerned, then this implies that the measures of efficiency are robust and can be used as a basis of policy recommendation.

REFERENCES

Abler, D.G. and Sukhatme, V.A. (2006) The "Efficient but Poor" Hypothesis, *Applied Economic Perspectives and Policy*, **28**(3), 338-348

Adams, M. (2003) Current Land Reform and Land Policy Processes in Kenya. [Internet]AvailableURL:http://www.oxfam.org.uk/resources/learning/landrights/east.html (Accessed 03/12/11).

Ahmad, M. Chaudhry, G.M. and Iqbal, M. (2002) Wheat Productivity, Efficiency, and Sustainability: A Stochastic Production Frontier Analysis, *The Pakistan Development Review,* **41**(4):643-663.

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

Ajibefun, I. A.and Abdulkadri, A. O. (1999) An Investigation of Technical Inefficiency of Production of Farmers Under the National Directorate of Employment in Ondo State, Nigeria, *Applied Economic Letters*, **6**:111-114.

Andersen and Peterson, N.C. (1993) A Procedure for Ranking Efficient Units in Data Envelopment Analysis, *Management Science* **39**(10):1261-1264

Anderson, T.L. and Hill, P. J. (1977) From Free Grass to Fences: Transforming the Commons of the American West' 201-216 in Hardin, G. and Baden, J (eds) *Managing The Commons* W H Freeman and Company PP 118-134

Arindam, L. and Pravat, K. K. (2011) Measurement of Allocative Efficiency in Agriculture and its Determinants: Evidence from Rural West Bengal, India. *International Journal of Agricultural Research*, **6***: 377-388.*

Assuncao, J .J. and Ghatak, M. (2003) Can Unobservable Heterogeneity in Farmer Ability Explain the Inverse Relationship between Farm Size and Productivity? *Economics letters*, **80**: 189-194

Atwood, D.A (1990) Land Registration in Africa: The Impact on Agricultural Production, *World Development*, **18**(5):659-671

Ault, D.E. and Rutman, G.L. (1979)The Development of Individual Rights to Property in Tribal Africa, Journal *of Law and Economics* **22**(1):163-182

Ball, R., and L. Pounder (1996) "Efficient but Poor' Revisited." *Economic Development and Cultural change*, **44:**735–760.

Barnet, V (1974) *Elements of Sampling Theory*, Hodder and Stoughton

Banker, R.D. and Thrall, R.M. (1992) Estimation of Returns to Scale Using Data Envelopment Analysis ,*European Journal of Operational Research*, **62**: 74-84.

Banker, R.D., Charnes, A.and Cooper,W.W. (1984) Some Models for Estimating Technical and Scale Inefficiency: Data Envelopment Analysis, *Management science*, **30**:1078-1092.

Barbier, E.B. (1987) The Concept of Sustainable Economic Development, *Journal of Environmental Conservation*, **14**: 101-110

Barrett, B.C. (1996) On Price Risk and the Inverse Farm Size-Productivity Relationship, *Journal of Development Economics* **51**:193-215.

Barrett, B.C., Bezuneh, Clay, C.D. and Reardon, T. (2000) Heterogeneous Constraints, Incentives and Income Diversification Strategies in Rural Africa, Report to USAID/BASIS CRSP, Cornell University and Michigan State University, Ithaca and East Lansing.

Barrows, B. and Roth, M. (1990) Land Tenure and Investment in African Agriculture: Theory and Evidence, *The Journal of Modern African Studies*, **28**(2): 265-297.

Battese, G.E. (1996a) On the Estimation of Production Functions Involving Explanatory Variables Which Have Zero Values [Internet] Available URL: https://www.une.edu.au/bepp/working-papers/econometrics/emetwp86.pdf (Accessed 04/12/11)

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

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

Battese, G.E (1992) Frontier Production Functions and Technical Efficiency: A Survey of Empirical Applications in Agricultural Economics, *Agricultural Economics*, **7**: 185-208

Battese, G.E., Malik, S.J. and Broca, S.S. (1993) Production Functions for Wheat Farmers in Selected District of Pakistan: An Application of a Stochastic Frontier Production Function with Time-Varying Inefficiency Effects. *The Pakistan Development Review* **32**,233-268

Battese, G.E. and Corra, G.S. (1977) Estimation of a Production Frontier Model: with Application to the Pastoral Zone of Eastern Australia, *Australian Journal of Agricultural Economics*, **21**: 169-79

Becker, G .S (1964) *Human Capital: A Theoretical and Empirical Analysis, with Special Reference to Education.* Chicago, University of Chicago Press

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

Belen, I. Manuel,R. and Idoia,Z. (2003) Assessing The Technical Efficiency of Horticultural Production in Navarra, Spain, *Agricultural Systems*, **78**:387-403.

Belloumi, M. and Matoussi, M.S. (2009) Measuring Agricultural Productivity Growth in MENA countries, *Journal of Development and Agricultural Economics* Vol. **1** (4):103-113

Benjamin, D. (1995) Can Unobserved Land Quality Explain the Inverse Productivity Relationship? *Journal of Development Economics*, **46** (51):84

Binswanger, H.P. and Rosenzweng, M. (1993) Wealth, Weather Risk and the Composition and Profitability of Agricultural Investments, *Economic Journal*, **103**: 56-78

Binswanger, H.P. and Mcintire, J. (1987) Behavioural and Material Determinants of Production Relations in Land-Abundant Tropical Agriculture, *Economic Development and Cultural Change* Vol.**36** (1): 73-99

Boone, R. and Hobbs, T.N. (2004) Lines around Fragments: Effects of Fencing on Large Herbivores, *African Journal of Range and Forage Science*, **21**(3):147-158

Boone, R.B. and Coughenour, M.B. (2001) A system for Integrated Management and Assessment of East African Pastoral Lands: Balancing Food Security, Wildlife Conservation, and Ecosystem integrity, Report to the Global Livestock Collaborative Research Support Program, University of California Davis, USA

Bravo-Ureta, B.E and Rieger, L. (1991) Dairy Farm Efficiency Measurement Using Stochastic Frontiers and Neoclassical Duality, *American Journal of Agricultural Economics*, **73**(2):421-428

Brown, K.M. and Lee, B. (2004) Exploring the Relationship Between Common Property, Natural Resources and Rural Development: The Case of Crafting Common Grazing, Aberdeen Discussion Paper Series: People, Environment and Development.

Carter, C., Jing Chen, J. and Chu, B. (1999) Agricultural Productivity Growth in China: Farm Level versus National Measurement [Internet] Available URL: http://arelibrary.ucdavis.edu/working_papers/files/99-001.pdf(Accessed 21/02/09)

Charnes, A., Cooper, W.W. and Rhodes, E. (1978) Measuring The Efficiency of Decision Making Units, *European Journal of Operational Research* **2**(6): 429-444.

Charnes, A., Cooper, W.W. and Rhodes, E. (1981) Evaluating Program and Managerial Efficiency: An Application to Data Envelopment Analysis to Program Follow Through, *Management Science* **27** (6): 668-697.

Chirwa, E. W. (2007) Sources of Technical Efficiency among Smallholder Maize Farmers in Southern Malawi, *African Economic Research Consortium*, Research Paper 172.

Clevenger, A.P., Chruszez, B, B. and Gunson, K. E (2001*)* Highway Mitigation Fencing Reduces Wildlife-Vehicle Collisions, *Wildlife Society Bulletin* **29**: 646–653.

Coelli, T.J. (1996) A Guide to FRONTIER version 4.1: A Computer Program for Stochastic Frontier Production and Cost Function Estimation, Mimeo, Department of Econometrics, University of New England, Armidale.

Coelli, T.J., Estache, A., Perelman, S. and Trywo.L (2003) A Primer on Efficiency Measurement for Utilities and Transport Regulators, World Bank Institute, Washington D.C

Coelli, T.J., Prasada, D.S. Rao, C.J., O'Donnel and.Battese, G.E. (2005) An Introduction to Efficiency and Productivity Analysis, 2nd Ed .USA: Springer Publishers.

Cornia, G.A. (1985) Farm size, Land yields and the Agricultural Production Function: An Analysis for Fifteen Developing Countries [Internet] Available URL:http://www.sciencedirect.com/science/article/B6VC6-458XH5N-82/2/8d37a73f802b41865820229c655d48c6 (Accessed 01/03/2009)

Cullinane, K. and Wang, T. (2007) Data Envelopment Analysis (DEA) and Improving Container Port Efficiency, *Research in transportation economics*, **17:**517-566

Dahlman, C.J. (1980) *The Open Field System and Beyond: A Property Rights Analysis of an Economic Institution*. Cambridge: Cambridge University Press.

Delgado, L.C. *et al*., (1999) Determinants of Nonfarm Earnings of Farm- Based Husbands and Wives in Northern Ghana, *American Journal of Agricultural Economics*, **81**:117-130

Demeke, M. The Production Efficiency of Food Grain Producers in Ethiopia: The Case of Some Farms in Arssi Province, PhD thesis, University of Strathclyde, Glasgow, 1989

Demsetz, H. (1967) Toward a Theory of Property Rights *American Economic Review* **57**: 347-59.

Diewert, W.E. (2008) What is to be Done for Better Productivity Measurement. [Internet]AvailableURL:http://209.85.229.132/search?q=cache:JG7WApwLTkYJ:www.csls.ca/ipm/16/IPM-16-diewert-e.pdf+Diewert+and+lawrence1980&hl=en&ct=clnk&cd=1&gl=uk(Accessed 27/02/09).

Dolan, C. (2009) Fencing for Wildlife [Internet] Available URL: http://ag.arizona.edu/backyards/articles/winter09/p12-13.pdf (Accessed 03/12/11)

Dhungana, B.R., Nuthall, P.L. and Nartea, G.V.(2004) Economic Inefficiency of Nepalese Rice Farms using Data Envelopment Analysis, *The Australian Journal of Agricultural and Resource Economics* **48**(2):347-369

Ekborm (1998) Some Determinants to Agricultural Productivity-An Application to Kenyan Highlands, Paper presented at the World Conference of Environmental Economics, Venice Italy, 25-27 June 1998

Ellis, Frank (1988) *Peasant Economics: Farm Households and Agrarian Development*, Cambridge University Press, Cambridge.

Eswaran, and Kotwal, A. (1986) Access to Capital and Agrarian Production Organisation, *Economic Journal*, **96**: 482–498.

Farrell, M.J. (1957). The Measurement of Productive Efficiency, *Journal of the Royal Statistical Society*, **120**: 253-290

FAO/UNEP, (1997) Land Quality Indicators and their Use in Sustainable Agriculture and Rural Development, FAO, Rome, Italy

Feder, G. (1984) The Relation Between Farm Size and Farm Productivity: The Role of Family Labour, Supervision and Credit Constraints, *Journal of Development Economics* **18** (1985).297-313

Feder, G., Chalamwong, Y., Hongladarom, C. and Oncham, T. (1988) Land Policies and Farm Productivity in Thailand, Baltimore, John Hopkins University press

Field, B.C. (1984) The Evolution of Individual Property Rights in Massachusetts Agriculture, 17th-19th Centuries, *Northeastern Journal of Agricultural and Resource Economics* **14:**97-109

Field, B.C. (1985) The Optimal Commons, *American Journal of Agricultural Economics* **67**:364-367

Foley, J (2009) The Other Inconvenient Truth, the Crisis in Global Land Use, [Internet] Available URL:http://e360.yale.edu/content/feature.msp?id=2196 (Accessed 1/06/10)

Gadd, M. E. (2008) *Barriers, the Beef Industry and Unnatural selection: A Review of the Impacts of Veterinary Fencing on Mammals in Southern Africa*, in Hayward, Kerley and Somers: Fencing for Conservation.

Gavian, S. and Fafchamps, M. (1996) The spatial integration of Livestock Markets in Niger, *Journal of African Economies* **5**(3):366-405

Gebremedhin, B. and Swinton, S.M (2003) Investment in Soil Conservation in Northern Ethiopia: The role of Land Tenure Security and Public Programs, *Journal of Agricultural economics*, **29**:69-84.

Government of Kenya, (2011) *Economic Survey*, Nairobi: Government Printer

Government of Kenya (2009a), *Taita District Development Plan 2008-2012* Nairobi: Government Printers

Government of Kenya (2009b), *Narok North District Development Plan 2008-2012* Nairobi: Government Printers

Government of Kenya (2009c), *Mwala District Development Plan 2008-2012* Nairobi: Government Printers

Government of Kenya (2009d), *Koibatek District Development Plan 2008-2012* Nairobi: Government Printers

Government of Kenya (2009e), *Suba District Development Plan 2008-2012* Nairobi: Government Printers

Government of Kenya (2008) Draft land policy [INTERNET]. Available URL:http://www.ilegkenya.org/pubs/docs/DraftNationalLandPolicy.pdf. Accessed 7/05/09

Government of Kenya (2007), *Kenya Vision 2030: A Globally competitive and Prosperous Kenya* Nairobi: Government Printers

Government of Kenya (2004a) *Strategy for Revitalising Agriculture, 2004-2014*.Nairobi: Government Printer

Government of Kenya (2004b) *Report of the Commission of Inquiry into the Illegal/Irregular Allocation of Public Land* Nairobi: Government Printer

Government of Kenya (2003a) *Economic Recovery Strategy for Wealth and Employment Creation (2003-2007)*. Nairobi: Government Printer

Government of Kenya (2003b) *Characterization of the ASAL of Kenya (CETRAD* Nairobi: Government Printer

Government of Kenya, (2001) *Poverty Reduction Strategy Paper for the Period 2001-2002.* Nairobi: Government Printer

Government of Kenya, (1993) *Range Management Handbook of Kenya, Volume II, 5,* Ministry of Agriculture and Livestock Development and Marketing, Nairobi

Government of Kenya (1992) *ASAL Development Policy*, Nairobi: Government Printer

Hardin, G. (1968) The Tragedy of the Commons, *Science*, **162**: 1243-1248.

Harvey, C.A., Villanueva, Villaus, C., Chacon, J.*et al*. (2005) Contribution of Live Fences to the Ecological Integrity of Agricultural Landscapes, *Agriculture, Ecosystems and Environment*, **111**:200-230.

Heltberg, R. (1998) Rural market Imperfections and the Farm Size-Productivity Relationship: Evidence from Pakistan. *World Development*, **26** (10):1807-1826

Hoare, R.E. (1992) Present and Future use of Fencing in the Management of Larger African Mammals *Environmental Conservation* **19**:160–164

IPAR (2002) How Public Policy Can Improve the Situation of Kenya's Pastoralists [Internet] Available URL: http://www.ipar.or.ke/pb3,%202002.pdf (Accessed 25/04/09).

Kabubo-Mariara (2006) Land Conservation in Kenya: The Role of Property Rights, AERC Research paper 153, African Economic Research Consortium. Nairobi

Kabubo-Mariara (2003) The Linkages between Property Rights, Migration and Productivity: The case of Kajiado district, Kenya *Environment and Development Economics*, 8(4):621-36

Kenya Economic Report (2009) The Kenya Institute for Public Policy Research and Analysis (KIPPRA), Nairobi, Kenya.

Kombo, D.K. and Tromp, D.L.A. (2006) *Proposal and Thesis writing*: *An introduction*, Nairobi, Paulines publications Africa.

Koop (2008) *Introduction to econometrics*, University of Strathclyde: John Wiley & Sons, England.

Kumbhakar, S.C., and Lovell, K.C.A (2000) *Stochastic Frontier Analysis*, University of Cambridge: UK.

Lamb, L.R., (2002) Inverse Productivity: Land Quality, Labor Markets, and Measurement Error, *Journal of Development Economics*, 71 (2003):71-95.

Little, P.D. (1992) The Elusive Granary: Herder, Farmer, and State in Northern Kenya, *Current Anthropology*, **33**: 481-483

Liu, Z. Zhuang, J. (2000) Determinants of Technical Efficiency in Post-Collective Chinese Agriculture: Evidence from Farm Level Data. Journal of Comparative Economics **28**:545–564

Livingstone, I (1981) *Agricultural Economics for Tropical Africa*, 1st edition, London, Heinemann

Lopez, R (1986) Structural Models of the Farm Household That Allow for Interdependent Utility and Profit-Maximization Decisions in Singh et al(eds) *Agricultural Household Models-Extensions, Applications and Policy*, Baltimore: The Johns Hopkins University Press.

Löthgren, M. and Tambour, M. (1996) Alternative Approaches to Estimate Returns to Scale in DEA Models. *Working Paper NO.90, The Economic Research Institute*, *Stockholm School of Economic.*

Maschinski, J. Frye, R. and Rutman, S. (1996) Demography and Population Viability of an Endangered Plant Species Before and After Protection from Trampling, *Conservation Biology* **11**: 990–999.

Meeusen, W. and.Vanden Broech, J (1977) Efficiency Estimation from Cobb-Douglas Production Function with Composed Error, International Economic Review, **18**:435-44.

Mefford, R.N. (1986) Introducing Management into the Production Function [Internet] Available URL: http://www.jstor.org/sici?sici=0034-535%28198602%2968%3A1%3C96%3AIMITPF%3E2.0.CO%3B2-D&origin=repec Accessed: (13/11/2008)

Miller, D.J. (2007) An Information Theoretic Approach to Flexible Stochastic Frontier Models, Economics, Missouri, Working Papers

Monchuk, C.D., Chen, Z. and Bonaparte, Y. (2010) Explaining Production Inefficiency in China's Agriculture Using Data Envelopment Analysis and Semi-Parametric Bootstrapping, *China Economic Review*, **21**:346-354

Morduch, J. (1995) Income Smoothing and Consumption Smoothing, *The Journal of Economic Perspectives* **9** (3):103-114

Muniafu, M., Iraki, F.K., Makau, M. and Otiato, E. (2008) Exploiting indigenous knowledge in the environmental conservation and promotion of African plants:

case study on Mwingi and Kyuso districts, Kenya, *Journal of Language, Technology and Entrepreneurship in Africa* **1**(1):126:132

Nation correspondent: “Agriculture Africa’s only hope” Daily Nation 4 May, 2010:13

Nation correspondent: “Kenya joins big financiers of agriculture in Africa” Daily Nation 21 June, 2011:3

Nation correspondent: “President Mwai Kibaki Inaugurates the Longest Conservation Fence” Daily Nation 12 March, 2010:15

Nchare, A. (2007) Analysis of Factors Affecting Technical Efficiency of Arabica Coffee Producers in Cameroon, *African Economic Research Consortium*, Research Paper 163

Nerlove, M. (1956) Estimates of Supply of Selected Agricultural Commodities, *Journal of Farm Economics*, **38**(2):496:509

Nguyen Khac Minh and Giang Thanh Long (2008) *Measuring Agricultural Production Efficiency in Vietnam: An application of Data Envelopment Analysis (DEA)* Vietnam Development Forum Working Paper 0813.

Nkamleu, G.B. (2004) Productivity Growth, Technical Progress and Efficiency Change in African Agriculture, *African Development Review*, **16:203**-222

North, D. C. and Thomas, R. P. (1973) *The Rise of the Western World: A New Economic History*, Cambridge: Cambridge University Press

Nyberg, G. (2007) *Land Rehabilitation Experiences from West Pokot, Kenya*, Working papers of the Finnish forest research institute. 50:71-75

Odhiambo, W. and. Nyangito, H. (2002) *Land Laws and Land use in Kenya: Implications for Agricultural Development*. KIPPRA Discussion paper NO.15. Kenya institute for public policy Research and Analysis, Nairobi

Odingo, R .S. (1985) *The Dynamics of Land Tenure and of Agrarian Systems in Africa: Land-Tenure study in the Nakuru, Kericho and Machakos areas of the Kenya Highlands*. Rome, United Nations Food and Agricultural Organization

OECD (2001) Measuring Capital [Internet] Available URL: http://www.oecd.org/dataoecd/61/57/1876369.pdf (Accessed 17/05/12)

Ogundari, K., Ojo, S.O., and Ajibefun, I.A., (2006) Economies of Scale and Cost Efficiency in Small Scale Maize Production: Empirical Evidence from Nigeria, *Journal of Social Science* **13**(2): 131-136

Ojo, S.O. (2003) Productivity and Technical Efficiency of Poultry Egg Production in Nigeria, *International Journal of Poultry Science* **2**(6):459-464

Okon, E.U., Enete A.A. and Bassey, N.E (2010) Technical Efficiency and its Determinants in Garden Egg (Solanum spp) production in Uyo Metropolis, Akwa Ibom State, *Field Actions Science Report Vol. 4* [Internet] Available URL: http://factsreports.revues.org/458(Accessed 21/05/12)

Okoth-Ogendo, H (1999) Land Policy Development in East Africa: A survey of Recent Trends. [Internet] Available URL:http://www.oxfam.org.uk.what_we_do/issues/livelihoods/landrights/africa_east.htm (Accessed 9/04/10)

Olson, M. (1965) *The Logic of Collective Action: Public Goods and the Theory of Groups*, Cambridge, Mass: Harvard University Press, 1st ed.

Onyango, C.H. and Omiti, J.M. (2008) *Scaling up Domestic support for Sustainable Development of Agriculture in Kenya*, KIPPRA Discussion paper NO.25. Kenya Institute for Public Policy Research and Analysis, Nairobi

Ostrom, E. (2009) Ostrom's Take on the Tragedy of the Commons [Internet] Available URL: http://www.env-econ.net/2009/10/ostroms-take-on-the-tragedy-of-the-commons-.html (Accessed 21/05/12)

Ostrom, E. (1999) *Self Governance and Forest Resources*, C/FOR Occasional paper No.20

Ostrom, E.(1994) Neither Market nor State: Governance of Common Pool Resources in the Twenty-First Century[Internet] Available URL:http://dlc.dlib.indiana.edu/dlc/bitstream/handle/10535/891/ostrom-E-neither_market_nor_state_governance_of_common_pool_resources_in_the_twenty_first_century.pdf?sequence=1 (Accessed 22/05/12)

Ostrom, E. (1990) *Governing the Commons, The Evolution of Institutions for Collective Action*, Cambridge university press, Cambridge

Piesse, J. and Thirtle, C. (2000) A Stochastic Frontier Approach to Firm Level Efficiency, Technological Change and Productivity During the Early Transition in Hungary [Internet] Available URL: http://cosmic.rrz.uni-hamburg.de/webcat/hwwa/edok01/bbkuk/WP99.08.pdf (Accessed 22/05/09)

Place, F. and. Otsuka, K. (2002) The Role of Tenure in the Management of Trees at the Community Level: Theoretical and Empirical Analysis from Uganda and Malawi, CAPRi working paper No.9, International Food policy Research Institute, Washington, D.C.

Place, F. and Swallow. (2000) Assessing the Relationship between Property Rights and Technology Adoption in Smallholder Agriculture: A Review of Issues and Empirical Methods, CAPRi working paper No.2, International Food policy Research Institute, Washington, D.C

Platt, S. and Temby, I. (1999) Fencing Wildlife Habitat Land for Wildlife Notes, Department of Natural Resources and Environment, Victoria, Australia, LW0029

Pule, W.N. and Thabane, M. (2004) Lesotho's Land Tenure Regimes: Experiences of Rural Communities and the Calls for Land Reform, *The Journal of Modern African Studies*, **42**(2): 283-303

Reig-Martinez, E. and Picazo-Tadeo, A.J. (2004) Analysing Farming Systems with Data Envelopment Analysis: Citrus Farming in Spain, *Journal of Agricultural Systems*, **82**(1):17-30

Rick, B. and Carol, T. (2007) Measurement of Agricultural Output in the Australian System of National Accounts: Methods and Issues [Internet] Available URL: http://www.stats.gov.cn/english/icas/papers/P020071114297516724826.pdf. (Accessed 08/03/09).

Ricciuti, E. R. (1993) The Elephant Wars, *Wildlife Conservation*, **96**:14–34

Rosenzweng, M. and Stark, O (1989) Consumption Smoothing, Migration and Marriage: Evidence from Rural India, Journal *of Political Economy*, **97**(4): 905-926

Roth, M. J., Cochrane, J. A. and Kisamba-Mugerwa, W.(1994) Tenure Security, Credit Use, and Farm Investment in the Rujunbura Pilot Land Registration Scheme, Rukungiri District, Uganda. In Bruce, J.W. and Migot-Adholla, S. eds., *Searching for Land Tenure Security in Africa*, pp. 169-98 Dubuque, Iowa: Kendall/Hunt Publishing Co

Roth, M. J., Unruh, and Barrows, R.(1994) Land Registration, Tenure Security, Credit Use, and Investment in the Shebelle Region of Somalia. Pilot Land Registration Scheme, Rukungiri District, Uganda in Bruce, J.W. and Migot-Adholla, S. eds., *Searching for Land Tenure Security in Africa*, pp. 199-230 Dubuque, Iowa: Kendall/Hunt Publishing Co

Saunders, M., Lewis, P. and Thornhill, A. (2003) *Research Methods for Business Students:* Pearson, England

Serrao, (2003) *An Agricultural Productivity Analysis of European Union and Eastern Regions*, American Agricultural Economics Association Annual meeting, Montreal, Canada, July 27-30

Sharma, R.K., Delgado, C.L., Staal, S. and Singh, R.V. (2003) Livestock Industrialization, Trade and Social Health Environment Impacts in Developing

Countries [Internet] Available URL: http://www.fao.org/WAIRDOCS/LEAD/X6170E/x6170e36.htm#TopOfPage (Accessed 16/05/12)

Sharma, R.K., Leung, P. and Zaleski, M.H. (1997) Productive Efficiency of the Swine Industry in Hawaii: Stochastic Frontier vs. Data Envelopment Analysis, *Journal of Productivity Analysis,* **8**:447-459.

Shenggen, F. (1997) How Fast have China's Agricultural Production and Productivity really been Growing? New Measurement and Evidence [Internet] Available URL**:** http://www.ifpri.org/divs/eptd/dp/papers/eptdp30.pdf (Accessed 08/03/09)

Singh, l., Squire, L. and. Strauss, J. (1986) A Survey of Agricultural Household Models: Recent Findings and Policy Implications, *The World Bank Economic Review*, **1**:149-179

Stock, J. H., and Watson, M. W. (2007) *Introduction to econometrics*: 2nd edition, Addison Wesley, New York.

Taylor, E.J and Adelman, I. (2003), Agricultural Household Models: Genesis, Evolution, and Extensions, *Review of Economics of the Household*, **1**:33-58

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

The Aspen Times (2010) "Fencing reduces car- wildlife collisions on Hwy 82" [Internet] Available URL: http://trib.com/lifestyles/recreation/article_39350d7d-584a-579f-ae34-e10c2e0e17ea.html Accessed 04/12/11 April 22nd

The Economist "Food in Africa, a Recipe for Riots, Rising Prices can cause Mayhem" Thursday May 26th 2011
Theodoridis, A.M. and. Psychoudakis, A. (2008) Efficiency Measurement in Greek Dairy Farms: Stochastic Frontier vs. Data Envelopment Analysis. [Internet] Available URL: http://www.ijesar.org/docs/volume1_issue2/efficiency.pdf (Accessed 26/01/11)

Turner, L.W., Absher, C.W. and. Evans, J.K. (2009) Planning Fencing Systems for Intensive Grazing Management. Virginia Cooperative Extension Publication 442-130

Twyman, C., Doughill, A. Sporton, D. and David, T. (2001) Community Fencing in Open Rangelands: Self-empowerment in Eastern Namibia, *Review of African Political Economy* **87**:9-26.

Udoh, E.J. (2005) Technical Inefficiency in Vegetable Farms of Humid Region: An Analysis of Dry Season Farming by Urban Women in South Zone, Nigeria, *Journal of Agriculture and social science*, **2**: 80-85.

United Nations (2008) Measuring Capital- Beyond the Traditional Measures, UN, New York and Geneva.

Wadud, A. and White, B. (2000) Farm Household Efficiency in Bangladesh: A Comparison of Stochastic Frontier and DEA Methods, *Applied Economics*, **32**:1665-1673

Waithaka, J. (1993) The Elephant Menace, *Wildlife Conservation*, **96**:62–65.

Wang, Q., Vuitton, D. A. and Qiu, J.M. (2004) Fenced Pasture: a Possible Risk Factor for Human Alveolar Echinococcosis in Tibetan Pastoralist Communities of Sichuan, China, *Acta Tropica*, **90**:285-293.

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

Wooldridge, J.M. (2003) *Introductory Econometrics. A Modern Approach*: 2e, Thomson, South-Western, USA

Xu,X. and Jeffrey, R.S, (1995) Efficiency and Technical Progress in Traditional and Modern Agriculture: Evidence from Rice Production in China, *Rural Economy*, *Staff Paper*,95-02

APPENDICES

APPENDIX A.1

Questionnaire

Fencing and its contribution to agricultural productivity and the environment

Serial No. ☐

Date of Interview: / / 2010

Time: ☐ AM ☐ PM

[A] Background information

1. Province:
2. District:
3. Division:
4. Location:
5. Sub-Location:
6. Village:

7. Highest level of Education

☐ Illiterate ☐ Primary

☐ Secondary ☐ College/University

8. Are you the household head?

☐ Yes ☐ No

9. Age of household head (years):

10. Have you been involved in any farming activity in the last 2 – 3 years?

☐ Yes ☐ No

11. If Yes above, which farming activity?

☐ Crop farming ☐ Livestock farming

☐ Poultry farming ☐ Others ________________________

12. Present farm production

I) Crops harvest	**Quantity produced last year in (kg/acre/year)**	**Unit Price of each commodity at current prices (Kshs)**	**Reference period**
(a) Maize			
(b) Beans			
(c) Millet			
(d) Sorghum			
(e) Wheat			
(f) Vegetables			
(g) Others			

II) Livestock & products	**Units per /year**	**Unit Price of each commodity at current prices (Kshs)**	**Reference period**
(a) Milk (litres)			
(b) No. of Cows			
(c) No. of Goats			

III) Others	**Units per /year**	**Unit Price of each commodity at current prices (Kshs)**	**Reference period**
(a) Poultry(No's)			
(b) Honey harvest (Kgs)			
(c) F-wood/charcoal(sacks)			

13. Total work hours

I) Crop production	**No. of hrs/day**	**No. of days.**	**No. of workers**	**Labour forms** **a) Hired** **b) Family** **c) Recipr.**	**Average wage rate (Kshs) per hour**	**Ref. period**
(a) Plough/harrow						
(b) Planting						
(c) Weeding						
(d) Harvesting						

II) Livestock production	**No. of hrs/day**	**No. of days.**	**No. of workers**	**Labour forms** **a) Hired** **b) Family** **c) Recipr.**	**Average wage rate (Kshs) per hour**	**Ref. period**
(a) Herding						
(b) Spraying						
(c) Milking						

III) Others	**No. of hrs/day**	**No. of days.**	**No. of workers**	**Labour forms** **a)Hired** **b) Family** **c)Recipr.**	**Average wage rate (Kshs) per hour**	**Ref. period**
(a) Poultry						
(b) Bee-keeping						
(c) F-wood/charcoal						

14. What kind of sharing do you do?

____

____

____

15. On a day to day basis, where do your animals graze?

☐ Own land ☐ Common land

[B] Information on fencing and land

16. What is the total area (acres) of your Land? ____

17. Is your land fenced?

☐ Yes ☐ No

18. If Yes for the above, when did you fence your land (year)? __________________________

19. What is the total area of your fenced homestead? ___________________________________

20. What were the reason(s) for fencing your homestead?

(i)____

(ii)____

21. Did it work?

☐ Yes ☐ No

22. If your homestead is not fenced, what are the reasons?

(i)____

(ii)____

(iii)____

23. Form of fencing

☐ Natural ☐ Artificial

24. Strength of the fence

☐ Porous(Cow proof) ☐ Semi-porous(Goat proof) ☐ Non-porous(Chicken proof)

25. What factors influenced your choice of fence?

☐ Cost ☐ Durability ☐ Availability

☐ Other Benefits ☐ Easy to construct ☐ Others

26. What is the height of your fence (meters)?

☐ < 1 ☐ 1 - 2 ☐ > 2

27. Have your farm yields gone up since you fenced?

☐ Yes ☐ No

28. If Yes in 27 above, by how much? ____

29. Apart from fencing, have there been other factors that influenced your total crop yields?

☐ Yes ☐ No

30. If Yes in 29 above, specify.

____
____
____

31. Do you have trees in your farm?

☐ Yes ☐ No

32. If Yes in 31 above, specify type(s)

____
____
____

33. Why did you plant the trees?

☐ Firewood/ Charcoal ☐ Beautification

☐ Shade ☐ Other_________

34. Do trees increase crop and livestock production?

☐ Yes ☐ No

35. If Yes in 34 above, specify

____

36. Since fencing your land, has the number of trees increased?

☐ Yes ☐ No

37. What activities would you NOT do if you didn't have a fence?

(i)____

(ii)____

(iii)____

38. How would you rate your land?

☐ Fertile ☐ Not fertile

39. What is your perception on fencing?

☐ Increase productivity ☐ Decrease productivity

40. Farm equipment

I) Crop production	**Type of equipment**	**Total number of equipment**	**When was equipment bought**	**Purchase value of equipment**	**Cost of repair for the past one year**
(a) Ploughing/Harrow					
(b) Planting					
(c) Weeding					
(d) Harvesting					

II) Livestock production	**Type of equipment**	**Total number of equipment**	**When was equipment bought**	**Purchase value of equipment**	**Cost of repair for the past one year**
(a) Herding					
(b) Spraying					
(c) Milking					

III) Others	**Type of equipment**	**Total number of equipment**	**When was equipment bought**	**Purchase value of equipment**	**Cost of repair for the past one year**
(a) Poultry					
(b) Bee-keeping					
(c) Firewood/charcoal					

[C] <u>Information on land rights</u>

41. Does the land belong to you?

☐ Yes ☐ No

42. If Yes in 41 above, do you have a title deed or an adjudication number to this land?

☐ Yes ☐ No

43. If No in 41 above, who owns this land?

☐ Common property ☐ Group ranches(Scheme) ☐ Hired Land

Additional information or comments by the respondent

____

____

____

____

____

APPENDIX A.2

Descriptive Statistics

A. 2.1: Descriptive statistics for market prices –NAROK NORTH DISTRICT

Variable	**Mean**	**Std. deviation**	**Minimum**	**Maximum**
Price of goats (Kshs/unit)	2458.70	351.87	1800	3000
Price of sheep (Kshs/kg)	2895.00	425.44	2000	3800
Price of milk (Kshs/kg)	24.29	2.81	10	28
Price of maize (Kshs/kg)	42.53	6.70	22	60
Price of beans (Kshs/kg)	45.64	5.90	33	56
Price of cows (Kshs/unit)	21124.44	3940.07	15000	30000
Price of chicken (Kshs/unit)	300.00	70.71	250	500
Daily wages (Kshs)	251.00	7.07	250	300

A .2.2: Descriptive statistics for market prices-KOIBATEK DISTRICT

Variable	**Mean**	**Std. deviation**	**Minimum**	**Maximum**
Price of goats (Kshs/unit)	2755.26	297.46	1800	3000
Price of sorghum (Kshs/kg)	27.33	4.62	22	30
Price of milk (Kshs/kg)	19.43	4.30	10	30
Price of maize (Kshs/kg)	10.00	0	10	10
Price of vegetables (Kshs)	14.00	0	14	14
Price of cows (Kshs/unit)	36.22	6928.94	5000	35000
Price of chicken (Kshs/unit)	178.91	36.22	20	250
Daily wages (Kshs)	169.35	27.92	100	200

A. 2.3: Descriptive statistics for market prices-SUBA DISTRICT

Variable	Mean	Std. deviation	Minimum	Maximum
Price of goats (Kshs/unit)	1729.17	423.44	1200	2500
Price of beans (Kshs/kg)	116.00	49.43	72	180
Price of milk (Kshs/kg)	28.67	2.29	25	30
Price of maize (Kshs/kg)	28.13	4.14	20	31
Price of vegetables (Kshs)	54.61	18.43	20	72
Price of cows (Kshs/unit)	14370.59	1262.82	12700	18000
Price of chicken (Kshs/unit)	261.11	39.51	200	350
Price of Sorghum (Kshs)	28.52	6.03	11	36

A. 2.4: Descriptive statistics for market prices-TAITA TAVETA DISTRICT

Variable	Mean	Std. deviation	Minimum	Maximum
Price of goats (Kshs/unit)	2261.91	515.24	1500	3500
Price of beans (Kshs/kg)	36.75	6.34	30	44
Price of milk (Kshs/kg)	38.36	11.01	8	50
Price of maize (Kshs/kg)	27.23	2.18	20	28
Price of vegetables (Kshs)	28.75	10.57	10	50
Price of cows (Kshs/unit)	21866.67	9493.36	3000	40000
Price of chicken (Kshs/unit)	306.00	26.30	250	350

A. 2.5 Descriptive statistics for market prices-MWALA DISTRICT

Variable	Mean	Std. deviation	Minimum	Maximum
Price of goats (Kshs/unit)	1397.92	533.14	250	2500
Price of beans (Kshs/kg)	24.24	8.30	20	50
Price of milk (Kshs/kg)	32.08	3.96	30	40
Price of maize (Kshs/kg)	13.56	1.28	11	17
Price of sorghum(Kshs/kg)	21.67	18.28	14	80
Price of millet (Kshs/kg)	36.67	24.63	15	80
Price of peas (Kshs)	17.91	4.68	12	30
Price of cows (Kshs/unit)	23111.11	1421.37	7000	50000
Price of chicken (Kshs/unit)	252.56	33.32	200	400
Daily wages (Kshs)	200	62.02	100	300

APPENDIX A.3

Instrumental Variable Technique

The instrumental variable technique can be formalized as follows; given a regression linking *F* and *Z:*

$$F_i = \beta_0 + \beta_1 Z_i + v_i$$

Where β_0 is the intercept, β_1 is the slope, and v_i is the error term. The equation provides the needed decomposition of F_i. One component is $\beta_0 + \beta_1 Z_i$, the part of F_i that can be predicted by Z_i. Since Z_i is exogenous, this component of F_i is uncorrelated with ε the error term in Equation 3.5 in the text. The other component of F_i is v_i, which is the problematic component of F_i that is correlated with ε. The idea behind TSLS is to use the problem-free component of F_i, $\beta_0 + \beta_1 Z_i$ and to disregard v_i. Unfortunately, this may be complicated in that the values of β_0 and β_1 are unknown and so $\beta_0 + \beta_1 Z_i$ cannot be computed. Consequently, the first stage of TSLS applies OLS to the equation and uses the predicted value from the OLS regression, $\hat{F}_i = \hat{\beta}_0 + \hat{\beta}_1 Z_i$, where $\hat{\beta}_0$ and $\hat{\beta}_1$ are the OLS estimates. The second stage of TSLS entails the regression of Q on $\hat{F}_i$ using OLS. The resulting estimators from the second stage regression are the TSLS estimators, $\hat{\beta}_0^{TSLS}$ and $\hat{\beta}_1^{TSLS}$ (Stock & Watson, 2007; Wooldridge, 2003).

APPENDIX A.4

Production Frontier

A production frontier can be defined as a function that represents the maximum output that can be produced using a given amount of input. It is usually estimated using sample data on the inputs and outputs used by a number of firms. Moreover, for better understanding of production frontiers, a brief description as illustrated by Coelli *et al.* (2003) is given in the hypothetical example in Table and Figure A.

Table A: Hypothetical example

FIRM	INPUT (labour)	OUTPUT (kg)
A	5	7
B	3	5
C	1	1
D	2	2
E	5	6

Source: *Adapted from Coelli et al, 2003*

In Figure A, firms A, B and C are used to construct the frontier from the sample data presented in Table A while firms D and E lie below the frontier. As discussed in the text, Coelli *et al.* (2003) asserts that standard production functions are usually fitted using regression methods and that these regression methods fit a line through the centre of the data, and hence measure average practice. Frontier methods, on the other hand, fit a surface over the data, and hence measure best practice.

From Figure A, the distance between the data point and the frontier determines the technical efficiency (TE) of the farm. For instance, firm E in figure A could potentially increase its output up to the frontier at point A. The TE of firm E is thus defined as being equal to the ratio of what it is producing (6kg) over what it could potentially produce(7kg), given its current level of inputs(5 labourers). TE for firm E is 6/7=0.86 and this can be interpreted to mean that it is producing 86 percent of its potential output. The TE of the frontier firms A, B and C is equal to 1 because they define the frontier. This measure of TE is called output-oriented.

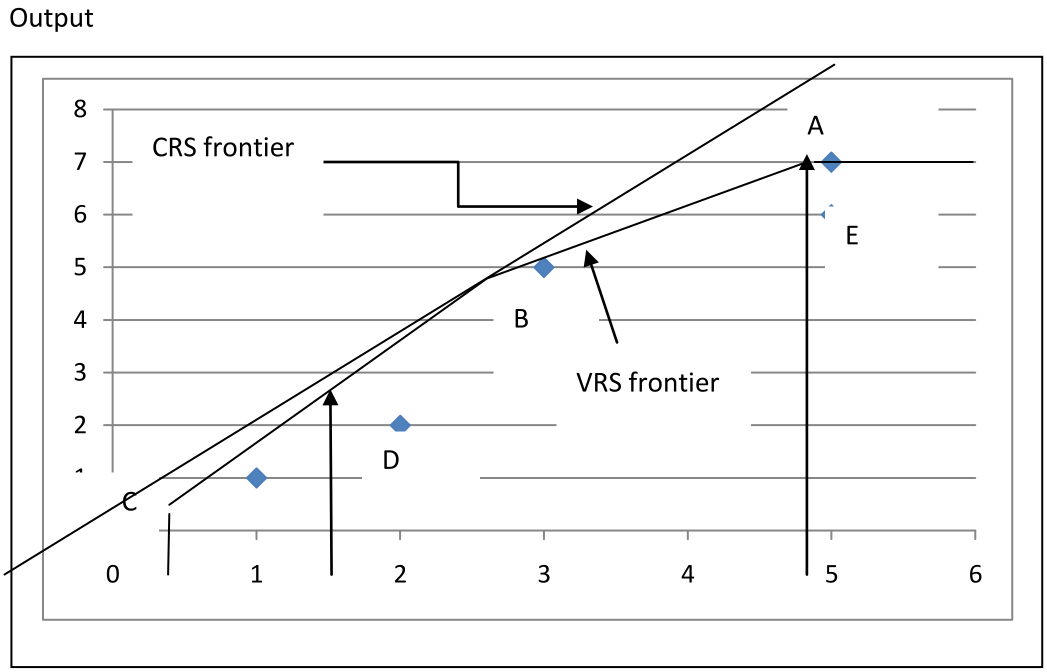

Figure A: A production Frontier

Also as discussed in the main body of the research, SE reflects the fact that there is usually an optimal firm size, and not all firms operate at the optimal size. Thus, to measure scale efficiency, an additional frontier namely, constant returns to scale (CRS) is constructed in figure A to allow firms of any size to be benchmarked against each other and the variable returns to scale (VRS) frontier to allow small firms to be benchmarked against big firms. The distance between each data point and the CRS frontier is called TE_{CRS} .This measure of efficiency will contain both TE and SE. The gap between the CRS and VRS frontier provides a measure of SE.

APPENDIX A.5

DEA Model

DEA measures efficiency by solving separate linear programming (LP) problem for each firm. Charnes *et al.* (1978) introduced the method of DEA which defines a non-parametric frontier and measures the efficiency of each unit relative to that frontier .The output –oriented DEA model for a single output is formalized below (Theodoridis *et al.*, 2008; Dhungana *et al.*, 2004; Sharma *et al.*, 1997).

Assume that farm *j* (j=1, 2,..., 249) produces a single output(y_j) using a combination of inputs x_{ij} (*i*=land, labour, capital, land quality ,fence) as defined in the text. A Separate LP problem is solved for each DMU. λ_j is weight of the *j*-th DMU. The variable return to scale (VRS) output-oriented DEA model for each DMU is expressed as follows:

$$\max_{\theta,\lambda} \theta \quad \text{s.t.} \quad \sum_{j=1}^{n} y_j\lambda_j - y_j\theta \geq 0\,;\; x_{ij} - \sum_{i=1}^{m} x_{ij}\lambda_j \geq 0\;\; ;\sum_{j} \lambda_j = 1\,;\lambda_j \geq 0$$

i = 1, …, m inputs; j = 1, …, n DMUs

where θ is the proportional increase in output that can be obtained by the farm given input vector x_{ij} .The value θ taken at the results is efficiency score of each farm. It will satisfy the condition $\theta \leq 1$, with a value of 1 indicating a point on the frontier and hence a technically efficient farm. The constant returns to scale (CRS) output-oriented model is obtained by eliminating the restriction $\sum_{j} \lambda_j = 1$

The projected or frontier level of production for the *j*th DMU, denoted by

$$`y_j = \sum_{j=1}^{n} \lambda_j y_j = \theta y_j$$

The output-oriented measure of technical efficiency of the *j*th farm unit, denoted by TE_i, can be estimated by

$$TE_j = \frac{y_j}{`y_j} = \frac{1}{\theta}$$

APPENDIX A.6

Data Envelopment Analysis (DEA) General Algebraic Modelling System (GAMS) Model-Total Output

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$ontext

WHAT IN THIS FILE:

    -Data Envelopment Analysis

    -Input vs output oriented DEA

    -Constant returns to scale (CRS-CCR-) vs Variable returns to scale (VRS-BCC-)

$offtext

SET I 'DMU' /DMU1*DMU249/;

SET

    J

    INPUT (J)

    OUTPUT (J)

;

ALIAS (I, II);

    PARAMETER

    DATA (I, J)

    X (INPUT, I)

    Y (OUTPUT, I)

    RESULTS (II,*,*);

    NIRS

;

NIRS=0;

$CALL GDXXRW i=DEA_DATA.xls o=DEA_DATA.gdx index=indexsheet! A1

$gdxin DEA_DATA.gdx

$LOAD J INPUT OUTPUT

$LOAD DATA

$gdxin
```

```
DATA(I,J)=DATA(I,J)/1000;
X (INPUT, I)     = data (I, INPUT);
Y (OUTPUT, I)   = data (I, OUTPUT);

      POSITIVE VARIABLES
      LAMBDA (II,I);
      VARIABLES
      THETA (II)
      Z
      ;
      EQUATIONS
      OBJ
      EQUINPUT1 (II, OUTPUT)
      EQUINPUT2 (II, INPUT)
      CONSTRAIN (II)
      CONSTRAIN2 (II)
      EQUOUTPUT1 (II, INPUT)
      EQUOUTPUT2 (II, OUTPUT)
      ;
           OBJ...
           Z=E=SUM (II, THETA (II));

           EQUINPUT1 (II, OUTPUT)..
           SUM (I, LAMBDA (II, I)*Y (OUTPUT, I)) =G=Y (OUTPUT, II);

           EQUINPUT2 (II, INPUT)..
           THETA(II)*X(INPUT,II)=G=SUM(I,LAMBDA(II,I)*X(INPUT,I));

           EQUOUTPUT1 (II, INPUT)..
           SUM (I, lambda (II, I)*X (INPUT, I)) =l=X (INPUT, II);
```

```
EQUOUTPUT2 (II, OUTPUT)..
THETA(II)*Y(OUTPUT,II)=L=SUM(I,LAMBDA(II,I)*Y(OUTPUT,I));

CONSTRAIN (II) $(NIRS EQ 0)..
SUM (I, LAMBDA (II, I)) =E= 1;

CONSTRAIN2 (II) $(NIRS EQ 1)..
SUM (I, LAMBDA (II, I)) =E= 1;

MODEL INP_CCR /OBJ
EQUINPUT1
EQUINPUT2
/;

MODEL INP_BCC/
OBJ
EQUINPUT1
EQUINPUT2
CONSTRAIN/;

MODEL OUT_CCR/
OBJ
EQUOUTPUT1
EQUOUTPUT2
/;

MODEL OUT_BCC /
OBJ
EQUOUTPUT1
```

```
            EQUOUTPUT2

            CONSTRAIN/;


SOLVE INP_CCR USING LP MINIMIZING Z;

RESULTS (II,'INPUT ORIENTED','CCR_CRS') =THETA.L (II);


SOLVE INP_BCC USING LP MINIMIZING Z;

Results (II,'INPUT ORIENTED','BCC_VRS')=THETA.L(II);


SOLVE OUT_CCR USING LP MAXIMIZING Z;

RESULTS (II,'OUTPUT ORIENTED','CCR_CRS')=1/THETA.L(II);


solve OUT_BCC using lp maximizing z;

RESULTS (II,'OUTPUT ORIENTED','BCC_VRS')=1/THETA.L(II);


EXECUTE_UNLOAD "Result_DEA.gdx" RESULTS


EXECUTE 'gdxxrw.exe Result_DEA.gdx par=RESULTS RNG=RESULTS!A1'
```

APPENDIX A.7

Data Envelopment Analysis (DEA) General Algebraic Modelling System(GAMS) Model- Used to distinguish between crops and livestock

```
$ontext

WHAT IN THIS FILE:
    -Data Envelopment Analysis
    -Input vs output oriented DEA
    -Constant returns to scale (CRS-CCR-) vs Variable returns to scale (VRS-BCC-)
$offtext
SET I 'DMU' /DMU1*DMU249/;
SET
    J
    INPUT (J)
    OUTPUT (J)
;
ALIAS (I, II);
    PARAMETER
    DATA (I, J)
    X (INPUT, I)
    Y (OUTPUT, I)
    RESULTS (II,*,*);
;
$CALL GDXXRW i=DEA_DATA.xls o=DEA_DATA.gdx index=indexsheet! A1
$gdxin DEA_DATA.gdx
$LOAD J INPUT OUTPUT
$LOAD DATA
$gdxin
DATA(I,J)=DATA(I,J)/1000;
```

```
;
X (INPUT, I)       = data (I, INPUT);
Y (OUTPUT, I)      = data (I, OUTPUT);
Y(OUTPUT,I)$(data(I,OUTPUT) EQ 0)      =0.1;

        POSITIVE VARIABLES
        LAMBDA (II,I);

        VARIABLES
        THETA(II)
        Z
        ;
        EQUATIONS
        OBJ
        EQUINPUT1 (II, OUTPUT)
        EQUINPUT2 (II, INPUT)
        CONSTRAIN (II)
        EQUOUTPUT1 (II, INPUT)
        EQUOUTPUT2 (II, OUTPUT)
        ;
            OBJ..
            Z=E=SUM (II, THETA (II));

            EQUINPUT1 (II,"OUTPUTC")..
            SUM (I, LAMBDA (II, I)*Y ("OUTPUTC", I)) =G=Y ("OUTPUTC", II);

            EQUINPUT2 (II, INPUT)..
            THETA(II)*X(INPUT,II)=G=SUM(I,LAMBDA(II,I)*X(INPUT,I));

            EQUOUTPUT1 (II, INPUT)..
```

```
SUM (I, lambda (II, I)*X (INPUT, I)) =l=X (INPUT, II);

EQUOUTPUT2 (II,"OUTPUTC")..
THETA(II)*Y("OUTPUTC",II)=L=(SUM(I,LAMBDA(II,I)*Y("OUTPUTC",I)));

CONSTRAIN (II)..
SUM (I, LAMBDA (II, I)) =E= 1;

MODEL INP_CCR /OBJ
EQUINPUT1
EQUINPUT2
/;

MODEL INP_BCC/
OBJ
EQUINPUT1
EQUINPUT2
CONSTRAIN/;

MODEL OUT_CCR/
OBJ
EQUOUTPUT1
EQUOUTPUT2
/;

MODEL OUT_BCC /
OBJ
EQUOUTPUT1
EQUOUTPUT2
CONSTRAIN/;
```

```
SOLVE INP_CCR USING LP MINIMIZING Z;
RESULTS (II,'INPUT ORIENTED','CCR_CRS') =THETA.L (II);

SOLVE INP_BCC USING LP MINIMIZING Z;
Results (II,'INPUT ORIENTED','BCC_VRS') =THETA.L (II);

SOLVE OUT_CCR USING LP MAXIMIZING Z;
RESULTS (II,'OUTPUT ORIENTED','CCR_CRS') =1/THETA.L (II);

SOLVE OUT_BCC using lp maximizing z;
RESULTS (II,'OUTPUT ORIENTED','BCC_VRS')=1/THETA.L(II);

EXECUTE_UNLOAD "Result_DEA.gdx" RESULTS

EXECUTE 'gdxxrw.exe Result_DEA.gdx par=RESULTS RNG=RESULTS!A1'
```

APPENDIX A.8

Technical Efficiencies and Returns to Scale
(WHOLE SAMPLE)

DMU	CCR_CRS	BCC_VRS	SE	RTS	FENCE
DMU1	0.415896381	0.546210655	0.761421215	IRS	0
DMU2	0.110113523	0.181004550	0.608346712	IRS	0
DMU3	0.988984158	1	0.988984158	DRS	0
DMU4	0.248773473	1	0.248773473	IRS	1
DMU5	0.132266561	0.243298075	0.543639980	IRS	1
DMU6	0.039625805	0.044509662	0.890274219	IRS	1
DMU7	0.035339761	0.062110709	0.568980152	IRS	1
DMU8	0.135265696	0.135265696	1	CRS	0
DMU9	0.086154556	0.100388272	0.858213355	IRS	1
DMU10	0.105596381	0.179115843	0.589542384	IRS	1
DMU11	0.023809730	0.042967125	0.554138317	IRS	1
DMU12	0.060469082	0.083219554	0.726621078	IRS	1
DMU13	0.124211035	0.177661170	0.699145655	IRS	1
DMU14	0.082381170	0.138471004	0.594934449	IRS	1
DMU15	0.241056405	0.506601986	0.475829965	IRS	1
DMU16	0.132675126	0.133420833	0.994410868	IRS	0
DMU17	0.055200063	0.069790783	0.790936290	IRS	1
DMU18	0.336545760	0.352583778	0.954512886	IRS	1
DMU19	0.049271792	0.069410889	0.709856808	IRS	1
DMU20	0.090864529	0.148720571	0.610974857	IRS	1
DMU21	0.085873978	0.512326235	0.167615813	IRS	0
DMU22	0.144418729	0.144646388	0.998426097	IRS	1
DMU23	0.202797676	0.249744150	0.812021724	IRS	1
DMU24	0.082636882	0.153586676	0.538047204	IRS	1
DMU25	0.121287293	0.123151159	0.984865220	IRS	0
DMU26	0.117149942	0.155086423	0.755384900	IRS	1
DMU27	0.249152357	0.249350722	0.999204475	IRS	1
DMU28	0.020761872	0.024482957	0.848013246	IRS	1
DMU29	0.082901397	0.290733308	0.285145853	IRS	1
DMU30	0.145825774	0.247086470	0.590181137	IRS	1
DMU31	0.398699617	0.494692836	0.805953892	IRS	1
DMU32	0.136744022	0.136859955	0.999152907	IRS	1
DMU33	0.197868371	0.197868371	1	CRS	0
DMU34	0.038990966	0.098722250	0.394956211	IRS	1
DMU35	1	1	1	CRS	0
DMU36	0.050204385	0.095285940	0.526881349	IRS	1

DMU37	0.159592041	0.165685069	0.963225244	IRS	1
DMU38	0.832890087	1	0.832890087	IRS	1
DMU39	0.439888683	0.534661041	0.822743102	IRS	1
DMU40	0.416302119	0.418252784	0.995336157	IRS	1
DMU41	0.348953478	0.348953478	1	CRS	0
DMU42	1	1	1	CRS	1
DMU43	0.211269937	0.448865103	0.470675790	IRS	1
DMU44	0.782372204	0.894441995	0.874704239	IRS	1
DMU45	0.209356504	0.226051726	0.926144241	IRS	1
DMU46	1	1	1	CRS	0
DMU47	0.302652152	0.386881182	0.782287086	IRS	1
DMU48	0.145821981	0.145934369	0.999229871	IRS	1
DMU49	0.944772186	0.944772186	1	CRS	0
DMU50	0.862361189	0.862361189	1	CRS	0
DMU51	1	1	1	CRS	1
DMU52	0.278153224	0.278153224	1	CRS	0
DMU53	0.002569743	0.002569743	1	CRS	0
DMU54	0.230011073	0.232938039	0.987434572	IRS	1
DMU55	1	1	1	CRS	0
DMU56	0.013762526	0.013762526	1	CRS	0
DMU57	0.011537028	0.011593056	0.995167094	IRS	1
DMU58	0.005770698	0.005770698	1	CRS	0
DMU59	0.030060734	0.030137371	0.997457100	IRS	1
DMU60	0.098392670	0.112416750	0.875249192	IRS	1
DMU61	0.163168427	0.163297729	0.999208185	IRS	1
DMU62	0.026729481	0.026861121	0.995099232	IRS	1
DMU63	0.019038407	0.019038407	1	CRS	0
DMU64	0.939878446	1	0.939878446	IRS	1
DMU65	1	1	1	CRS	1
DMU66	1	1	1	CRS	0
DMU67	0.028710324	0.030784875	0.932611347	IRS	0
DMU68	0.194096494	0.195249017	0.994097164	IRS	1
DMU69	0.254794278	0.254794278	1	CRS	0
DMU70	0.165646074	0.165646074	1	CRS	0
DMU71	0.702706462	0.719616791	0.976500924	IRS	1
DMU72	0.087333899	0.093757715	0.931484935	IRS	1
DMU73	0.189865504	0.192277841	0.987453900	IRS	1
DMU74	0.381077319	0.419727379	0.907916276	IRS	0
DMU75	0.463184008	0.500063097	0.926251129	IRS	1
DMU76	0.665581723	0.665581723	1	CRS	0
DMU77	0.713627822	0.713627822	1	CRS	0
DMU78	0.068182957	0.068182957	1	CRS	0
DMU79	0.265760572	0.268849785	0.988509522	IRS	1

DMU80	1	1	1	CRS	1
DMU81	0.133188543	0.133188543	1	CRS	0
DMU82	1	1	1	CRS	1
DMU83	1	1	1	CRS	1
DMU84	0.934884462	0.957243715	0.976642047	IRS	1
DMU85	1	1	1	CRS	1
DMU86	0.862897795	0.868833062	0.993168691	IRS	1
DMU87	0.541976942	0.549396493	0.986495090	IRS	1
DMU88	0.824138110	0.837568623	0.983964881	IRS	1
DMU89	0.130183090	0.133139578	0.977794071	IRS	1
DMU90	0.713464671	0.713464671	1	CRS	0
DMU91	1	1	1	CRS	0
DMU92	1	1	1	CRS	1
DMU93	0.893097971	0.915318743	0.975723460	DRS	1
DMU94	0.606322523	0.620344222	0.977396905	IRS	0
DMU95	1	1	1	CRS	0
DMU96	0.329872338	0.329875722	0.999989741	DRS	1
DMU97	0.821558405	0.829670076	0.990223016	DRS	1
DMU98	0.204531419	0.214029043	0.955624598	IRS	1
DMU99	1	1	1	CRS	1
DMU100	0.264087987	0.305343987	0.864886810	IRS	1
DMU101	1	1	1	CRS	1
DMU102	1	1	1	CRS	1
DMU103	0.030077909	0.036369842	0.827001367	IRS	0
DMU104	0.017302433	0.018272667	0.946902444	IRS	0
DMU105	0.303657704	0.476473803	0.637301992	IRS	0
DMU106	0.090180117	0.157482273	0.572636622	IRS	0
DMU107	0.803697200	0.804808463	0.998619221	IRS	0
DMU108	1	1	1	CRS	1
DMU109	0.426787624	0.696472359	0.612784727	IRS	0
DMU110	0.255229742	0.257784429	0.990089832	IRS	1
DMU111	0.344090872	0.344090872	1	CRS	0
DMU112	0.085133929	0.221280782	0.384732591	IRS	1
DMU113	0.120287371	0.121825353	0.987375516	IRS	1
DMU114	0.345188380	0.393115719	0.878083382	IRS	1
DMU115	0.093146966	0.093146966	1	CRS	0
DMU116	0.027540390	0.027911546	0.986702427	IRS	1
DMU117	0.174639120	1	0.174639120	DRS	1
DMU118	0.484430773	1	0.484430773	IRS	1
DMU119	0.437657035	1	0.437657035	IRS	1
DMU120	0.359121869	0.525695437	0.683136743	IRS	1
DMU121	0.039493898	0.042003058	0.940262455	IRS	1
DMU122	0.069532177	0.069532177	1	CRS	0

DMU123	1	1	1	CRS	0
DMU124	0.198329348	0.248046901	0.799563901	IRS	0
DMU125	0.032173228	0.034889923	0.922135272	IRS	1
DMU126	1	1	1	CRS	1
DMU127	0.190477154	0.208419793	0.913911060	IRS	1
DMU128	0.098011662	0.140908234	0.695570863	IRS	1
DMU129	0.031584358	0.032790210	0.963225244	IRS	1
DMU130	0.306522310	0.306522310	1	CRS	0
DMU131	0.184700310	0.184903556	0.998900801	IRS	1
DMU132	1	1	1	CRS	0
DMU133	0.223400700	0.783671703	0.285069243	IRS	1
DMU134	0.693079469	0.693079469	1	CRS	0
DMU135	1	1	1	CRS	0
DMU136	0.250423172	0.314251345	0.796888148	IRS	1
DMU137	0.197001513	0.197001513	1	CRS	0
DMU138	0.114409560	0.126258730	0.906151678	IRS	1
DMU139	0.151797427	0.510178364	0.297537954	IRS	1
DMU140	0.109705531	0.126955530	0.864125659	IRS	1
DMU141	0.197752012	1	0.197752012	IRS	1
DMU142	0.133559989	0.149185377	0.895261933	IRS	1
DMU143	0.166966876	0.320153640	0.521521092	IRS	1
DMU144	0.028562556	1	0.028562556	IRS	1
DMU145	0.339852925	0.546602195	0.621755508	IRS	1
DMU146	0.122391946	0.229115445	0.534193344	IRS	1
DMU147	0.148236434	1	0.148236434	DRS	1
DMU148	0.092964905	0.109828835	0.846452615	IRS	1
DMU149	1	1	1	CRS	1
DMU150	0.023316197	0.023378453	0.997337029	DRS	1
DMU151	1	1	1	CRS	1
DMU152	0.092488595	0.095216213	0.971353430	IRS	1
DMU153	0.211770336	1	0.211770336	IRS	1
DMU154	0.232806899	0.341195722	0.682326547	IRS	1
DMU155	1	1	1	CRS	1
DMU156	1	1	1	CRS	1
DMU157	0.025000366	0.028799844	0.868072969	IRS	1
DMU158	1	1	1	CRS	1
DMU159	0.222043158	1	0.222043158	IRS	1
DMU160	0.265108822	0.407772980	0.650138277	IRS	1
DMU161	0.478920364	1	0.478920364	DRS	1
DMU162	0.039260805	0.414226581	0.094780988	IRS	1
DMU163	0.013749226	0.015962809	0.861328707	IRS	1
DMU164	0.022120707	0.024469187	0.904022953	IRS	1
DMU165	0.007692463	0.011124101	0.691513195	IRS	1

DMU166	0.109982448	0.353965697	0.310714990	DRS	1
DMU167	0.064103822	0.188492697	0.340086503	DRS	1
DMU168	0.059746114	0.089026726	0.671103127	IRS	1
DMU169	0.012257601	1	0.012257601	DRS	1
DMU170	0.093786384	1	0.093786384	DRS	0
DMU171	0.313426711	0.431818964	0.725828962	IRS	0
DMU172	0.001202615	1	0.001202615	DRS	0
DMU173	1	1	1	CRS	0
DMU174	0.052838482	0.052838482	1	CRS	0
DMU175	0.467220128	0.467220128	1	CRS	0
DMU176	0.102896639	0.102896639	1	CRS	0
DMU177	0.111812016	0.111812016	1	CRS	0
DMU178	0.820172470	1	0.820172470	IRS	0
DMU179	0.169205246	0.247124736	0.684695707	IRS	0
DMU180	0.083934372	0.108390211	0.774372255	IRS	0
DMU181	0.016047411	0.016047411	1	CRS	0
DMU182	0.019471049	0.019471049	1	CRS	0
DMU183	0.135903783	0.135903783	1	CRS	0
DMU184	0.145849924	0.145849924	1	CRS	0
DMU185	0.038844342	0.048103228	0.807520487	IRS	0
DMU186	0.156494484	0.195008932	0.802499058	IRS	0
DMU187	0.871936679	1	0.871936679	DRS	0
DMU188	0.069613901	0.113319028	0.614317849	IRS	0
DMU189	0.171544179	0.171544179	1	CRS	0
DMU190	0.662553416	0.662553416	1	CRS	0
DMU191	0.317300429	0.343717178	0.923143937	IRS	0
DMU192	0.801471229	1	0.801471229	DRS	0
DMU193	0.283535495	1	0.283535495	DRS	0
DMU194	1	1	1	CRS	0
DMU195	0.102207029	0.102207029	1	CRS	0
DMU196	0.241943648	0.334314672	0.723700358	IRS	0
DMU197	0.285019905	1	0.285019905	DRS	0
DMU198	0.039040207	0.064518112	0.605104616	DRS	0
DMU199	1	1	1	CRS	0
DMU200	0.062671560	0.111955173	0.559791550	DRS	1
DMU201	0.035605095	0.038002703	0.936909532	IRS	1
DMU202	0.059261135	0.065548450	0.904081397	DRS	1
DMU203	0.569787304	0.572312452	0.995587815	IRS	1
DMU204	0.182478242	1	0.182478242	DRS	1
DMU205	0.095003204	1	0.095003204	DRS	1
DMU206	0.159222668	0.181352255	0.877974570	IRS	1
DMU207	0.021305795	0.025508760	0.835234472	IRS	1
DMU208	0.059318178	1	0.059318178	DRS	1

DMU209	0.009100066	0.010498958	0.866758990	DRS	1
DMU210	1	1	1	CRS	1
DMU211	0.155969653	1	0.155969653	IRS	1
DMU212	0.130732395	0.152297827	0.858399610	DRS	1
DMU213	0.040324874	0.048673329	0.828479895	DRS	1
DMU214	0.131284805	0.306855318	0.427839434	IRS	1
DMU215	0.092861791	0.141057881	0.658324019	IRS	1
DMU216	0.078380706	0.085060405	0.921471113	IRS	1
DMU217	0.123900620	1	0.123900620	IRS	1
DMU218	0.031832024	0.042631417	0.746679946	DRS	1
DMU219	0.222693634	0.354756106	0.627737283	DRS	1
DMU220	0.067055142	0.074718092	0.897441839	DRS	1
DMU221	0.217263255	1	0.217263255	IRS	1
DMU222	0.029341745	0.041837436	0.701327506	DRS	1
DMU223	0.020876355	0.021481643	0.971823007	DRS	1
DMU224	0.055270113	0.081788258	0.675770757	DRS	1
DMU225	0.061875681	0.067423695	0.917714180	IRS	1
DMU226	1	1	1	CRS	1
DMU227	0.025323676	0.050232448	0.504129832	DRS	1
DMU228	0.118394193	0.240978822	0.491305385	IRS	1
DMU229	0.018409439	0.040646033	0.452920931	DRS	1
DMU230	0.046750745	0.050216784	0.930978469	DRS	1
DMU231	0.016665792	0.048448228	0.343991782	DRS	1
DMU232	0.085125946	0.104096077	0.817763248	DRS	1
DMU233	0.016726717	0.024429200	0.684701785	DRS	1
DMU234	0.059396217	0.117792000	0.504246613	DRS	1
DMU235	0.063040700	0.065972239	0.955564059	DRS	1
DMU236	1	1	1	CRS	1
DMU237	0.055612980	0.068914784	0.806981853	DRS	1
DMU238	0.017926487	0.019840041	0.903550876	IRS	1
DMU239	0.051209117	0.059759146	0.856925185	DRS	1
DMU240	0.013869040	0.017007374	0.815472158	DRS	1
DMU241	0.027227863	0.036404867	0.747918207	DRS	1
DMU242	0.041946810	1	0.041946810	DRS	1
DMU243	0.192615359	1	0.192615359	IRS	1
DMU244	0.094377896	0.128362677	0.735244057	DRS	1
DMU245	0.060087282	0.060764958	0.988847581	IRS	0
DMU246	0.061966271	0.095578375	0.648329408	IRS	1
DMU247	0.022430919	0.029355555	0.764111556	IRS	1
DMU248	0.033035460	0.037227297	0.887398842	IRS	1
DMU249	0.101218894	0.148270454	0.682663950	DRS	1

APPENDIX A. 9

Technical Efficiencies and Returns to Scale
(LIVESTOCK PRODUCTION)

DMU	CCR_CRS	BCC_VRS	SE	RTS	FENCE
DMU1	0.011575	0.099169	0.116716	DRS	0
DMU2	0.041262	0.113736	0.362789	DRS	0
DMU3	0.074753	1	0.074753	DRS	0
DMU4	0.04372	1	0.04372	DRS	1
DMU5	0.042938	0.192845	0.222658	IRS	1
DMU6	0.00706	0.027177	0.259791	IRS	1
DMU7	0.020545	0.055672	0.369035	IRS	1
DMU8	3E-05	5.63E-05	0.533202	DRS	0
DMU9	0.035365	0.089571	0.394825	DRS	1
DMU10	0.069801	0.165299	0.422269	IRS	1
DMU11	0.010559	0.034082	0.30981	IRS	1
DMU12	0.018553	0.060812	0.305079	IRS	1
DMU13	0.043091	0.119695	0.360006	IRS	1
DMU14	0.047173	0.124942	0.37756	IRS	1
DMU15	0.181406	0.488391	0.371437	IRS	1
DMU16	0.001521	0.00436	0.348773	DRS	0
DMU17	0.01656	0.046556	0.355705	IRS	1
DMU18	0.046517	0.147751	0.31483	IRS	1
DMU19	0.015807	0.047536	0.332521	IRS	1
DMU20	0.038207	0.111154	0.343733	IRS	1
DMU21	0.027887	0.512326	0.054432	DRS	0
DMU22	1.47E-05	4.18E-05	0.352198	DRS	1
DMU23	0.057839	0.15462	0.37407	IRS	1
DMU24	0.035681	0.120011	0.297309	IRS	1
DMU25	0.005454	0.016433	0.33191	DRS	0
DMU26	0.038745	0.109058	0.35527	DRS	1
DMU27	0.049201	0.107341	0.458365	IRS	1
DMU28	0.004583	0.014874	0.308092	DRS	1
DMU29	0.039476	0.241183	0.163677	DRS	1
DMU30	0.096523	0.213355	0.452403	DRS	1
DMU31	0.116241	0.261885	0.443861	DRS	1
DMU32	0.008658	0.024526	0.353001	DRS	1
DMU33	0.002021	0.006344	0.318538	DRS	0
DMU34	0.031599	0.090081	0.350781	IRS	1

DMU35	0.00142	0.004209	0.337523	DRS	0
DMU36	0.030336	0.085215	0.355989	IRS	1
DMU37	0.00164	0.0029	0.565631	DRS	1
DMU38	0.115014	0.277857	0.413934	DRS	1
DMU39	0.112768	0.223343	0.504908	DRS	1
DMU40	0.054924	0.154709	0.355015	DRS	1
DMU41	2E-05	5.75E-05	0.347567	DRS	0
DMU42	0.275457	0.7152	0.385146	IRS	1
DMU43	0.028987	0.228778	0.126706	IRS	1
DMU44	0.044072	0.222987	0.197646	IRS	1
DMU45	0.035	0.112133	0.312132	IRS	1
DMU46	0.218641	0.663337	0.329608	DRS	0
DMU47	0.105944	0.280601	0.37756	IRS	1
DMU48	0.013018	0.036548	0.356191	IRS	1
DMU49	0.019956	0.09242	0.215928	DRS	0
DMU50	0.001522	0.003996	0.380859	DRS	0
DMU51	1	1	1	CRS	1
DMU52	0.040855	0.044348	0.921258	IRS	0
DMU53	0.00248	0.002516	0.985755	DRS	0
DMU54	0.230011	0.232938	0.987435	IRS	1
DMU55	1	1	1	CRS	0
DMU56	0.013211	0.013211	1	CRS	0
DMU57	0.011537	0.011593	0.995167	DRS	1
DMU58	0.005534	0.005534	1	CRS	0
DMU59	0.030061	0.030137	0.997457	DRS	1
DMU60	0.098393	0.112417	0.875249	DRS	1
DMU61	0.163168	0.163298	0.999208	DRS	1
DMU62	0.026729	0.026861	0.995099	DRS	1
DMU63	0.018836	0.018836	1	CRS	0
DMU64	0.938691	1	0.938691	IRS	1
DMU65	1	1	1	CRS	1
DMU66	1	1	1	CRS	0
DMU67	0.028459	0.030784	0.924465	IRS	0
DMU68	0.19403	0.195227	0.99387	IRS	1
DMU69	0.254399	0.254483	0.999667	IRS	0
DMU70	0.165029	0.165029	1	CRS	0
DMU71	0.063047	0.063345	0.995293	DRS	1
DMU72	0.079244	0.079244	1	CRS	1
DMU73	0.189845	0.192278	0.987347	IRS	1
DMU74	0.069347	0.074697	0.928385	IRS	0
DMU75	0.462863	0.500063	0.92561	IRS	1
DMU76	0.664867	0.664867	1	CRS	0
DMU77	0.704306	0.704306	1	CRS	0

DMU78	0.067458	0.067458	1	CRS	0
DMU79	0.265166	0.267092	0.992786	DRS	1
DMU80	1	1	1	CRS	1
DMU81	0.131299	0.131299	1	CRS	0
DMU82	1	1	1	CRS	1
DMU83	1	1	1	CRS	1
DMU84	0.934842	0.957244	0.976598	IRS	1
DMU85	1	1	1	CRS	1
DMU86	0.862898	0.868833	0.993169	DRS	1
DMU87	0.541241	0.548929	0.985995	DRS	1
DMU88	0.824138	0.837569	0.983965	IRS	1
DMU89	0.106292	0.109046	0.974746	DRS	1
DMU90	0.710219	0.710219	1	CRS	0
DMU91	1	1	1	CRS	0
DMU92	1	1	1	CRS	1
DMU93	0.891824	0.914829	0.974853	IRS	1
DMU94	0.606023	0.620242	0.977075	DRS	0
DMU95	1	1	1	CRS	0
DMU96	0.329872	0.329876	0.99999	IRS	1
DMU97	0.821558	0.82967	0.990223	IRS	1
DMU98	0.130113	0.136628	0.952319	IRS	1
DMU99	1	1	1	CRS	1
DMU100	0.202195	0.212525	0.951392	DRS	1
DMU101	0.893743	1	0.893743	IRS	1
DMU102	0.000796	0.040217	0.019789	IRS	1
DMU103	0.011892	0.023924	0.497096	IRS	0
DMU104	1.8E-05	6.04E-05	0.298404	IRS	0
DMU105	0.15338	0.361482	0.424308	IRS	0
DMU106	0.04673	0.118722	0.393608	IRS	0
DMU107	3.32E-05	6.8E-05	0.488767	IRS	0
DMU108	0.000787	1	0.000787	IRS	1
DMU109	0.262604	0.432571	0.607077	IRS	0
DMU110	3.33E-05	9.56E-05	0.347878	IRS	1
DMU111	0.004381	0.008958	0.489107	IRS	0
DMU112	0.075817	0.215709	0.351476	IRS	1
DMU113	1.54E-05	9.24E-05	0.167113	IRS	1
DMU114	0.15575	0.253537	0.614307	IRS	1
DMU115	3E-05	6.07E-05	0.493929	IRS	0
DMU116	1.69E-05	4.78E-05	0.354158	IRS	1
DMU117	0.173896	1	0.173896	IRS	1
DMU118	0.484431	1	0.484431	DRS	1
DMU119	0.414029	1	0.414029	IRS	1
DMU120	0.35895	0.525295	0.683331	IRS	1

DMU121	3.27E-05	6.67E-05	0.490174	IRS	1
DMU122	7.5E-05	8.31E-05	0.903026	IRS	0
DMU123	0.000347	0.000719	0.483073	IRS	0
DMU124	0.19507	0.248047	0.786426	IRS	0
DMU125	1.88E-05	4.94E-05	0.379795	IRS	1
DMU126	1	1	1	CRS	1
DMU127	1.88E-05	4.67E-05	0.401992	IRS	1
DMU128	5.57E-05	0.000135	0.411746	IRS	1
DMU129	2.31E-05	3.88E-05	0.594938	IRS	1
DMU130	5E-05	6.02E-05	0.830748	IRS	0
DMU131	2.78E-05	0.000146	0.190427	IRS	1
DMU132	1	1	1	CRS	0
DMU133	0.071703	0.659007	0.108805	DRS	1
DMU134	0.00015	0.000156	0.964255	IRS	0
DMU135	0.390116	0.44241	0.881798	IRS	0
DMU136	5.57E-05	8.12E-05	0.686506	IRS	1
DMU137	7.5E-05	8.25E-05	0.908987	IRS	0
DMU138	1.88E-05	5.57E-05	0.337119	IRS	1
DMU139	1.7E-05	0.00078	0.021821	IRS	1
DMU140	1.45E-05	4.05E-05	0.358336	IRS	1
DMU141	2.78E-05	1	2.78E-05	IRS	1
DMU142	3.27E-05	9.93E-05	0.329277	IRS	1
DMU143	1.8E-05	0.00031	0.05817	IRS	1
DMU144	2.34E-05	1	2.34E-05	IRS	1
DMU145	0.339774	0.546423	0.621815	DRS	1
DMU146	0.087722	0.210871	0.416	IRS	1
DMU147	0.148003	1	0.148003	IRS	1
DMU148	8.62E-05	0.000125	0.688118	IRS	1
DMU149	1	1	1	CRS	1
DMU150	0.002356	0.006247	0.377081	IRS	1
DMU151	0.049509	1	0.049509	IRS	1
DMU152	0.002346	0.003534	0.663771	IRS	1
DMU153	0.169044	1	0.169044	IRS	1
DMU154	0.213153	0.327833	0.650187	IRS	1
DMU155	1	1	1	CRS	1
DMU156	0.009394	1	0.009394	DRS	1
DMU157	2.12E-05	0.000106	0.200055	DRS	1
DMU158	0.189919	0.212499	0.893743	DRS	1
DMU159	0.156064	1	0.156064	DRS	1
DMU160	0.241685	0.388547	0.622021	DRS	1
DMU161	0.009437	1	0.009437	DRS	1
DMU162	0.037792	0.414227	0.091234	DRS	1
DMU163	0.004362	0.007486	0.582622	DRS	1

DMU164	0.005355	0.01415	0.378452	DRS	1
DMU165	0.00389	0.008596	0.452564	DRS	1
DMU166	0.109982	0.353966	0.310715	DRS	1
DMU167	0.064104	0.188493	0.340087	DRS	1
DMU168	0.027274	0.07115	0.383339	DRS	1
DMU169	0.009104	1	0.009104	DRS	1
DMU170	0.093315	1	0.093315	DRS	0
DMU171	0.312471	0.431819	0.723615	DRS	0
DMU172	0.000385	1	0.000385	DRS	0
DMU173	0.000385	0.000425	0.907517	DRS	0
DMU174	2E-05	7.23E-05	0.276706	DRS	0
DMU175	2E-05	6.09E-05	0.328482	DRS	0
DMU176	2E-05	6.09E-05	0.328482	DRS	0
DMU177	3E-05	6.3E-05	0.476451	DRS	0
DMU178	0.322388	0.959729	0.335915	IRS	0
DMU179	0.0003	0.001168	0.256837	DRS	0
DMU180	2.22E-05	0.000112	0.198042	DRS	0
DMU181	2E-05	6.23E-05	0.32125	DRS	0
DMU182	3E-05	5.83E-05	0.51442	DRS	0
DMU183	3E-05	6.09E-05	0.492723	DRS	0
DMU184	0.037406	0.041378	0.904001	DRS	0
DMU185	3E-05	9.49E-05	0.316196	DRS	0
DMU186	0.007076	0.00973	0.727209	DRS	0
DMU187	0.843746	1	0.843746	DRS	0
DMU188	0.041834	0.103478	0.404285	DRS	0
DMU189	0.00283	0.005502	0.514435	DRS	0
DMU190	0.00032	0.000933	0.342947	DRS	0
DMU191	3.75E-05	0.000126	0.298477	DRS	0
DMU192	0.780682	1	0.780682	DRS	0
DMU193	0.002542	1	0.002542	DRS	0
DMU194	0.0003	0.000611	0.491175	DRS	0
DMU195	0.00033	0.00069	0.478259	DRS	0
DMU196	0.054273	0.085005	0.638468	DRS	0
DMU197	0.007803	1	0.007803	DRS	0
DMU198	0.0003	0.000476	0.62991	DRS	0
DMU199	1	1	1	CRS	0
DMU200	0.061641	0.110415	0.558268	DRS	1
DMU201	0.035605	0.038003	0.93691	DRS	1
DMU202	0.059261	0.065544	0.904138	DRS	1
DMU203	0.007413	0.009019	0.821978	DRS	1
DMU204	0.079567	1	0.079567	DRS	1
DMU205	0.089022	1	0.089022	DRS	1
DMU206	0.159223	0.181352	0.877975	IRS	1

DMU207	0.019202	0.023257	0.825636	DRS	1
DMU208	0.056916	1	0.056916	DRS	1
DMU209	0.008225	0.009068	0.907027	DRS	1
DMU210	1	1	1	CRS	1
DMU211	0.155558	1	0.155558	DRS	1
DMU212	0.130732	0.152298	0.8584	DRS	1
DMU213	0.038951	0.046562	0.836539	DRS	1
DMU214	0.131285	0.306855	0.427839	DRS	1
DMU215	0.092842	0.141058	0.658184	DRS	1
DMU216	0.078381	0.08506	0.921471	DRS	1
DMU217	0.123901	1	0.123901	DRS	1
DMU218	0.031832	0.042602	0.747194	DRS	1
DMU219	0.222694	0.354756	0.627737	DRS	1
DMU220	0.067055	0.074718	0.897442	DRS	1
DMU221	0.217263	1	0.217263	DRS	1
DMU222	0.029342	0.041756	0.702691	DRS	1
DMU223	0.020808	0.021482	0.968618	DRS	1
DMU224	0.055014	0.081096	0.678385	DRS	1
DMU225	0.061876	0.067424	0.917714	DRS	1
DMU226	1	1	1	CRS	1
DMU227	0.024822	0.048892	0.507696	DRS	1
DMU228	0.118394	0.240979	0.491305	DRS	1
DMU229	0.018238	0.040112	0.454677	DRS	1
DMU230	0.04657	0.049769	0.935726	DRS	1
DMU231	0.015967	0.045886	0.347978	DRS	1
DMU232	0.085126	0.103595	0.821716	DRS	1
DMU233	0.016727	0.024429	0.684702	DRS	1
DMU234	0.059396	0.117456	0.505687	DRS	1
DMU235	0.062971	0.065972	0.954507	DRS	1
DMU236	1	1	1	CRS	1
DMU237	0.055496	0.068387	0.811492	DRS	1
DMU238	0.017926	0.01984	0.903551	DRS	1
DMU239	0.051156	0.059759	0.856042	DRS	1
DMU240	0.013586	0.016505	0.823106	DRS	1
DMU241	0.027221	0.036405	0.747723	DRS	1
DMU242	0.041708	1	0.041708	DRS	1
DMU243	0.192615	1	0.192615	DRS	1
DMU244	0.094378	0.128363	0.735244	DRS	1
DMU245	0.060019	0.060626	0.989993	DRS	0
DMU246	0.061966	0.095578	0.648329	DRS	1
DMU247	0.022431	0.029344	0.764408	DRS	1
DMU248	0.032997	0.037227	0.886373	IRS	1
DMU249	0.101219	0.14827	0.682664	DRS	1

APPENDIX A. 10

Technical Efficiencies and Returns to Scale
(CROPS PRODUCTION)

DMU	CCR_CRS	BCC_VRS	SE	RTS	FENCE
DMU1	0.415896	0.546211	0.761421	IRS	0
DMU2	0.087931	0.093773	0.937694	DRS	0
DMU3	0.939875	1	0.939875	IRS	0
DMU4	0.247584	1	0.247584	DRS	1
DMU5	0.128671	0.139572	0.921899	DRS	1
DMU6	0.039382	0.039423	0.998955	DRS	1
DMU7	0.031293	0.031746	0.98574	IRS	1
DMU8	0.135266	0.135266	1	CRS	0
DMU9	0.058062	0.059169	0.981291	DRS	1
DMU10	0.08913	0.090361	0.986372	IRS	1
DMU11	0.022412	0.022436	0.998955	DRS	1
DMU12	0.047892	0.051069	0.937779	IRS	1
DMU13	0.12063	0.120757	0.998955	DRS	1
DMU14	0.074429	0.075015	0.992193	IRS	1
DMU15	0.123397	0.130344	0.946699	IRS	1
DMU16	0.131342	0.131342	1	CRS	0
DMU17	0.04234	0.045833	0.923785	IRS	1
DMU18	0.335052	0.335402	0.998955	IRS	1
DMU19	0.045237	0.045285	0.99895	DRS	1
DMU20	0.080143	0.080227	0.99895	DRS	1
DMU21	0.078788	0.3016	0.261235	DRS	0
DMU22	0.144419	0.144646	0.998426	DRS	1
DMU23	0.158949	0.171792	0.925243	IRS	1
DMU24	0.075817	0.075896	0.998955	DRS	1
DMU25	0.118967	0.118967	1	CRS	0
DMU26	0.110314	0.110429	0.998952	DRS	1
DMU27	0.24217	0.248408	0.974887	IRS	1
DMU28	0.019633	0.019653	0.99895	DRS	1
DMU29	0.071884	0.081374	0.88338	DRS	1
DMU30	0.061529	0.065381	0.941088	DRS	1
DMU31	0.30166	0.320544	0.941088	DRS	1
DMU32	0.136643	0.136786	0.998955	DRS	1
DMU33	0.197868	0.197868	1	CRS	0
DMU34	0.027438	0.027467	0.99895	DRS	1
DMU35	1	1	1	CRS	0
DMU36	0.039578	0.040033	0.988616	IRS	1

DMU37	0.159592	0.165685	0.963225	DRS	1
DMU38	0.773114	0.972069	0.795328	IRS	1
DMU39	0.351346	0.351346	1	CRS	1
DMU40	0.403722	0.41142	0.981291	IRS	1
DMU41	0.348953	0.348953	1	CRS	0
DMU42	1	1	1	CRS	1
DMU43	0.196388	0.321541	0.61077	IRS	1
DMU44	0.781511	0.847718	0.921899	IRS	1
DMU45	0.208286	0.208504	0.998952	DRS	1
DMU46	1	1	1	CRS	0
DMU47	0.285623	0.28787	0.992193	IRS	1
DMU48	0.145475	0.145716	0.998348	DRS	1
DMU49	0.944772	0.944772	1	CRS	0
DMU50	0.862361	0.862361	1	CRS	0
DMU51	0.000138	0.000138	0.99986	DRS	1
DMU52	0.250926	0.250926	1	CRS	0
DMU53	0.000744	0.000744	1	CRS	0
DMU54	7.24E-05	7.31E-05	0.990952	DRS	1
DMU55	0.004927	0.005099	0.966284	DRS	0
DMU56	0.000917	0.000917	1	CRS	0
DMU57	0.000119	0.00012	0.99337	DRS	1
DMU58	0.000639	0.000639	1	CRS	0
DMU59	0.000119	0.000119	0.994973	DRS	1
DMU60	0.000251	0.00026	0.968449	DRS	1
DMU61	6.39E-05	0.000197	0.323737	DRS	1
DMU62	0.000533	0.00054	0.987643	DRS	1
DMU63	0.000586	0.000586	1	CRS	0
DMU64	0.006458	0.008611	0.749986	DRS	1
DMU65	0.003727	0.004324	0.862024	DRS	1
DMU66	0.001821	0.001821	1	CRS	0
DMU67	0.00089	0.00089	1	CRS	0
DMU68	0.00054	0.000574	0.939979	DRS	1
DMU69	0.002079	0.002079	1	CRS	0
DMU70	0.002455	0.002455	1	CRS	0
DMU71	0.702128	0.716937	0.979344	IRS	1
DMU72	0.034423	0.036476	0.943714	DRS	1
DMU73	0.000241	0.000416	0.578595	DRS	1
DMU74	0.347887	0.367923	0.945543	DRS	0
DMU75	0.003781	0.004282	0.882902	DRS	1
DMU76	0.003566	0.003566	1	CRS	0
DMU77	0.013483	0.013483	1	CRS	0
DMU78	0.00096	0.00096	1	CRS	0
DMU79	0.06937	0.072966	0.95071	DRS	1

DMU80	0.932571	0.935008	0.997394	IRS	1
DMU81	0.002454	0.002454	1	CRS	0
DMU82	0.004144	0.004193	0.988457	DRS	1
DMU83	1	1	1	CRS	1
DMU84	0.003297	0.003449	0.955944	DRS	1
DMU85	0.002798	0.003079	0.908653	DRS	1
DMU86	0.07488	0.07488	1	CRS	1
DMU87	0.002828	0.00317	0.89222	DRS	1
DMU88	0.058746	0.060134	0.976923	DRS	1
DMU89	0.037943	0.03854	0.984496	DRS	1
DMU90	0.005452	0.005452	1	CRS	0
DMU91	1	1	1	CRS	0
DMU92	0.000315	0.000384	0.820131	DRS	1
DMU93	0.003583	0.00462	0.775675	DRS	1
DMU94	0.002438	0.002438	1	CRS	0
DMU95	0.003537	0.003537	1	CRS	0
DMU96	0.000252	0.000345	0.728485	DRS	1
DMU97	0.10594	0.116678	0.907968	IRS	1
DMU98	0.086216	0.086925	0.991842	DRS	1
DMU99	0.114078	0.121219	0.941088	DRS	1
DMU100	0.100913	0.103484	0.975153	DRS	1
DMU101	0.316385	1	0.316385	DRS	1
DMU102	1	1	1	CRS	1
DMU103	0.023981	0.024089	0.995518	DRS	0
DMU104	0.017302	0.018273	0.946902	DRS	0
DMU105	0.16112	0.166921	0.965251	DRS	0
DMU106	0.046696	0.048377	0.965251	DRS	0
DMU107	0.803697	0.804808	0.998619	IRS	0
DMU108	1	1	1	CRS	1
DMU109	0.338291	0.350333	0.965627	IRS	0
DMU110	0.25523	0.257784	0.99009	DRS	1
DMU111	0.344091	0.344091	1	CRS	0
DMU112	0.014438	0.014931	0.966979	DRS	1
DMU113	0.120287	0.121825	0.987376	DRS	1
DMU114	0.214355	0.227774	0.941088	DRS	1
DMU115	0.093147	0.093147	1	CRS	0
DMU116	0.02754	0.027912	0.986702	IRS	1
DMU117	0.005499	1	0.005499	DRS	1
DMU118	0.0009	1	0.0009	DRS	1
DMU119	0.054501	0.068526	0.795328	DRS	1
DMU120	0.001573	0.003092	0.508725	DRS	1
DMU121	0.039494	0.042003	0.940262	DRS	1
DMU122	0.069532	0.069532	1	CRS	0

DMU123	1	1	1	CRS	0
DMU124	0.017546	0.017546	1	CRS	0
DMU125	0.032173	0.03489	0.922135	IRS	1
DMU126	0.011735	0.017977	0.652767	DRS	1
DMU127	0.190477	0.20842	0.913911	IRS	1
DMU128	0.098012	0.140908	0.695571	DRS	1
DMU129	0.031584	0.03279	0.963225	DRS	1
DMU130	0.306522	0.306522	1	CRS	0
DMU131	0.1847	0.184904	0.998901	IRS	1
DMU132	0.001873	0.001873	1	CRS	0
DMU133	0.176001	0.294785	0.597049	IRS	1
DMU134	0.693079	0.693079	1	CRS	0
DMU135	1	1	1	CRS	0
DMU136	0.250423	0.314251	0.796888	DRS	1
DMU137	0.197002	0.197002	1	CRS	0
DMU138	0.11441	0.126259	0.906152	IRS	1
DMU139	0.151797	0.510178	0.297538	DRS	1
DMU140	0.109706	0.126956	0.864126	IRS	1
DMU141	0.197752	1	0.197752	DRS	1
DMU142	0.13356	0.149185	0.895262	DRS	1
DMU143	0.166967	0.320154	0.521521	DRS	1
DMU144	0.028563	1	0.028563	DRS	1
DMU145	0.00139	0.002135	0.651162	DRS	1
DMU146	0.046995	0.051421	0.913929	IRS	1
DMU147	0.005499	1	0.005499	DRS	1
DMU148	0.092965	0.109829	0.846453	DRS	1
DMU149	1	1	1	CRS	1
DMU150	0.02306	0.023112	0.997787	DRS	1
DMU151	1	1	1	CRS	1
DMU152	0.092489	0.095216	0.971353	DRS	1
DMU153	0.09791	1	0.09791	DRS	1
DMU154	0.040149	0.040149	1	CRS	1
DMU155	0.05105	0.07243	0.704819	DRS	1
DMU156	1	1	1	CRS	1
DMU157	0.025	0.028792	0.868314	DRS	1
DMU158	1	1	1	CRS	1
DMU159	0.091665	1	0.091665	DRS	1
DMU160	0.053886	0.063347	0.850642	DRS	1
DMU161	0.476093	1	0.476093	DRS	1
DMU162	0.005562	0.011847	0.469437	DRS	1
DMU163	0.010834	0.012736	0.850642	DRS	1
DMU164	0.018527	0.020126	0.920537	IRS	1
DMU165	0.004671	0.005074	0.920671	DRS	1

DMU166	0.030208	0.030798	0.980825	DRS	1
DMU167	0.006291	0.006409	0.981569	DRS	1
DMU168	0.041025	0.043755	0.937614	IRS	1
DMU169	0.005874	1	0.005874	DRS	1
DMU170	0.000685	0.003967	0.172642	DRS	0
DMU171	0.002933	0.003419	0.857779	DRS	0
DMU172	0.000909	1	0.000909	DRS	0
DMU173	1	1	1	CRS	0
DMU174	0.052838	0.052838	1	CRS	0
DMU175	0.46722	0.46722	1	CRS	0
DMU176	0.102897	0.102897	1	CRS	0
DMU177	0.111812	0.111812	1	CRS	0
DMU178	0.627764	0.627764	1	CRS	0
DMU179	0.169205	0.247125	0.684696	DRS	0
DMU180	0.083934	0.10839	0.774372	DRS	0
DMU181	0.016047	0.016047	1	CRS	0
DMU182	0.019471	0.019471	1	CRS	0
DMU183	0.135904	0.135904	1	CRS	0
DMU184	0.14585	0.14585	1	CRS	0
DMU185	0.038844	0.048103	0.80752	DRS	0
DMU186	0.156494	0.194343	0.805248	DRS	0
DMU187	0.078099	0.158737	0.492003	DRS	0
DMU188	0.050206	0.050206	1	CRS	0
DMU189	0.171544	0.171544	1	CRS	0
DMU190	0.662553	0.662553	1	CRS	0
DMU191	0.3173	0.343655	0.923312	IRS	0
DMU192	0.032213	1	0.032213	DRS	0
DMU193	0.283535	1	0.283535	DRS	0
DMU194	1	1	1	CRS	0
DMU195	0.102207	0.102207	1	CRS	0
DMU196	0.241944	0.310553	0.779074	DRS	0
DMU197	0.281444	1	0.281444	DRS	0
DMU198	0.038923	0.064518	0.603295	DRS	0
DMU199	0.001622	1	0.001622	DRS	0
DMU200	0.00341	0.007958	0.428468	DRS	1
DMU201	9.74E-05	0.000114	0.854581	DRS	1
DMU202	0.000753	0.00076	0.991644	DRS	1
DMU203	0.569787	0.572312	0.995588	IRS	1
DMU204	0.136144	1	0.136144	DRS	1
DMU205	0.015387	1	0.015387	DRS	1
DMU206	0.009148	0.009269	0.987015	DRS	1
DMU207	0.008413	0.010574	0.795553	DRS	1
DMU208	0.00444	1	0.00444	DRS	1

DMU209	0.001259	0.002035	0.618941	DRS	1
DMU210	0.024148	1	0.024148	DRS	1
DMU211	0.004345	1	0.004345	DRS	1
DMU212	0.000433	0.000565	0.766634	DRS	1
DMU213	0.002467	0.004199	0.587697	DRS	1
DMU214	0.015068	0.038374	0.392659	DRS	1
DMU215	0.000515	0.000579	0.888977	DRS	1
DMU216	0.000771	0.000773	0.997382	DRS	1
DMU217	0.000472	1	0.000472	DRS	1
DMU218	0.000611	0.001068	0.571962	DRS	1
DMU219	0.000984	0.003207	0.306937	DRS	1
DMU220	0.000411	0.00053	0.77669	DRS	1
DMU221	0.000969	1	0.000969	DRS	1
DMU222	0.000564	0.00175	0.322363	DRS	1
DMU223	0.000227	0.000227	1	CRS	1
DMU224	0.001262	0.002387	0.528946	DRS	1
DMU225	0.001469	0.001473	0.997497	DRS	1
DMU226	0.003807	0.003807	1	CRS	1
DMU227	0.001077	0.002601	0.414142	DRS	1
DMU228	0.000704	0.001625	0.433469	DRS	1
DMU229	0.000518	0.001266	0.409308	DRS	1
DMU230	0.002541	0.002549	0.996854	DRS	1
DMU231	0.001247	0.004617	0.270107	DRS	1
DMU232	0.001076	0.002233	0.481739	DRS	1
DMU233	0.000282	0.000425	0.662398	DRS	1
DMU234	0.000518	0.001689	0.306745	DRS	1
DMU235	0.000367	0.000448	0.817529	DRS	1
DMU236	0.001969	1	0.001969	DRS	1
DMU237	0.001261	0.002447	0.515488	DRS	1
DMU238	0.000235	0.000269	0.871986	DRS	1
DMU239	0.000252	0.000318	0.790254	DRS	1
DMU240	0.00061	0.001126	0.541982	DRS	1
DMU241	0.000301	0.000414	0.72747	DRS	1
DMU242	0.001401	1	0.001401	DRS	1
DMU243	0.000176	1	0.000176	DRS	1
DMU244	0.000423	0.000478	0.884947	DRS	1
DMU245	0.001555	0.001555	1	CRS	0
DMU246	0.000517	0.001229	0.420781	DRS	1
DMU247	0.000238	0.000354	0.672001	DRS	1
DMU248	0.000353	0.000353	0.998921	DRS	1
DMU249	0.000146	0.000295	0.493498	DRS	1