Economic analysis of beef cattle farmers' technical efficiency and willingness to comply with Disease Free Zones in Kenya

by

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Declaration

The contents of this thesis are my original research work and have not been presented elsewhere for any other award. I confirm that the word length is within the prescribed limit as advised by my school. There is no collaborative or jointly-owned work in this thesis, whether published or not. Any form of support received for the study and all cited work have been duly acknowledged.

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Otieno, D. J., Ruto, E. and Hubbard, L. (2010), 'Cattle farmers' preferences for Disease Free Zones: A choice experiment analysis in Kenya' A contributed oral paper presented at the 84th Annual Conference of the Agricultural Economics Society (AES), 29-31 March, University of Edinburgh, Scotland. Available from: http://purl.umn.edu/91951, http://www.aes.ac.uk/_pdfs/_conferences/245_paper.pdf

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Abstract

In Kenya, the cattle enterprise is an important source of livelihood for many farmers. However, lack of analytical evidence on efficiency levels of farmers in various production systems constrains policy making on optimal resource allocation. In addition, inability to control livestock diseases, such as Foot and Mouth Disease (FMD), has led to low beef supply in Kenya and loss of export markets. Although the government of Kenya plans to establish Disease Free Zones (DFZs) to address the disease challenge, there is no empirical evidence on farmers' willingness to comply with DFZs.

This study analyses farmers' technical efficiency (TE) and willingness to comply with DFZs, across three main cattle production systems in Kenya. Primary data were gathered through household surveys using a structured questionnaire and a choice experiment (CE) based on a *D-optimal* design. The stochastic metafrontier model was applied to estimate TE and technology gaps across farms. Subsequently, possible determinants of TE were assessed using a Tobit model. In addition, farmers' preferences for DFZ attributes and various possible policy scenarios were investigated using a random parameter logit (RPL) model.

Results show that there is significant inefficiency in both the nomadic and agro-pastoral systems, but less in ranches. Further, in contrast with the other two systems, ranches are found to have higher meta-technology ratios (MTRs). The average pooled TE with respect to the metafrontier is estimated to be 0.69, which suggests that there is considerable scope to improve beef production in Kenya. The main factors that are found to have a positive influence on TE include: use of controlled cattle breeding method, access to market contract, presence of farm manager, off-farm income and larger herd size. The findings also show that farmers would be willing to pay to participate in a DFZ where: adequate training is provided on pasture development, record keeping and disease monitoring; market information is provided and sales contract opportunities are guaranteed; cattle are properly labelled for ease of identification; and some monetary compensation is provided in the event that cattle die due to severe disease outbreaks. In general, there is a higher preference for DFZ policy scenarios that incorporate training, and market information and contract. Further, farmers with relatively low TE, and typically limited access to disease control services, are shown to be more willing to participate in the DFZs. These insights should guide policies on beef cattle production and the design of DFZ programmes in Kenya and other countries that face similar challenges.

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Acronyms

AE	Allocative Efficiency
ACP	Africa, Caribbean and the Pacific
AES	Agricultural Economics Society
AI	Artificial Insemination
AnGR (s)	Animal Genetic Resource (s)
APP	Average Physical Product
AoA	Agreement on Agriculture
ASAL (s)	Arid and Semi-Arid Land (s)
ASC	Alternative Specific Constant
ATIRI	Agricultural Technology and Information Response Initiative (Kenya)
AU-IBAR	African Union-Interafrican Bureau for Animal Resources
BJD	*Bovine Johne's* Disease
BSE	*Bovine Spongiform Encephalopathy*
CA	Conjoint Analysis
CAC	*Codex Alimentarius* Commission
CAIS	Central Artificial Insemination Station (Kenya)
CBO (s)	Community-Based Organization (s)
CBP	Contagious *Bovine Pleuropneumonia*
CE	Choice Experiment
CM	Choice Modelling
CRS	Constant Returns to Scale
CS	Compensating Surplus
CSC	Commonwealth Scholarship Commission
CV	Contingent Valuation
DEA	Data Envelopment Analysis
DFZ	Disease Free Zone
DMU	Decision Making Unit
DRS	Decreasing Returns to Scale
EC	European Commission
EPA (s)	Economic Partnership Agreement (s)
EPZ	Export Processing Zone (Kenya)
ETGR	Environment-Technology Gap Ratio
EU	European Union

FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization Statistical Database
FGD (s)	Focus Group Discussion (s)
FMD	Foot and Mouth Disease
FML	Finite Mixture Logit
GDP	Gross Domestic Product
HACCP	Hazard Analysis and Critical Control Point
HEV	Heteroscedastic Extreme Value
IIA	Independence from Irrelevant Alternatives
IID	Independent and Identically Distributed
IPPC	International Plant Protection Convention
IRS	Increasing Returns to Scale
IVS	Independent Valuation and Summation
JAE	Journal of Agricultural Economics
KARI	Kenya Agricultural Research Institute
KEBS	Kenya Bureau of Standards
KEVEVAPI	Kenya Veterinary Vaccine Production Institute
KIPPRA	Kenya Institute for Public Policy Research and Analysis
KLMC	Kenya Livestock Marketing Council
KMC	Kenya Meat Commission
KNAIS	Kenya National Artificial Insemination Service
KNBS	Kenya National Bureau of Statistics
KSB	Kenya Stud Book
KVB	Kenya Veterinary Board
LCM	Latent Class Modelling
LP	Linear Programming
LPM	Linear Probability Model
LR	Likelihood Ratio
LTMSK	Livestock Trading and Marketing Society of Kenya
MNL	Multinomial Logit
MoA	Ministry of Agriculture (Kenya)
MPP	Marginal Physical Product
MRS	Marginal Rate of Substitution
MTR	Meta-Technology Ratio
NALEP	National Agriculture and Livestock Extension Programme (Kenya)

OIE	Office of International Epizootics
OLS	Ordinary Least Squares
PCPB	Pest Control Product Board (Kenya)
PPB	Pharmacy and Poisons Board (Kenya)
QP	Quadratic Programming
RP	Revealed Preference
RPL	Random Parameters Logit
RTS	Returns To Scale
RVF	Rift Valley Fever
SD	Standard Deviation
SFA	Stochastic Frontier Approach
SP	Stated Preference
SPS	Sanitary and Phytosanitary
SSA	Sub-Saharan Africa
TAA	Tropical Agriculture Association
TE	Technical Efficiency
TGR	Technology Gap Ratio
TPP	Total Physical Product
UK	United Kingdom
UNIDO	United Nations Industrial Development Organization
USA	United States of America
USFDA	United States Food and Drug Administration
VCF	Veterinary Cordon Fence
VIF	Variance Inflation Factor
VRS	Variable Returns to Scale
WHO	World Health Organization
WTA	Willingness To Accept
WTO	World Trade Organization
WTP	Willingness To Pay

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Chapter One

1. Background of the Study

1.1 Introduction

This study focuses on the analysis of Kenyan beef cattle farmers' technical efficiency (TE) and their willingness to comply with Disease Free Zones (DFZs). In total, the thesis contains eight chapters. In this background chapter, the context of the study is set by discussing the importance of farmer efficiency and compliance with DFZs, as a Sanitary and Phytosanitary (SPS) measure. In addition, it highlights the relative contribution of beef cattle enterprises to Kenya's economy. Furthermore, the research issues, objectives and justification of the study are presented in this chapter, which concludes with a summary of the thesis structure.

1.2 Context of the study

Rapid population growth and changes in consumer preferences due to urbanisation, among other factors, in many countries contribute to higher demand for food, especially meat and milk (Delgado *et al*. 1999; Rosegrant *et al*. 2001; FAO, 2009a). This suggests that it is important to enhance the supply system, for instance by improving resource utilisation at the farm level. Indeed, considering the general challenge of resource scarcity, it is worthwhile to enhance farmers' ability to supply more or at least current levels of output at minimum cost.

According to the seminal work of Farrell (1957), the ability to produce a given level of output at the lowest cost is known as efficiency. This differs from productivity, which measures the output per unit of inputs (Coelli *et al*., 2005). Further, Farrell (1957) defined economic efficiency as a product of technical efficiency (TE) and allocative efficiency (AE). The TE measures the ability of a firm to produce maximum output from a given level of inputs, or achieve a certain output threshold using a minimum quantity of inputs, under a given technology. This reflects the ability to operate on the highest feasible point along the production frontier. In contrast, the AE refers to the use of inputs in optimal proportions to produce a given quantity of output at minimum cost, considering existing technology and prices of inputs. It is worthwhile to note, that in the efficiency literature, the term frontier is commonly used (rather than function) to emphasise the fact that the efficient function yields the highest possible output that is technologically feasible (Coelli *et al*., 2005). Measurement of TE provides useful insights that may enhance decision-making on optimal use of resources and effective capacity utilisation (Aigner *et al*., 1977; Kumbhakar and Lovell, 2000). As noted by Abdulai and Tietje (2007), analysis of TE can also deliver important information on competitiveness of farms and their potential for increasing productivity.

In addition to improving the efficiency at the farm-level, it is important to enhance the quality of output. Generally, the World Trade Organization (WTO) agreement on the application of SPS measures provides guidelines for countries to protect their production from pests and diseases (WTO, 1995a). Some of the SPS measures include disease mitigation strategies at the farm-level or border measures such as import tariffs and bans (see section 2.3 in chapter 2 for details). Compliance with the SPS measures is necessary in order to provide safe food for consumers and to enable farmers to access high value markets (Hall *et al*., 2004).

In livestock production and trade, some of the SPS measures (referred to as zoosanitary measures for animals) include disease mitigation strategies such as vaccinations, culling animals and establishing a Disease Free Zone (DFZ). A DFZ may be described as a programme whereby a country or region is demarcated into sub-units on the basis of the level of cattle disease incidence; safe and non-safe areas, and various disease control strategies are applied in the different regions or zones. The zoning may also consider existing geographic features and/or production systems, for ease of programme administration and policy coherence (Zepeda *et al*., 2005). DFZs are specifically prescribed by the WTO, to manage the spread of four main trans-boundary cattle diseases that are officially recognised to be of considerable economic importance – Foot and Mouth Disease (FMD), Contagious *Bovine Pleuropneumonia* (CBP), mad cow disease (*Bovine Spongiform Encephalopathy*-BSE) and Rinderpest (WTO, 1995a). In Kenya, the design of DFZs is still at a pilot stage (Republic of Kenya, 2008a); hence it is important to understand how farmers would like the DFZs to be designed.

This study investigates farmers' TE and willingness to comply with DFZs in three main beef cattle production systems (nomadic pastoralism, agro-pastoralism and ranches) in Kenya.

1.3 An overview of Kenya's economy and livestock sector

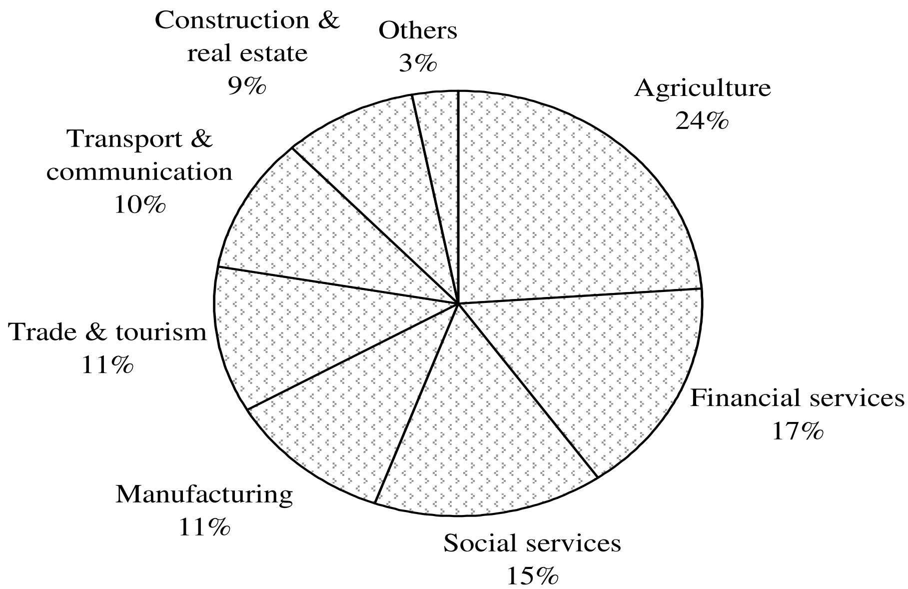
Kenya is a developing economy situated on the East African coast on the equator at $1^{0}00'$N, $38^{0}00'$E. It is bordered by Ethiopia and the Republic of South Sudan to the north, the Indian Ocean and Somalia to the east, the United Republic of Tanzania to the south, and Uganda and Lake Victoria to the west (Figure 1). Kenya's human population is estimated to be 38.6 million (Republic of Kenya, 2010a) and it has a total Gross Domestic Product (GDP) of about USD$34.6 billion (Republic of Kenya, 2010b). The total area of the country is approximately 582, 650 km^2, of which only 17 percent is suitable for crop farming, while the rest is Arid and Semi-Arid Lands (ASALs). The arable land is mainly used for cultivation of export crops (e.g., coffee, horticulture and tea), dairy farming and production of food crops such as maize. Livestock production is the main economic activity in the ASALs, where 20 percent of the national population lives (KIPPRA, 2009).

Figure 1: Geographic location of Kenya

Source: World Atlas (2011a).

The relative contribution of different sectors to Kenya's national GDP is shown in Figure 2. Agriculture (crops, livestock and fisheries) contributes nearly a quarter of Kenya's GDP. Other important activities that generate considerable output to the economy include: financial services, social services (e.g., education and health), manufacturing, trade and tourism, transport and communication, and construction and real estates (KNBS, 2009). The livestock sector in Kenya contributes about 10 percent of the national GDP, approximately 42 percent of total agricultural output and about 30 percent of marketed agricultural output (KIPPRA, 2009).

Figure 2: Sectoral contribution to Kenya's GDP in 2008



Source: KNBS (2009).

More than 60 percent of Kenya's livestock is found in the ASALs, and the livestock sector accounts for 90 percent of employment and more than 95 percent of family incomes in those areas (Otieno, 2008; KIPPRA, 2009). On average, Kenya's livestock herd comprises approximately 31.8 million chicken, 14.1 million indigenous cattle and 3.4 million exotic cattle; about 9.5 million of these are beef cattle (70 percent are kept in the ASALs) while the rest comprise dairy and multipurpose cattle. There are also about 27.7 million goats, 17.1 million sheep, 3 million camels, 1.8 million donkeys, 334,700 pigs, and other emerging livestock enterprises such as bee keeping (Republic of Kenya, 2010a). About 35 percent of the total livestock output and 80 percent of income from red meat trade in Kenya is derived from beef cattle (EPZ, 2005). Moreover, cattle production is an important source of livelihood for more than two-thirds of the population, especially those residing in the remote rural and marginal or dry areas (Kristjanson *et al*., 2004). However, frequent outbreaks of transboundary cattle diseases, especially FMD and Rift Valley Fever (RVF), and the associated zoonotic food-borne illnesses often cause considerable losses (Otieno, 2008). These diseases are classified as transboundary because they spread fast across borders and might significantly reduce livestock populations, and could lead to huge losses in livelihoods and economies across regions (Asiedu *et al*., 2009).

There are three main beef cattle production systems in Kenya, i.e., nomadic pastoralism, agro-pastoralism, and ranches. **Nomadic pastoralists** (also referred to as nomads) are usually found in climatically marginalised (mostly drier) environments; they are less sedentary and migrate seasonally with cattle and other livestock in search for pasture and water (Fratkin, 2001). They are less commercialised, but derive a relatively large share of their livelihood from cattle and other livestock. Generally, nomads are considered to maintain cattle principally as a capital and cultural asset, and sell only when absolutely necessary (Thornton *et al*., 2007). In contrast, the **agro-pastoralists** are sedentary; they keep cattle and other livestock, besides cultivating crops, and are relatively commercialised. Finally, **ranchers** run purely commercial livestock enterprises; and may also grow some crops mainly for use as on-farm fodder or for sale. Ranchers mainly use controlled grazing on their private land, and purchased supplementary feeds. In contrast, the nomads and agro-pastoralists generally depend on open grazing, with limited use of purchased feeds (except during dry periods). Nomadic pastoralism and agro-pastoralism together supply about 65 percent of beef in Kenya, while the rest is obtained from ranches and dairy-culls (Aklilu, 2002; Omiti and Irungu, 2002).

1.4 Research problem statement

There is an extensive literature on TE analysis on crop, dairy and mixed crop-livestock enterprises. However, published research on TE of beef cattle farms is limited; exceptions include Featherstone *et al*. (1997), Rakipova *et al*. (2003), Iraizoz *et al*. (2005), Hadley (2006), Barnes (2008), Ceyhan and Hazneci (2010) and Fleming *et al*. (2010). A detailed documentation of some TE studies focusing on crops and other agricultural enterprises can be found in Bravo-Ureta *et al*. (2007). In Kenya, no study has analysed TE in beef cattle production, despite the considerable contribution of livestock to livelihoods and agricultural output (KIPPRA, 2009). The few TE studies undertaken in Kenya mainly focus on crops (e.g., Liu and Myers, 2009, Mulwa *et al*., 2009a&b, and Nyagaka *et al*., 2010) and dairy farms (e.g., Kavoi *et al*., 2010).

Livestock and crop enterprises in Kenya are generally characterised by stagnating or declining productivity (KIPPRA, 2009). This is partly due to high unit cost of production and inability by farmers to afford high yielding farm technologies. Further, public funds allocated to livestock development are relatively low (generally less than 10 percent of annual national development expenditure) (Otieno, 2008; Mugunieri *et al*., 2011). Moreover, there is limited investment in the provision of livestock inputs such as veterinary and extension services, or market infrastructure. Public agricultural research and extension services are relatively limited in scope due to inadequate number of trained personnel (Oluoch-Kosura, 2010). Further, private extension providers tend to focus mainly on high value export crops (e.g., coffee, horticulture, tea) and dairy (Muyanga and Jayne, 2006); service provision to beef cattle farmers is very limited. These issues might have a considerable bearing on beef cattle farmers' production decisions and efficiency levels. Research on the TE of beef cattle production systems is important in order to fill the knowledge gap, as well as to offer insights to farmers' decisions on resource allocation and government policies on livestock development. Furthermore, as noted by Babagana and Leyland (2008), improving efficiency might enable developing countries such as Kenya to produce requisite output for the domestic market and/or export.

Inability to control livestock diseases, such as FMD, is also a challenge to the country's beef sub sector (Irungu, 2002). Frequent disease outbreaks cause considerable losses including death of cattle, loss of production and incomes; these affect farmers and other actors in the livestock value chains. For instance, Kenyan livestock farmers incurred large losses in income in 2006/2007 due to outbreaks of two important diseases; FMD and RVF, at a time when cattle prices were seasonally higher. Further, domestic consumers were affected by *zoonotic* food-borne illnesses and in severe cases some human lives were lost. Many workers in abattoirs also lost jobs for over two months, while some traders were unable to continue abattoir operations post-outbreak due to depletion of their cash reserves during the closure occasioned by the outbreak (Rich and Wanyoike, 2010).

Due to supply-side constraints, including disease-endemic status, Kenya is unable to utilise preferential export market access. For example, the relatively low quota allocation for beef exports (142 metric tonnes annually) to the European Union (EU) has never been achieved. The country's total beef export supply has been on a steady decline from about 4,000 metric tonnes in 1977 to less than 100 tonnes in 2004. Key export markets for beef (e.g., Japan) have been lost and only a few live cattle are occasionally exported to the Middle East and Mauritius (Otieno, 2008).

In response to the disease challenges, the government of Kenya plans to establish some DFZs in various parts of the country, with initial focus mainly on rehabilitation of previous livestock holding grounds, upgrading of abattoirs and separation of wildlife from livestock ranches (Ackello-Ogutu *et al*., 2006; Republic of Kenya, 2008a). Generally, the need to enhance compliance with SPS measures (e.g., DFZs) at the farm-level is relatively well documented (see for example, Hall *et al*., 2004). However, there is no empirical evidence on farmers' preferences for DFZs. The lack of research insights limits assessment of acceptability and implementation of the proposed DFZs, considering that it is a relatively new concept in Kenya.

By its nature, a DFZ divides a country into sub-regions; the safe and non-safe. This demarcation creates a price differential between regions, and might provide an incentive for farmers to smuggle cattle during a disease outbreak from the low-priced infected region to the high-priced disease-free area. If inter-regional movements occur, then the DFZ might be rendered ineffective in assuring a safe and stable beef supply (Loppacher *et al*., 2006). There is lack of information on how compliance with DFZs could be enforced in Kenya. Major beef exporting countries such as Botswana, Brazil, Namibia and Australia where DFZs have succeeded are mainly characterised by clear demarcation of cattle producing and non-producing zones, and substantial financial support from the government for the programme. In Kenya however, some of these aspects are not feasible considering differences across production systems and resource limitations. For instance, encroachment due to differences in land ownership and grazing systems often cause conflicts between pastoralists and other land users in Kenya (Obunde *et al*., 2005). Also, most developing countries (including Kenya) are faced with budgetary constraints and would be unlikely to be able to provide full funding for DFZs on a long term basis. It is therefore necessary to investigate farmers' preferences on various aspects of DFZs, including funding.

Finally, in the existing literature, the analysis of farmers' efficiency and preferences for different goods/services are separately documented. There is no empirical evidence on possible links between efficiency and farmers' preferences. This is an important knowledge gap, which the present study looks to fill, by assessing how farmers' efficiency might influence their willingness to comply with DFZs.

1.5 Research objectives

The main objective of the study is to analyse beef cattle farmers' TE and willingness to comply with DFZs in Kenya. The specific objectives include:

i. to measure farm-specific TE in different production systems;

ii. to investigate factors that influence farmers' TE;

iii. to assess farmers' willingness to comply with requirements in DFZs;

iv. to estimate the possible influence of TE levels on farmers' willingness to comply with requirements in DFZs.

1.6 Justification of the study

This study contributes to agricultural economics and agribusiness literature in three ways. First, it seeks to estimate the efficiency levels of different beef cattle production systems in Kenya and assess factors that might influence TE levels; such an analysis has not been undertaken in Kenya in the past. Second, the study investigates farmers' willingness to comply with DFZs; this has not been studied elsewhere. The third innovative addition to the literature is the assessment of how TE might influence farmers' willingness to comply with DFZs. The analysis is motivated by the hypothesis that efficiency might have a bearing on choices made by farmers regarding their investments on adoption of DFZs.

The study provides analytical insights that should guide policies aimed at improving the efficiency of cattle production in Kenya and inform strategies that contribute towards increased beef production. Moreover, analysis of TE across different production systems is essential for targeting of investments to meet policy needs in various localities. This view is informed by concerns that, generally, there are relative disparities in socio-economic development across different production systems and/or regions in Kenya. For instance, despite being one among very few livelihood strategies capable of making good economic use of drylands in Africa where more than half of the world's pastoralists are found (Reid *et al*., 2008), the nomadic pastoralist system seems to be relatively neglected by policy in Kenya (SOS SAHEL, 2009). Elsewhere, governments have established long-term policy measures to encourage sedentarisation of nomadic pastoralists, for example through increased investment in water and social infrastructure in Uganda (Wurzinger *et al*., 2009), or by legislation to recognise group user rights on their communal land, as is envisioned in Ethiopia (Elias, 2008). Investigating the TE of various cattle production systems in Kenya should provide insights on how to integrate livestock development in the national economic agenda. Moreover, improving efficiency of crop and livestock enterprises is important for reduction of poverty in agriculture-dependent developing countries such as Kenya; where more than 50 percent of pastoralists live below the poverty line, i.e., they survive on less than USD$1 per day (Thornton *et al*., 2007; Larsen *et al*., 2009).

DFZs have been successfully implemented in other beef producing countries, e.g., Australia, Botswana, Brazil and Namibia (see section 2.5 in chapter 2). In Kenya, however, the design of DFZs is still at a pilot stage (Republic of Kenya, 2008a). Information on farmers' preferences on the features that they would like to be included in a DFZ is therefore useful to policy-makers on two grounds: to enable assessment of potential acceptability of the DFZ programme; and to provide insights on some of the issues that may affect implementation of the DFZ, considering differences in production systems and relative resource endowments between farmers in Kenya and elsewhere.

Furthermore, incorporating farmers' views in the design of DFZs would enhance local ownership and participation. This might also boost sustainability of the DFZs by encouraging farm-level resource contributions towards implementation (Loppacher *et al.*, 2006). It is worthwhile to put more responsibility for livestock disease control strategies on farmers, considering that livestock compete for limited resources with other investment opportunities, and livestock diseases generally influence other farm decisions (Stott and Gunn, 2008). Moreover, incorporating farmers' preferences in the DFZ design would possibly reduce vandalism or sabotage of the programme. Inclusion of farmers' views is also useful to understand the necessary incentives that they would require in order to support or participate in a disease control programme, such as a DFZ (Rich and Perry, 2010).

Assessment of TE should provide insights for optimal beef production and might possibly contribute towards offsetting the shortfall in domestic supply in a cost-effective manner. In addition, improvements in TE and compliance with DFZs are essential to enable beef farmers' access to high-income markets; both domestic and export. Further, achieving these accords with the view of Hume *et al.* (2011), that maximising efficiency and reducing losses from infectious diseases in livestock production systems are important in improving productivity and sustainability of these enterprises, considering that there are competing demands on resources. Enhanced compliance with DFZs is also a necessary intervention to reduce *zoonotic* foodborne illnesses, which are mostly associated with infected meat and milk, and are considered to be the major cause of more than 3 million child deaths annually in developing countries (WHO, 2002).

Moreover, engaging farmers in maintaining DFZ requirements would ensure food safety to both domestic and external consumers (Hall *et al.*, 2004). Local participation in disease control is also useful to increase/restore consumer confidence in the safety of beef production

(Henson and Northen, 2000) in Kenya; this would enable beef farmers to obtain stable and possibly better incomes and livelihood opportunities. Finally, improvement of TE and design of better DFZs are envisaged to contribute towards enhancing food security (in accordance with the Millennium Development Goal on *reducing extreme hunger and poverty*), and promoting equitable development in line with Kenya's economic vision 2030 plan and growth potential (KIPPRA, 2009).

1.7 Thesis structure

This thesis is organised into eight chapters. The background chapter has laid out the research issues and rationale for the study. Chapter two provides a discussion of relevant contextual issues in the livestock sector, including beef production, trade and the SPS measures. In chapter three, the theoretical framework for measuring TE and empirical applications are reviewed. Chapter four contains a review of non-market valuation methods and an assessment of their suitability for the analysis of preferences for DFZs. The specific research methodologies applied in the study are discussed in chapter five. Results on the TE estimates and factors that might influence efficiency are presented and discussed in chapter six. Choice experiment (CE) results on farmers' preferences for DFZs are provided in chapter seven. Finally, some important conclusions and suggestions for future research are offered in chapter eight.

Chapter Two

2. Contextual Issues in the Livestock Sector

2.1 Introduction

This chapter provides an overview of some important issues in the livestock sector, both global and in Kenya, which are pertinent to the broader context of the present study. Specifically, meat demand and supply aspects, including production and trade, are discussed in section 2.2. Further, Sanitary and Phytosanitary (SPS) measures established by the World Trade Organization (WTO), and specific food safety and quality requirements applicable to livestock trade in the European Union (EU) are highlighted in section 2.3. Subsequently, in section 2.4, some important economic losses associated with livestock diseases are discussed. Key features of Disease Free Zones (DFZs) are presented in section 2.5. An overview of livestock production and marketing services in Kenya is discussed in section 2.6. Lastly, a summary of this chapter is provided in section 2.7.

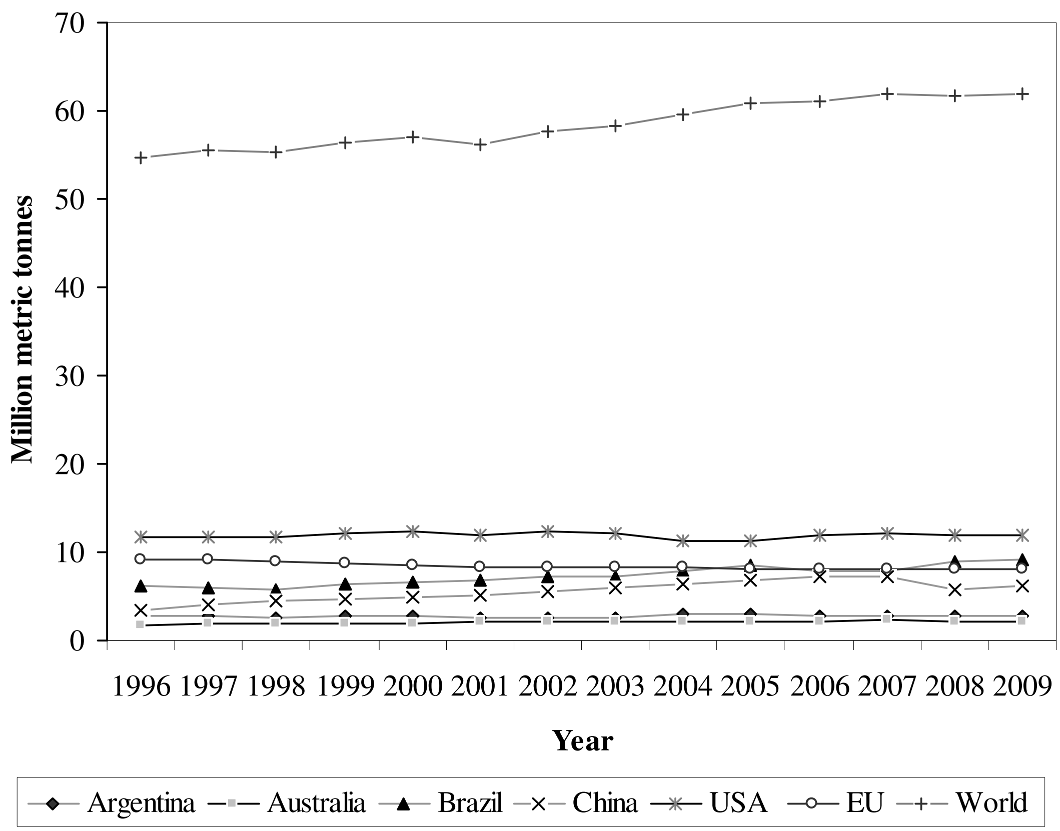
2.2 Meat demand and supply

Edible livestock products, including meat, are important sources of nutrients, such as proteins in human diet, and micro-nutrients (e.g., vitamin B12) that are essential for physical and cognitive development in children (AU-IBAR, 2010). According to the FAO (2009a), global demand for food is expected to increase by up to 70 percent by 2050. In order to meet this demand, it is estimated that meat production should increase from some 229 million metric tonnes in 1999 to about 470 million metric tonnes in 2050 (Scollan *et al*., 2010). The status of global beef production and trade is reviewed in this section as follows.

2.2.1 Global beef production and emerging issues

Generally, world beef production constitutes about 40 percent of the livestock output (FAO, 2005). The total beef output in 2009 was estimated to be 62 million metric tonnes (FAOSTAT, 2011). The United States of America (USA) is the leading producer of beef, supplying 19 percent (11.9 million metric tonnes) of the total output. Brazil is second with 15 percent (9.1 million metric tonnes), followed by China at 10 percent (6.1 million metric tonnes), Argentina with 5 percent (2.8 million metric tonnes) and Australia with 4 percent (2.1 million metric tonnes) in 2009. On average, these five main producers supply about 53 percent of total beef output, while the EU produces a further 13 percent (Figure 3). However, the growth rate in beef output from the five countries fell from about 11 percent per annum during the period 2001–2005, to only 1 percent in 2005–2009 (FAOSTAT, 2011). Beef output in the EU also declined during this period.

Figure 3: Annual world beef production, 1996 - 2009



Source: FAOSTAT Data (2011).

Generally, a decrease in total beef output might be expected in future, due to emerging competition for land and other inputs from bio-fuel generation (Banse *et al.*, 2008; Trostle, 2008). However, human population in the world is expected to increase from its current level of nearly 7 billion in 2011, to about 9.1 billion by 2050 (United Nations, 2009). More than 90 percent of the predicted increase in population will likely occur in developing countries, including sub-Saharan Africa (SSA) where the annual population growth rate is expected to be about 1.2 percent. The projected rise in population, together with urbanisation and possible changes in expenditure due to growth in incomes, are expected to drive demand for livestock products upwards (Delgado, 2005; Steinfeld *et al.*, 2006). It is estimated that the average annual per capita consumption of meat (including beef) in developing countries will increase from some 28 kg in 2002 to about 44 kg by 2050 (Thornton, 2010).

The need to meet expected increases in demand for meat is coupled with challenges such as competition for resources between enterprises, and concerns to reduce greenhouse gas emissions in livestock food chains. Greenhouse gases such as *methane* and *nitrous oxide* are considered to be major causes of global warming (commonly referred to as *climate change*) that is associated with adverse effects on the environment, including water pollution and loss of biodiversity. It is estimated that livestock production systems contribute about 25 percent of greenhouse gases globally (Steinfeld *et al.*, 2006). Consequently, as noted by AU-IBAR (2010) there is often a rather extreme argument in some environmental debates that one option for the world to manage global warming is to stop livestock production. However, considering the important role that livestock play in human nutrition and livelihood enhancement (Delgado *et al.*, 1999), there is need for balanced interventions.

Generally, livestock production supports the livelihood of over 65 percent of the rural population in Africa, Caribbean and the Pacific (ACP) countries. It contributes between 14 –

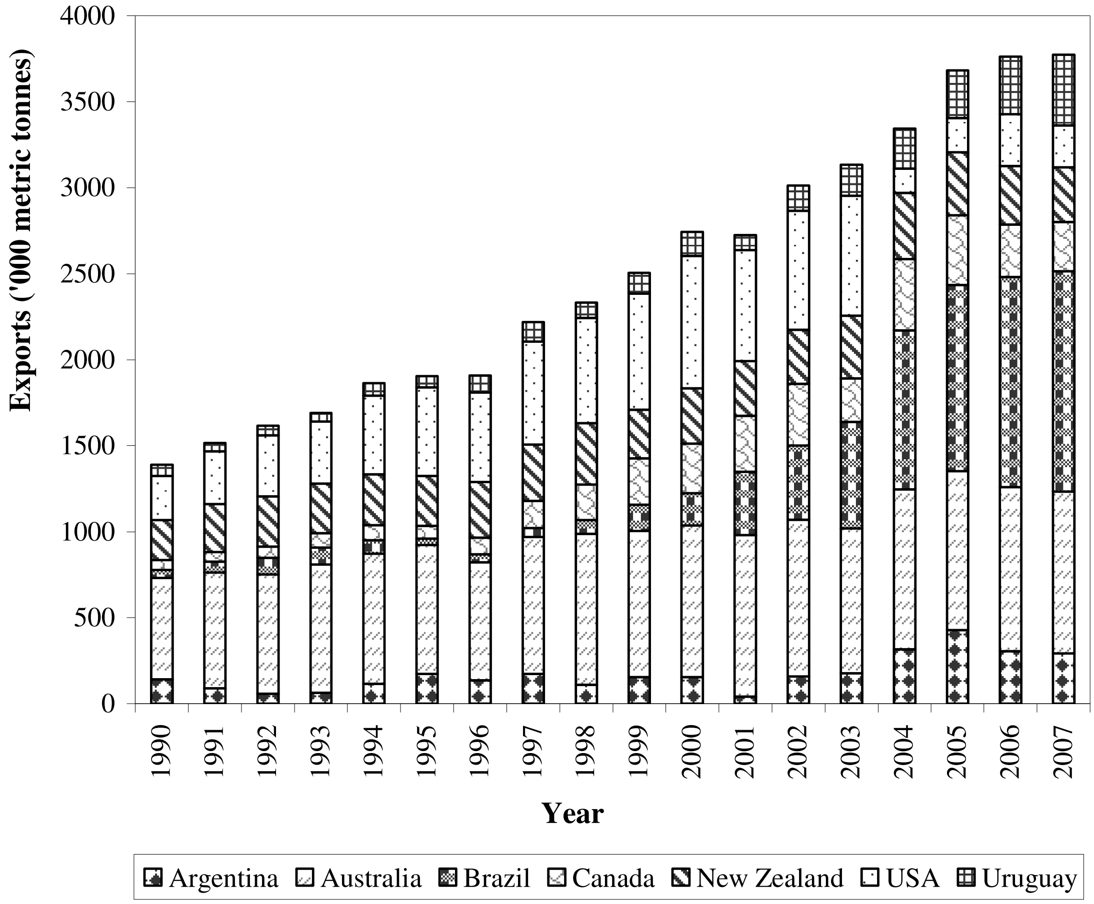
30 percent of their agricultural Gross Domestic Product (GDP), provides food, draught power, manure, serves as a form of capital investment and provides cash income in times of need, serves as means of transport for goods and services, and livestock are often used in various African socio-cultural ceremonies, e.g., bullfighting contests (Otieno, 2005; Asiedu *et al*., 2009). Moreover, in the SSA region, where over 70 percent of land in pastoral areas is arid or semi-arid, and therefore largely unsuitable for crop farming, livestock production is often one of the most viable enterprises in such areas (AU-IBAR, 2010). However, the ACP countries produce only 4 percent of total meat output in the world, and they have relatively low productivity. For example, the average slaughter weight of cattle is less than 170 kg in Africa, while for most developed countries it is over 400 kg (Asiedu *et al*., 2009).

These issues suggest that it is important to improve the manner in which inputs and technologies are used in livestock production systems (TAA, 2010). Improving the production efficiency is considered as a possible '*win-win'* strategy that could reduce both the economic costs of production and greenhouse gas emissions. This should entail producing optimal output and minimising the emissions per unit product, for instance, by use of better cattle breeds, improving animal disease control methods and enhancing other farm management practices, including feeding (Scollan *et al*., 2010). Efficient food production is important in order to improve supply for domestic and export markets.

2.2.2 An overview of international beef trade

Beef exports by various countries are shown in Figure 4. Generally, Australia and New Zealand have been the leading beef exporters and their annual export supply is relatively consistent. However, Brazil overtook them in 2005 and continues to be the major exporter. Other main exporters include Argentina, Canada and USA, albeit with fluctuations, while Uruguay has had relatively steady increments in its export supply over the years.

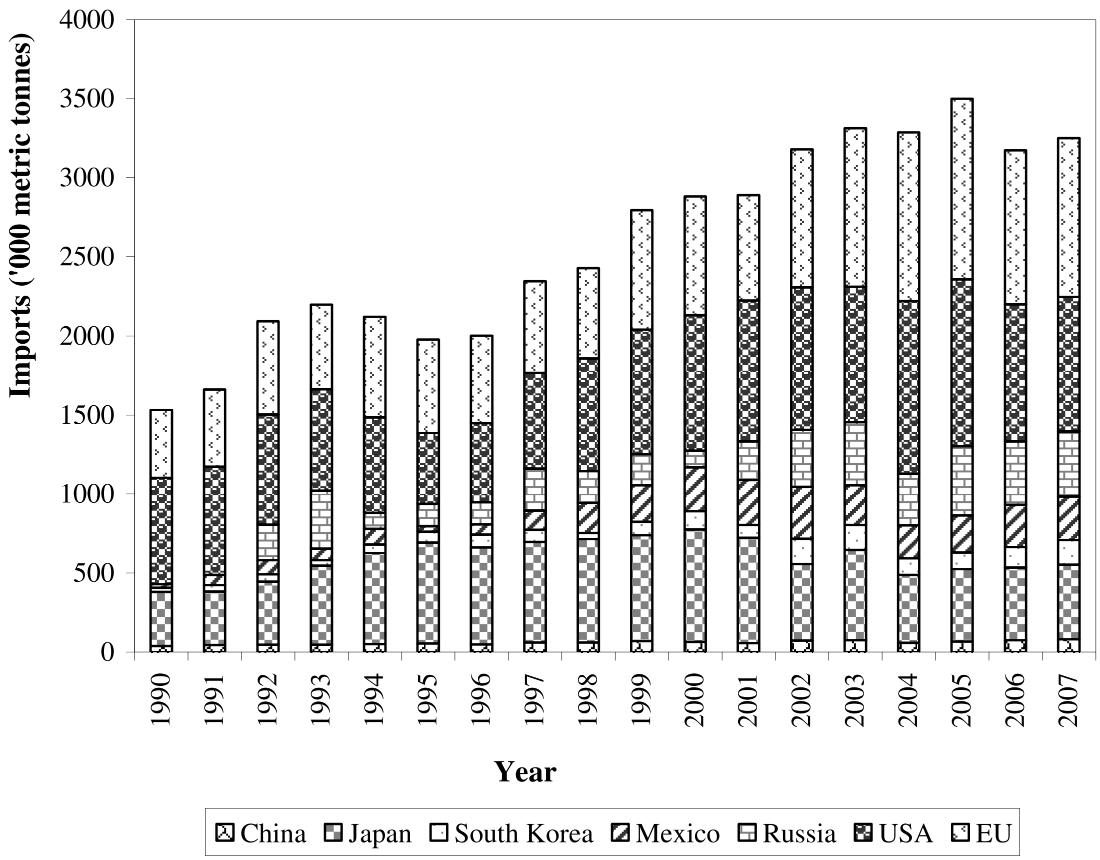
Figure 4: Major beef exporters, 1990 - 2007



Source: FAOSTAT Data (2011).

The EU, USA and Japan are the leading importers of beef. Mexico and Russia also import considerable amounts (Figure 5). China, which is the third largest beef producing country (see Figure 3), is also a significant importer, perhaps due to high food demand for its population of over 1.3 billion people (United Nations, 2009). Among the main beef importers from 1990 to 2007, South Korea took the least amount on average.

Figure 5: Main beef importers, 1990 - 2007



Source: FAOSTAT Data (2011).

It is predicted that by the year 2020, developed countries will export about 2.7 million metric tonnes of beef annually to the developing world, after meeting their own consumption needs if production policies remain unchanged (Hall *et al.*, 2004). West Asia and North Africa will be the major importers (1.7 million metric tonnes), while exports from Latin America (especially Brazil and Argentina) will drop to about 600,000 metric tonnes. Further, India is expected to be able to export 100,000 metric tonnes (Table 1). These projections suggest that there might be considerable opportunities for trade in beef; perhaps Kenya could benefit by improving its production and possibly export to the North African market where it might have relative geographic advantage in trade, due to proximity.

Table 1: Projected net trade in beef by 2020

Region	Net trade in beef (million metric tonnes)
China	-1.0
Other East Asia	-0.6
India	0.1
Other South Asia	-0.3
Southeast Asia	-0.6
Latin America	0.6
West Asia/North Africa	-1.7
Sub-Saharan Africa	-0.2
Developing world	-2.7
Developed world	2.7

Source: Delgado *et al*. (1999) and Rosegrant *et al*. (2001).

2.2.3 Beef supply and demand in Kenya

The total beef output in Kenya is estimated to have increased from some 343,000 metric tonnes in 2003 (MoA and KIPPRA, 2009) to about 445,000 metric tones in 2007 (FAO, 2009b), but the consumption level is considerably higher (Aklilu, 2002; FAO, 2005). About 40 percent of the demand is usually met through imports of cattle from neighbouring countries such as Ethiopia and Tanzania.

The annual per capita beef consumption in Kenya ranges from 8 kg among the relatively lower income households to 24 kg in high income households; the average national per capita consumption is estimated to be 10.8 kg. The per capita consumption of two main substitutes to beef (mutton and chevron) is about 2 kg (Ackello-Ogutu *et al.*, 2006). The relatively low substitutability of beef and the growing demand for various types of beef in Kenya, especially roast meat popularly known as '*Nyama choma*', suggest that there might be opportunities for further trade in beef in the domestic market. Therefore, it appears reasonable to improve resource utilisation in order to enhance supply.

Besides concern for the amount of output available, there is growing attention on food safety not only in developed nations, but also in the developing countries, both in the domestic and export markets. This is triggered by emerging preference for safe food among the middle and high income population segments, technological advancements in measurement of food contaminants, intense competition for markets, and increased consumer awareness on effects of food-borne illnesses (Narrod *et al*., 2008). In global trade, ensuring food safety is an important requirement in the WTO agreement on the application of the SPS measures (WTO, 1995a).

2.3 World Trade Organization and the sanitary and phytosanitary measures

The WTO is an international organization which formulates rules that govern trade between nations. Its membership comprises some 153 countries, representing over 95 percent of world trade. Kenya is a member of the WTO since the establishment of the organization on 1st January 1995. In recognition of the sovereignty of nations to protect humans, animals, plants and the environment, the WTO established the agreement on SPS measures (WTO, 1995a).

The SPS measures refer to '*Any measure applied:*

(a) to protect animal or plant life or health within the territory of the Member from risks arising from the entry, establishment or spread of pests, diseases, disease-carrying organisms or disease-causing organisms;

(b) to protect human or animal life or health within the territory of the Member from risks arising from additives, contaminants, toxins or disease-causing organisms in foods, beverages or feedstuffs;

(c) to protect human life or health within the territory of the Member from risks arising from diseases carried by animals, plants or products thereof, or from the entry, establishment or spread of pests; or

(d) to prevent or limit other damage within the territory of the Member from the entry, establishment or spread of pests.

Sanitary or phytosanitary measures include all relevant laws, decrees, regulations, requirements and procedures including, inter alia, end product criteria; processes and production methods; testing, inspection, certification and approval procedures; quarantine treatments including relevant requirements associated with the transport of animals or plants, or with the materials necessary for their survival during transport; provisions on relevant statistical methods, sampling procedures and methods of risk assessment; and packaging and labelling requirements directly related to food safety' (WTO, 1995a, p. 77).

2.3.1 Important considerations in the application of SPS measures

The SPS measures consist of,

a) Regulations, which are mandatory requirements; imports that do not conform may be prohibited from the market, and

b) Standards, which are voluntary; imports that fail to meet standards may theoretically be allowed into a market, but consumer preference for other products that fully address standards may limit the market share of those that do not comply (WTO, 1998a).

In the application of SPS measures, countries should consider the potential damage in terms of loss of production or sales due to the disease or pest infestation, cost of disease/pest control and relative cost-effectiveness of alternative methods of reducing the risk (*SPS Agreement, Article 5:3*). Further, the measures adopted must minimise negative trade effects (*SPS Agreement, Article 5:4*) and must be consistently applied, and they should consider technological and economic feasibility aspects (*SPS Agreement, Article 5:6*) (WTO, 1995a). However, the SPS agreement permits WTO members to accord priority to food safety, animal and plant health, over trade expansion and profit motives (WTO, 1998b).

The SPS measures can be broadly classified as farm-level or border measures. Farm-level interventions might help to mitigate or manage risks at the production stage. These include vaccinations, quarantines and Disease Free Zones (DFZs). Disease risk mitigation may also be achieved through the application of Hazard Analysis and Critical Control Point (HACCP), which involves systematic identification, evaluation and control of food safety hazards. The HACCP method is considered to be a rational way of improving trade by increasing producer efficiency (Wilson and Anton, 2006), and assuring food safety from the point of harvest to consumption (USFDA, 1997).

Border SPS measures include import tariffs and bans. Countries may choose any SPS measure (s) that lower (s) the risk of disease or pest infestation. However, '*the best measures are those that are least trade distorting, superior in terms of welfare, and provide protection of health and safety for all concerned*' (Wilson and Anton, 2006, p. 195). For instance, direct risk mitigating strategies are generally considered to be less trade distorting than tariffs. Paarlberg and Lee (1998) suggest that appropriate tariffs are those that adjust accordingly with the level of disease risk, in order to reduce the risk of disease importation, but still permit trade. Among the SPS measures, import bans are the most stringent and trade restrictive, but may provide absolute protection from pest or disease infestation (Wilson and Anton, 2006).

Member countries in the WTO are permitted to apply mandatory SPS measures to restrict or prevent imports under three situations (Isaac, 2007):

i. Presence of risks of pests and disease incidences in the exporting country (*SPS Agreement, Article 2:3*),
ii. Existence of legitimate justification (sufficient scientific evidence of risks) to establish domestic SPS measures higher or tighter than the accepted international standard (*SPS Agreement, Article 3:3*), and

iii. Provisional SPS measures based on precaution, if no sufficient scientific evidence is available to enable relevant risk assessment (*SPS Agreement, Article 5:7*).

Furthermore, the *SPS Agreement, Article 5:1* specifies the relevant institutions that determine appropriateness of scientific evidence or level of risks. These are: the *Codex Alimentarius* Commission (CAC) for food safety issues, the Office of International Epizootics (OIE) for animal safety matters, and International Plant Protection Convention (IPPC) for all aspects of plant safety. Improving compliance with SPS measures has potential benefit in the ability to trade in high value markets, both domestic and export.

For agricultural food products, SPS measures address food safety and agricultural health risks associated with pests, food-borne and zoonotic diseases (such as Foot and Mouth Disease - FMD) and other contaminants. The SPS measures arise from global concern to prevent transmission of diseases and pests across national boundaries. As noted by Babagana and Leyland (2008), international standards that govern livestock trade put a considerable focus on the geographic origin of a product, as well as the disease status of that region. According to the OIE, highly infectious cattle diseases such as Contagious *Bovine Pleuropneumonia* (CBP), FMD, Rift Valley Fever (RVF) and rinderpest are classified as *List A* diseases; these are considered as notifiable diseases whose outbreak must be promptly reported to the OIE. Further, the OIE classifies countries as FMD-infected, FMD-free with vaccination or FMD-free without vaccination. The FMD-free status is only granted through approval after a period of continuous veterinary interventions, including vaccination depending on the degree of disease outbreak. Exports are allowed from a country or parts of it, which have been certified to be FMD-free with no on-going vaccination for a minimum 12-month period prior to the date of intended trade (OIE, 2008). Generally, the risk of importing FMD virus restricts trade in live animals and their products from parts of the world where the virus is present, such as in sub-Saharan Africa (SSA) (Paton *et al.*, 2010).

In order to prove compliance with SPS measures, a country must establish internationally accepted mechanisms for testing, certification and accreditation (UNIDO, 2006). Each country may set its own food safety and animal and plant health standards based on adequate risk assessment, and in accordance with the SPS guidelines. Under the SPS measures, an importing country is permitted to conduct site visits to verify disease-free status and assess disease surveillance data, diagnostic facilities, and animal health services of its trading partner. Further, the SPS agreement recognizes the sovereign right of countries to maintain standards that are stricter than the OIE standards. Henson and Caswell (1999) note that better standards along the supply chain may enhance competitive advantage by improving the control and efficiency in inspection of food quality. However, heterogeneous regulations on food standards might hamper developing countries' access to export markets (Fulponi, 2006). In order to promote trade, the SPS agreement requires that stricter standards must be justified by scientific evidence and must be equitably applied to imported and domestic products (Walton, 2000).

Compliance with food safety standards is considered as a minimum requirement for firms to gain access in high value markets, including in Europe (Hammoudi *et al.*, 2009). As noted earlier, the EU is a major importer of beef (see Figure 5) and offers preferential market access to Kenya (see section 1.4 in chapter 1), subject to meeting sanitary requirements. Generally, the EU applies stricter food safety and quality requirements on imports from non-member countries. Some of the sanitary measures in the EU, regarding livestock trade, are discussed in the following section.

2.3.2 Food safety standards in the European Union

In the EU, relevant inspections for food safety and quality are undertaken by public and private entities at different levels in the supply chain, including contractual producers and exporters/agents in the country of origin. Further inspections are conducted by national control agencies, importers and retailers within the EU (Lee, 2006).

In order to export live animals and animal products to the EU, a country must address the following sanitary requirements (European Commission, 2003):

i. Animal health situation

Only WTO members that have been permitted by the OIE to trade in animals are allowed to export live animals or their products to the EU. The country must have reliable systems for rapid detection, reporting and confirmation of any outbreak of an OIE *List A* disease (e.g., FMD). Further, the country must make a formal commitment to notify the European Commission (EC) of any outbreak of these diseases within 48 hours of confirmation. In addition, the country must have consistent records of animal disease control systems, including registration of farms, animal identification and movement controls, to confirm compliance with EU health certification conditions. The EU also considers the exporting country's import policy, particularly cross-border controls on animal movement, and animal health situation in neighbouring countries.

ii. Residue controls

Any country wishing to export to the EU must establish a programme and laboratory facilities for monitoring use of prohibited veterinary drugs, substances and practices. For example, as prescribed by the OIE, the EU prohibits imports from countries where there is active vaccination against FMD. But, further to this, the monitoring programme for all diseases must be submitted to the EC as the first step in the application for export approval. Subsequently, each year's programme must be submitted to the EC for review annually.

iii. National standards authority

The national standards authority must be able to deliver a competent level of veterinary controls; failure to meet this requirement can result in denial of export approval or revocation of an existing approval. The EU evaluates the authority's performance by assessing its management structure, independence in its operations, resources, personnel, legal/enforcement powers, prioritisation and documentation of controls, laboratory services, import controls, general animal health controls and food safety controls.

iv. Food safety standards in processing establishments

The national standards authority must ensure that standards in processing establishments are at least equivalent to requirements in the EU before any on-the-spot inspection is conducted. Further, while reporting the standards in place, officials in the processing establishments must be able to act independent of any influence from operators and other interest groups, including the government.

v. *Bovine Spongiform Encephalopathy* (BSE)-related import controls

In order to obtain approval to export live animals (particularly cattle, sheep and goats) or their products into the EU, countries must apply for risk assessment and evaluation of certain risk management measures to determine their BSE status. Some of the measures assessed to prevent spread of BSE include absence of risk materials in the products, and certification that the animals have not been slaughtered through brain destruction (e.g., by pithing or gas injection), and that the products do not comprise meat that is mechanically recovered from ruminant bones.

vi. Health certification

The exports must be accompanied by a correct health certificate signed by an official veterinarian or inspector to confirm compliance with the EU rules, including animal welfare requirements e.g., less-distressful slaughter practices (European Commission, 2003).

Generally, some markets import meat and meat products only from abattoirs and countries that meet EU standards. Therefore, it appears that, compliance with the EU requirements is critical not only for improving exports to Europe, but also to many other high-priced markets (e.g., Japan), which consider the EU certification as a form of confirmation that adequate zoo-sanitary standards have been maintained (Adcock, *et al.,* 2006).

The scientific evidence criterion (*Article 3:3*) is a contentious pillar of the SPS agreement. Kerr and Hobbs (2002) argue that scientific evidence can never be conclusive since it is based on statistical processes. Therefore, a country can cite some remaining level of risk or the need for further research as a justification to restrict imports from other trading partners. For example, some six artificial growth hormones (*estraiol*, *melengestrol acetate*, *progesterone*, *testosterone*, *trenbolone acetate* and *zeranol*) are widely used in some countries including in Canada and the USA to enhance the performance of beef cattle. However, the use of these hormones is banned in the EU due to fears of possible human health risks such as cancer and nerve disorders. Consequently, the EU banned beef imports from these countries in 1989. In return, the USA imposed retaliatory import tariffs of up to 100 percent on EU products, effective from 1989 to 1996. This trade dispute is yet to be resolved in the WTO, as both the EU and USA continue with further research and negotiations on what constitutes appropriate scientific evidence, regarding health risks in beef hormones (Johnson and Hanrahan, 2010).

Disease outbreaks can lead to huge losses in livestock production and other sectors. Some of the economic losses are highlighted in the following section.

2.4 Economic importance of livestock diseases

Generally, livestock diseases are associated with considerable economic losses, which include: reduction in the level of marketable outputs; reduction in (perceived or actual) quality of output; waste or higher level of use of inputs; disease prevention and control costs; human health costs of the presence of a disease (zoonoses); negative animal welfare impacts due to diseases; and international trade restrictions (Bennett, 2003). At the farm level, diseases that cause high cattle mortality (e.g., rinderpest) may lead to significant losses in production. Even in situations where a disease results in low mortality of adult animals (for example FMD), persistence of such diseases may cause on-going economic losses through death of calves, abortions in cattle and decline in productivity (Burrell, 2002). Globally, it is estimated that on average, about 10 percent of potential yield of meat protein is lost annually due to infectious diseases, including FMD (Shirley *et al*., 2010).

Moreover, severe disease outbreaks often have prolonged negative impacts on demand for livestock products. For instance, following a BSE incidence in the late 1980s, aggregate consumption of beef and other meats declined considerably across the EU during the scare and remained relatively low in the subsequent period (Burton and Young, 1996). Livestock diseases are also associated with negative spill-over effects in other sectors. For example, it is estimated that nearly half of the economic losses due to FMD outbreak in the United Kingdom (UK) in 2001 (approximately USD$6 million) were incurred in non-agricultural sectors such as services and tourism (McLeod and Rushton, 2007).

Generally, infectious animal diseases are considered to cause about 60 percent of human diseases in the world (AU-IBAR, 2010), and more than 3 million annual child deaths in developing countries (WHO, 2002). Further, in the developing countries where livestock play a considerable role in household livelihoods and often serve as one of the pathways out of poverty, livestock diseases have severe multidimensional impacts (Perry and Grace, 2009). Within sub-Saharan Africa (SSA), it is estimated that more than USD$4 billion (representing about 25 percent of the total value of animal production in the region) is usually lost annually due to diseases (AU-IBAR, 2010). For instance, the outbreak of RVF in 1997 led to a decline in foreign exchange earnings by over 75 percent in Somalia (Otte *et al.,* 2004). In Kenya, outbreaks of FMD and RVF in 2006/2007 reduced the national herd size by about 30 percent (Otieno, 2008) and led to loss of employment and business opportunities (Rich and Wanyoike, 2010).

Strengthening compliance with disease control strategies could help to overcome risks (e.g., rejection of consignments and loss of product value), which are associated with failure to meet the SPS requirements (Upton, 2001). Moreover, eradication of livestock diseases, especially FMD, offers considerable trade benefits, but stakeholder cooperation (across farms and regions) and large resource investments are required in order to achieve and maintain a disease-free status (Paton *et al*., 2009). Addressing production efficiency and compliance with SPS measures are therefore essential in order to improve the supply, protect consumers' health by providing safe food and promote participation in trade.

In livestock production, the SPS agreement (*Article 6*) allows establishment of Disease Free Zones (DFZs) within a country to ensure stability in the supply of safe beef and other livestock products for export; with concomitant food safety benefits in the domestic market as well (WTO, 1995a)[1]. Important features of DFZs are discussed in the following section.

2.5 Features of Disease Free Zones in some countries

Disease zoning or regionalisation may be used to separate a diseased area in an otherwise disease-free country or as a way to secure a disease-free area in an otherwise infected country (Zepeda *et al*., 2005). DFZs are particularly recommended to manage outbreaks of the OIE *List A* diseases e.g., FMD. For instance, in order to export beef, countries that are not FMD-free must establish one or more FMD-free zones where animals are completely separated from those in adjoining infected zones (Paton *et al*., 2010). Further, DFZs might serve to fulfil the WTO rules-of-origin or geographical labelling requirement by informing consumers of the production methods and sites in order to mitigate uncertainties on product quality and safety (Anders and Caswell, 2009). As a disease control strategy, DFZs have been successfully implemented in some major beef exporting countries such as Australia, Botswana, Brazil and Namibia. The main features of the DFZs in these countries are discussed as follows.

2.5.1 Disease free zones in Brazil

Brazil is the leading beef exporter in the world (FAOSTAT, 2011) and has over 70 percent of zebu cattle reared in ranches and extensive grazing systems. Since 1992 when the OIE formally agreed to recognise parts of a country (rather than an entire country as was previously the case) as disease-free, Brazil grouped its states into five regions to facilitate

[1] Generally, it is difficult to monitor or enforce compliance with conventional livestock disease control measures that cover large geographic areas (e.g., a country). Further, emergency mass vaccinations in case of disease outbreaks are usually costly and may not reach all farms in time. Another potential livestock disease control method is commodity-based trade approach, which involves treatment of products. However, this requires considerable investment to ensure there are effective procedures and institutions for risk assessment and certification of product safety within a country. Specialised private producer-buyer disease control arrangements (i.e., compartmentalisation) could be an alternative to DFZs, but are considered to be expensive to implement, hence they might exclude poorer farmers from high value markets, and generally offer limited market options to producers (Mapitse, 2008).

effective control of FMD. The regions are referred to as *circuits* and they include northern, north-eastern, centre and western, eastern, and southern *circuit*. Some DFZs have been established in each of the *circuits*. The disease zonation strategy is based on natural and geographical barriers such as rivers and mountains, rather than administrative boundaries. Each DFZ has an emergency surveillance area, which separates a disease-free area from an infected area. The surveillance area is created by placing a veterinary cordon fence (VCF) over a minimum distance of 30 km from the infected area.

The government provides legislation, financial support and supervises activities in the DFZs. These include establishment of local veterinary units that provide compulsory vaccination coverage for 95 percent of cattle twice a year, in the DFZs. Other activities in the DFZs include registration of rural properties and animals, official quarantine and animal movement control, compulsory notification of any suspicion of FMD, and implementation of a stamping-out policy that includes sanitary slaughter of all infected cattle in case of outbreaks (Mayen, 2003).

Through the zonation strategy, Brazil was able to increase its export market access from 36 importing countries in 1998 to over 109 in 2005. However, the main challenge has been delays in recognition of DFZs by major importers despite the OIE's approval. Indeed, the issue of laxity by trading partners to recognise DFZs has been raised as a serious concern by several countries and is often an important issue of debate in WTO negotiations (Isaac, 2007).

2.5.2 Disease zonation strategy in Botswana

In Africa, Botswana and Namibia have been relatively successful in implementation of DFZs. Botswana has about 2 million cattle and exports 90 percent of the beef that it produces mainly to the EU (where it has an export quota of about 19,000 metric tonnes annually), Hong Kong, Malawi, South Africa, Zimbabwe and Mauritius (Mapitse, 2008). It earns about USD$40 million from beef exports annually. The main production systems are communal grazing (70 percent) and fenced commercial ranches (30 percent), but the government has a policy aimed at converting all communal land into fenced ranches to address disease challenges.

Botswana has two FMD control zones: FMD-free area where vaccination is practised (70 percent of the country), and the remaining area is FMD-free with no vaccination. The zones are separated by disease control fences maintained by the government. Quarantines are put in the major beef producing areas to monitor movement of animals between the zones. Vaccination is done twice or thrice a year depending on the level of perceived risk in an area. Botswana meets about 60 percent to 70 percent of its EU quota through beef from non-vaccinated FMD-free zone (Mapitse, 2008). Although more beef is produced in the vaccinated FMD-free zone, this is not accepted in the EU market. The government covers all SPS implementation costs, including cattle traceability and vaccinations, and also provides extension visits to farmers, training on beef production and veterinary services.

However, with privatisation of services and potential elimination of preferential market access that might result from enforcement of Economic Partnership Agreements (EPAs) in the WTO negotiations, the cost of compliance could be high for producers if they are not assured of export markets; this is a potential challenge to the sustainability of DFZs. Options being considered in Botswana include cost sharing with farmers and the private sector in maintenance of the VCF, seeking private sector support for farmer compensation package, or diversifying export markets (but this implies addressing many different SPS requirements).

Another approach to disease control could be to operate DFZs through compartmentalisation. This is a producer-led initiative where the government only provides overall monitoring and regulation. It requires substantial private sector investment in surveillance, traceability, quarantine and fencing. The programme targets specific markets and producers must collaborate with importers' agents in quality assurance. Compartmentalisation can be implemented by individual farmers (if they can afford it) or by a group of farmers to share costs. However, there is no compensation in compartmentalisation programmes (Mapitse, 2008).

2.5.3 Namibia's disease free zones

Namibia exports 90 percent of the beef it produces to the EU and South Africa. Disease control strategy is through zoning based on FMD-status. There are four zones where livestock movement is controlled through individual producer identification (by brands), individual animal identification using animal ear-tags and a permit system. The zones are characterised by (Bishi and Kamwi, 2008):

i. Infected zone

This is a zone with high risk of FMD outbreaks due to presence of free roaming buffaloes and other wild animals. Vaccinations are carried out in this zone regularly (bi-annually). Movement of cattle from this zone to a buffer zone is only allowed after three weeks of quarantine and test of disease absence.

ii. Buffer zone

Free roaming animals are prohibited from entering this area. A double-fence corridor is maintained here to prevent livestock and wild animals from crossing to the surveillance zone. Annual vaccination of animals is done in this zone.

iii. Surveillance zone

Intensive inspections are carried out here. There are no FMD vaccinations. Movement of cattle from this zone is permitted for direct slaughter at quarantine abattoirs or after three weeks' quarantine they are moved to free zones.

iv. Free zone

This is a safe zone where no vaccination is conducted. Cattle from this zone are mainly slaughtered for export markets.

Namibia faces two main challenges regarding sustainability of its DFZs. First, communal farmers (who keep over 50 percent of cattle) are reluctant to abandon their transhumant system of livestock production for commercial ranches. This poses a threat to continued ability to supply beef from the FMD-free area to the EU. There is also rampant vandalism of the VCF due to influx of refugees from frequent civil unrest in a neighbouring country, Angola. In other areas, the fence is often damaged perhaps because of insufficient community consultation and participation (Bishi and Kamwi, 2008).

2.5.4 Regionalised disease control in Australia

Australia is also a key beef exporter in the world, and is classified by the OIE as totally FMD-free, but experiences occurrence of *Bovine Johne's* disease (BJD). This is a bacterial disease that inhibits the ability of cattle to absorb nutrients. Cattle are reared through extensive grazing, beef cattle in dairy farms, and feedlot production systems.

Australia has established four zones or regions for management of BJD (Hassall and Associates, 2003):

i. Free Zone

This is an area where the disease does not exist or has never occurred (e.g., Western Australia). On-going surveillance is done in this zone to maintain its disease-free status.

ii. Protected zones

These include areas with little occurrence but no tested evidence of the disease. On-going surveillance is done and vaccinations are carried out to eradicate the disease when detected.

iii. Control zones

Known infected herds are strictly monitored in these zones, and producers are required to adopt best practices when buying cattle to prevent infection of herds in other zones.

iv. Residual zones

These areas are characterised by widespread disease occurrences, and there are little or no official control procedures.

In order to achieve a free zone, the Australian government assists farmers to develop business disease control programmes. Under this approach, farmers are required to develop a disease control programme and submit it to chief veterinary officers for approval. The programmes are expected to focus on minimising spread of infections to other farms. Farmers are also required to identify animals at high risk for culling, observe proper calf husbandry and herd management, maintain accurate breeding records and permanent cattle identification, and ensure regular herd testing. The government compensates farmers the difference between market value and residual value received for a slaughtered animal during a disease outbreak (Hassall and Associates, 2003).

In conclusion, the DFZs in the above countries are generally characterised by:

i. Strict requirement on farmers to adhere to veterinary practices;
ii. Herd monitoring and prompt reporting of disease outbreaks;
iii. Fencing of DFZs;
iv. Controlled/confined grazing systems, and pastures/grazing areas;
v. A reliable system for traceability (identification) of cattle and farmers;
vi. A penalty to deter non-compliance;
vii. Cordoning wild animal areas from cattle grazing lands to prevent conflicts and re-infection of cattle;

viii. A zonation strategy based on disease risk patterns and natural geographic boundaries, such as rivers and mountains, rather than administrative borders;

ix. Government financial support for all activities in the DFZs, including supporting a compensatory scheme in the case of Australia.

A brief review on some livestock inputs and services in Kenya is provided in the next section.

2.6 Livestock production inputs and marketing services in Kenya

The policy and institutional framework for provision of some important livestock production inputs and marketing services in Kenya are briefly discussed in this section. These include animal feeds, breeding stock, livestock extension, veterinary services and marketing channels.

2.6.1 Animal feeds

The main livestock feeds comprise roughages, concentrates, minerals, vitamins and water. In Kenya, use of concentrates and minerals as supplementary feed is relatively higher among dairy farmers. In contrast, beef cattle are generally fed on improved pastures and fodder, or natural pastures depending on the production system. A relatively small proportion of beef farmers supplement the pastures with concentrates from cereals (e.g., maize, wheat, millet) and legumes.

Generally, pasture supply fluctuates due to seasonal rains. Further, pest infestation especially during dry seasons affects pasture quality. Production of Napier grass, which is the main fodder, has considerably declined due to diseases e.g., *Napier smut* and *Napier stunting* (Republic of Kenya, 2007). The supply of commercial feeds also varies; they are relatively available in market outlets in high potential dairy areas, but scarce in arid and semi-arid lands (ASALs) where pastoralism is practised. Further, there is frequent adulteration of commercial feeds (at manufacturing stage or in the distribution channels) and hence poor quality feeds might be sold to farmers, despite feed standardization guidelines set by the Kenya Bureau of Standards (KEBS).

2.6.2 Livestock breeding services

Cattle breeding methods and services are important technological inputs because the ultimate type of breed kept determines other input requirements and potential output. Breeding methods might include natural breeding (direct use of bulls; controlled or uncontrolled) or artificial insemination (AI). Generally, the responsibility of producing or selecting livestock breeding stock lies with farmers. Prior to liberalization of service provision in the 1990s, the government was supplementing farmers' efforts through breed multiplication farms. Currently, animal breeding services (e.g., provision of AI and breed selection advice) are facilitated by various government institutions and private organizations. These include the Central Artificial Insemination Station (CAIS), Kenya National Artificial Insemination Service (KNAIS), Kenya Stud Book (KSB) and breed associations.

However, lack of a central authority to regulate breeding programmes is often considered to have resulted in high cost of animal breeding and poor breeding records[2]. There is also loss of important quality breeding stock (including some indigenous cattle breeds) through indiscriminate crossbreeding (Republic of Kenya, 2007). Crossbreeding in beef cattle might involve combining genetic materials between different indigenous breeds (e.g., *Zebu* vs. *Boran*), among various exotic breeds (e.g., *Charolais*, *Simmental* and *Hereford*) or between an indigenous and exotic breed. Generally, exotic breeds have relatively higher growth rates, reproduction and market value, but are considered to have higher mortality, due to relatively low resistance to drought and diseases in Kenya.

[2] At the time of survey, the average costs of cattle breeding services in Kenya were USD$20 and USD$80 for natural bull service and AI, respectively.

It is important to improve the coordination of breeding programmes, considering that genetic dilution or eradication through use of exotic germplasm, indiscriminate crossbreeding due to changes in production systems and producer preferences for higher market value might lead to significant losses of animal genetic resources (AnGRs). Rege (1999) notes that, indeed, several indigenous African cattle breeds that had important adaptability traits, such as heat and disease tolerance, face the risk of extinction (32 percent) or have already been lost (22 percent). This might have a bearing on farmers' efficiency and overall beef supply.

2.6.3 Livestock extension services

Agricultural and livestock extension services include training and information on farming practices and adoption of technologies, e.g., breeding programmes, and feed preparation methods and equipment. In Kenya, extension services are provided by the government and various non-government organizations, including:

i. National Agriculture and Livestock Extension Programme (NALEP)

This is the main approach through which the government provides training and information to farmers. This method entails use of a 'shifting focal area approach', whereby commodity-specific extension personnel are deployed to a particular area for a specific period of time (e.g., one year) to train government 'general' extension workers and farmers on use/adoption of selected technologies, before shifting to a new area. It involves use of farmers' training centres and agricultural shows to disseminate information on various agricultural technologies and improved practices (Republic of Kenya, 2004).

However, the NALEP is considered to mainly benefit relatively educated and wealthier farmers who have resources to invest in new technologies, and are more likely to influence the selection of technologies to be promoted and/or demonstration plots (Muyanga and Jayne, 2006). Moreover, due to inadequate funding and shortage of qualified staff, the scope of

NALEP activities is relatively limited to arable areas and where there is high potential poultry and dairy farming (Kibett *et al*., 2005; Oluoch-Kosura, 2010). As noted earlier (see section 1.4 in chapter 1), public funds allocated to livestock development are relatively low. Further, a higher proportion of the livestock development budget is spent on wages and other activities, leaving only less than 8 percent for extension operations including field demonstration activities and transport costs (Muyanga and Jayne, 2006). Poor remuneration of agricultural employees in the public sector also discourages qualified extension personnel from working in the pastoral ASALs that are generally considered to be remote and hardship areas.

ii. Commodity-based extension

Private companies dealing with inputs e.g., agrochemicals, seeds and feeds, also offer commercial extension services in areas deemed to be relatively profitable (mostly those dealing with high value crops such as coffee or those practicing dairy farming). The extension services are provided as part of the companies' marketing and promotion strategy for their products, by co-financing agricultural shows and field demonstrations. In addition, some government corporations (parastatals) offer commodity-specific extension services, mainly to farmers who can afford them (Muyanga and Jayne, 2006).

iii. Agricultural Technology and Information Response Initiative (ATIRI)

This is an initiative by the Kenya Agricultural Research Institute (KARI) to empower farmers to adopt its technologies, mainly dealing with crop production and postharvest management. It involves provision of competitive grants for research outreach. The grants (on average USD$3,000 per group) are given to farmer organizations that offer training or exchange visits to farmers using KARI technologies. In 2005, there were about 178 groups supported by ATIRI, and working with some 11,835 farm households in Kenya (Muyanga and Jayne, 2006).

iv. Private non-commercial extension

There are various non-governmental, faith based and community-based organizations (CBOs) that provide information and training services on a diversity of issues, including basic health and sanitation, environmental conservation, conflict resolution, and agricultural and livestock production and marketing. Some of the CBOs that offer these services are *Care-Kenya*, *Sacred Africa*, *World Vision*, the Catholic Church and various women groups. The CBOs are considered to play an important role in decentralizing the provision of various services, including extension (Mugunieri and Omiti, 2007). However, these organizations are based in specific parts of the country/segments of the society where they undertake their core activities; provision of extension services is not their main priority.

Generally, rural and poorer households have to travel relatively longer distances to access extension services in Kenya. For example, Muyanga and Jayne (2006) noted that rural households in marginal areas are on average more than 10 km away from livestock advisory service providers, while at national level, the relatively wealthy farmers are, at most, less than 5 km away from these services. Further, weak linkages between research-extension service providers and farmers are considered to contribute to low and/or inappropriate use of inputs by farmers (Oluoch-Kosura, 2010).

2.6.4 Veterinary services

Livestock disease control services in Kenya are provided by government and private veterinarians. Further, the Kenya Veterinary Board (KVB) regulates veterinary practice and education, while the Kenya Veterinary Vaccine Production Institute (KEVEVAPI) conducts research on and produces veterinary vaccines. However, enforcement of animal health and product quality standards is hampered by conflicting legal mandates of various government departments. The participation of veterinary personnel in monitoring use of livestock vaccines and drugs is limited because the legal provision puts the veterinary drugs inspectorate under the Pharmacy and Poisons Board (PPB), which is in a public health department of the government. Further, monitoring of pests control is the responsibility of the Pest Control Product Board (PCPB) in the agriculture department (Republic of Kenya, 2007).

The lack of a coordinated inspection system leads to sale of veterinary drugs in non-designated places, which might result to wrong prescriptions and misuse of veterinary drugs. In remote rural areas where public veterinary services are limited, livestock disease control is mainly dealt with by community-based animal health service providers (Irungu *et al.*, 2006; Leonard and Ly, 2008), some of whom might lack professional veterinary skills.

Kenya experiences frequent occurrence of severe livestock diseases (e.g., FMD and RVF) and the government plans to establish DFZs in order to manage these (Republic of Kenya, 2008a). However, disjointed legal mandates of institutions responsible for veterinary inspection might hamper disease monitoring in regionalised disease control programmes such as DFZs (Matete *et al.*, 2010). This study investigates farmers' preferences for DFZs, and also offers insights on institutional arrangements that would support DFZ implementation in Kenya.

2.6.5 Livestock marketing channels

The government in 1950 established the Kenya Meat Commission (KMC) as a state corporation that would promote meat trade by purchasing livestock for slaughter and processing for the domestic and export markets. The KMC was also expected to act as a strategic drought management agent as a buyer of last resort. However, due to operational problems attributed to mismanagement, KMC was unable to fully utilise its processing capacity and was closed from 1963 to 1987, and placed under receivership from 1998 until 2006, before re-opening (Republic of Kenya, 2007).

The KMC has abattoirs with slaughtering capacity for 1,000 cattle and 1,200 shoats (sheep and goats) per day and it is expected to export up to 60 percent of the meat output. However, since re-opening almost five years ago, it has been unable to reach half of its operational capacity due to old and dilapidated processing equipment (Matete *et al*., 2010). The KMC contracts a few farmers to supply livestock, in order to ensure relative stability in its meat sales.

Due to the inadequacies of the KMC, livestock marketing in Kenya is largely handled by the private sector, while the government only provides regulatory services such as issuance of livestock movement permits. The key marketing agents are butchers, private live animal traders and middlemen who purchase the livestock in abattoirs, open air markets in designated areas (operating once or twice a week) or buy at the farm level. There are two main private sector organizations that deal with livestock marketing; Kenya Livestock Marketing Council (KLMC) and the Livestock Trading and Marketing Society of Kenya (LTMSK). The KLMC is a non-profit organization which coordinates export of live animals occasionally, from arid areas of Kenya to the Middle East countries, e.g., Oman. The LTMSK operates a few ranches in some parts of Kenya, and exports live animals and chilled meat.

Provision of market support services such as information on prices and livestock numbers depends on the market outlet. For example, farmers who sell to KMC have contracts which might indicate number of animals to be delivered and/or a ceiling price for each. In the open air markets, however, farmers use information from a wide range of sources, including mass media, and actual demand and supply conditions in the market to determine prices, e.g., by way of negotiation.

2.7 Summary

Some important contextual issues in the livestock sector have been reviewed in this chapter. The need to meet an increasing demand for meat (including beef) against the backdrop of emerging challenges, including competition for resources between agricultural enterprises and bio-fuel production, and concerns to mitigate greenhouse gas emissions in livestock farming, was discussed.

Further, the SPS measures were reviewed and some important considerations in their application to livestock production and trade were highlighted. Specific food safety and quality requirements that are applicable to imports of live animals and animal products in the EU were outlined; considering that the EU is a major beef importer and offers preferential market access to Kenya.

In order to emphasize the rationale for livestock disease control, some economic losses associated with animal disease outbreaks were explained. Further, the use of DFZs as an SPS measure for managing livestock diseases was explored, including a review of how the DFZs have been successfully implemented in some of the main beef exporting countries. Finally, some important livestock production inputs and marketing services in Kenya were highlighted, including the policy challenges that need to be addressed.

This study investigates Kenyan beef cattle farmers' technical efficiency (TE) and preferences for DFZs. The next chapter provides a review of the production theory and methods for measuring efficiency.

Chapter Three

3. Review of Production Theory and Efficiency Measurement

3.1 Introduction

Production refers to a process of transforming resources (inputs) into commodities (outputs) using a given level of technology. The production process can be measured using a production function, while efficiency is typically estimated through deterministic and/or parametric approaches. Subsequent sections of this chapter contain pertinent issues regarding production economics and efficiency. These include: a review of the general production theory and necessary consistency requirements (section 3.2); the main techniques for efficiency measurement, with examples of previous empirical applications (section 3.3); and a summary (in section 3.4) of the key points noted in the literature, including some gaps in knowledge where the present study possibly makes a contribution.

3.2 The classical production function

A production function (also commonly referred to as the production frontier) is often used to illustrate the technical relationship between inputs and outputs in the production process. The production function represents the maximum level of output attainable from alternative input combinations (Coelli *et al*., 2005). The classical production function (assuming only a single output is produced from various inputs) can be specified as:

$$Q_n = f(X_n, \beta) + \varepsilon \qquad (1)$$

where Q_n is the output (total physical product - TPP) of the n^{th} farm, X is a vector of inputs used in the farm, while β are parameters to be estimated, ε is the error term that is assumed to capture statistical noise in the model, and ($f(.)$) is the functional form used, for example the Cobb-Douglas or translog specification.

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Further, it is assumed in economic theory, that the production function (Equation 1) is characterised by the following regularity properties or conditions (Chambers, 1988):

a) Non-negativity: the value of output is a finite, non-negative real number;
b) Weak essentiality: at least one input is required in order to produce positive output;
c) Monotonicity: assuming that individuals are rational, additional units of an input should not decrease output. Thus, all marginal products or elasticities are non-negative for a continuously differentiable production function;
d) Concavity in inputs: the law of diminishing marginal productivity applies in a continuously differentiable production function. Thus, to satisfy the second-order condition for optimisation, all marginal products are non-increasing.

However, in practice these properties are not exhaustive and may not be universally maintained. For example, excess usage of inputs might result in input congestion, which relaxes the monotonicity assumption. Also, a stronger essentiality assumption often applies in cases where each and every input included proves to be essential in a production process (Coelli *et al*., 2005). Moreover, flexibility of a production function (i.e., no restrictions imposed except theoretical consistency) is another desirable feature in order to allow data to capture information on critical parameters. Fuss and McFadden (1978) noted further, that there is need for a careful consideration of a trade-off between computational requirements of a functional form (e.g., linearity-in-parameters and parsimony with respect to number of parameters) and the thoroughness of empirical analysis. Factual conformity with economic theory is also necessary (Sauer *et al*., 2006).

The productivity of any input is measured by the average physical product (APP), which is given by ratio of TPP to each input. Thus, the APP of the i^{th} input can be obtained as:

$$APP_i = \frac{Q_n}{X_i} \quad (2)$$

The slope (first derivative) of a production function defines the marginal physical product (MPP) for any input, i.e., the extra output that can be obtained by using one more unit of a given input, with all others held at some fixed levels.

$$MPP_i = \frac{\partial Q_n}{\partial X_i} > 0 \text{ if the monotonicity restriction holds for the } i^{th} \text{ input} \quad (3)$$

In a practical sense however, the production process requires optimal combinations of different inputs. Therefore, the continued application of one input, while maintaining others constant, only contributes to increments in the output until a certain limit beyond which the marginal productivity declines (usually from a point in stage I of the production function where APP reaches a maximum and APP=MPP). Thereafter, a drop in marginal returns intuitively results from congestion of the variable inputs on the fixed input. The MPP reaches zero when TPP is highest (at the end of stage II of the production function), but this does not necessarily imply attainment of efficiency. Instead, efficiency may only be achieved at a point within stage II (the economically-feasible region of production), where marginal product value equals the marginal cost for each input (Coelli *et al.*, 2005). Thus, in stage II, the second-order condition for optimization is satisfied and the slope of the marginal product curve is negative, implying that apart from being positive, the marginal products should be decreasing in inputs (Sauer *et al.*, 2006) [3]:

$$\frac{\partial MPP_i}{\partial X_i} = \frac{\partial^2 Q}{\partial X_i^{\,2}} = f_{ii} < 0 \quad (4)$$

---

[3] The concavity property is violated throughout stage I of the production function. Further, stage III is an irrational region of production where additional use of inputs lead to decline in output and negative MPP, i.e., monotonicity is violated.

Other useful concepts in the production theory that are applicable in this study include returns to scale (RTS), product value and cost of inputs. The RTS measures the responsiveness of output to a proportional increase in all inputs in the long run (Coelli *et al.*, 2005). It can be described as: constant returns to scale (CRS) if output increases by the same proportion as the increase in all inputs; decreasing returns to scale (DRS) if output increases by a lesser proportion compared to the increase in all inputs; increasing returns to scale (IRS) if output increases by a greater proportion to the increase in all inputs. The RTS is also referred to as the total elasticity of production or elasticity of scale and is calculated as follows:

$$RTS = \frac{MPP}{APP} \tag{5}$$

Alternatively, the elasticity of production can be measured using the degree of homogeneity of the production function. A function is considered to exhibit CRS if it is linearly homogeneous (i.e., degree of homogeneity equals to 1). Otherwise, production functions can be classified as DRS if the degree of homogeneity is less than 1 or IRS when the degree of homogeneity is greater than 1. The well known Cobb-Douglas functional form is a restrictive type of CRS production function in which there are no variations in output elasticities with respect to inputs as the input levels change, and the direct elasticity of substitution between inputs is equal to 1 (Coelli *et al.*, 2005).

The RTS experienced by a farm depends on the characteristics of the farm, amongst other factors. For instance, a large labour force might be necessary in order to achieve IRS if such labour is highly skilled and therefore promotes specialisation. However, as the number of employees increases, it could result in DRS because management may be unable to exercise effective control on an overwhelming work force in the production process (Coelli *et al.*, 2005).

Using the production theory, it is also possible to link efficiency with profitability. Given the output price (P_Q), the total product value TPV=TPP*P_Q, the average product value APPV=APP*P_Q, and the marginal product value MPV=MPP*P_Q. With a behavioural assumption of profit maximisation given a rational farmer, the efficient point of operation will be defined when the value of marginal product of each input is equal to the input price, i.e., each extra input applied in the production process contributes its cost as the value of output. The profit maximising level or point of efficient utilisation for the i^{th} input can be expressed as (Chiang, 1984):

$$\frac{\partial \pi}{\partial i} = MPV_i - MVC_i = 0 \qquad (6)$$

where π is profit and *MVC* is the input price.

Further details on the production theory can be obtained from some of the key microeconomics textbooks such as Henderson and Quandt (1980), Chambers (1988) and Varian (1992). Techniques for measuring technical efficiency (TE) are discussed in the next section.

3.3 Measurement of technical efficiency

Since the seminal paper of Farrell (1957), TE has typically been analysed using two principal approaches: the non-parametric data envelopment analysis (DEA) proposed by Charnes *et al.* (1978) and the econometric stochastic frontier approach (SFA) proposed by Aigner *et al.* (1977) and Meeusen and Van den Broeck (1977). These approaches are discussed in the following sections.

3.3.1 Data envelopment analysis

The DEA method is a deterministic approach for measuring efficiency, i.e., it assumes that any deviations from optimal output levels are due to inefficiency, rather than errors. The first DEA model was developed by Charnes *et al.* (1978), who extended the relative efficiency concept of Farrell (1957), to incorporate many inputs and outputs simultaneously. This approach involves use of linear programming (LP) methods to construct a non-parametric piece-wise surface or frontier over sample data, and then efficiency measures are computed relative to the surface (Coelli *et al*., 2005). Efficiency analysis can be considered to be input-oriented if the objective is to produce the same amount of output with fewer inputs, or output-oriented if the aim is to continue using the same quantity of inputs while producing a higher level of output. The DEA model proposed by Charnes *et al*. (1978) was input-oriented and assumed constant returns to scale (CRS). Formally, this can be expressed as:

$$
\begin{aligned}
&\max_{\ell,\hbar}(\ell'\hbar), \\
&st \\
&\hbar' x = 1, \\
&\ell' q_n - \hbar x_n \le 0, n = 1,2\ldots,N, \\
&\ell,\hbar \ge 0,
\end{aligned}
\qquad (7)
$$

where vector x and q are input and output matrices, respectively for individual firms; ℓ is a vector representing the input weights; and $\hbar$ denotes a vector of output weights.

Equation (7) is commonly referred to as the *multiplier* form of the DEA model, and solving it yields the normalised shadow prices or values of ℓ and $\hbar$ that maximise the efficiency measure for the n^{th} firm.

An equivalent *envelopment* form of equation (7) can be derived using the duality concept in LP (see Gabriel and Murat, 2010, for details on duality). The envelopment form is generally preferred in the literature because it entails fewer constraints than the multiplier form. This can be stated as:

$$
\begin{aligned}
&\min_{\vartheta,\lambda}(\vartheta), \\
&st \\
&-q + Q\lambda \ge 0, \\
&\vartheta x - X\lambda \ge 0, \\
&\lambda \ge 0,
\end{aligned}
\qquad (8)
$$

where X and Q respectively, denote input and output vectors for the entire industry; λ is an $Nx1$ vector of constants; and ϑ is the efficiency score for the n^{th} firm. According to Farell (1957), $\vartheta \leq 1$; a value of 1 indicates that a firm or decision-making unit (DMU) operates at a point on the frontier, and hence is considered to be technically efficient. Because in practice, changes in most production processes do not always follow the proportionate input-output ratio assumed in CRS, Banker *et al*. (1984) proposed a more flexible DEA model with a variable returns to scale (VRS) assumption. The use of VRS specification eliminates scale effects in calculating TE (Coelli, 1996a).

The main strengths of the DEA include: its ability to accommodate multiple inputs and outputs; it does not require explicit *a priori* determination of a production function; and it measures efficiency of each DMU relative to the highest observed performance of all other DMUs rather than against some average (Coelli *et al*. 2005; Odeck, 2007). Furthermore, by incorporating many inputs and outputs simultaneously in the estimation, the DEA provides a straightforward way of computing efficiency gaps between each DMU and the efficient producers (Haji, 2006). The DEA model has been extensively applied to assess TE, for example, in beef cattle analysis (Featherstone *et al*., 1997; Rakipova *et al*., 2003), extensive livestock farming systems (Gaspar *et al*., 2009), dairy farms (Fraser and Cordina, 1999); rice farms (Dhungana *et al*., 2004); and multiple production processes in transport services (Barnum and Gleason, 2010).

However, DEA has some limitations: deterministic frontiers do not account for measurement errors and other sources of stochastic variation, and hence do not permit hypothesis tests on TE estimates; and effective incorporation of the random term in estimation of stochastic DEA is usually hampered by computational complexities (Coelli *et al*., 2005). By failing to account for errors, the DEA estimates tend to exhibit greater variability compared to stochastic frontiers, by either overestimating mean TE (Bravo-Ureta *et al*., 2007; Odeck, 2007) or underestimating the efficiency measures (see for example, Sharma *et al*. 1997). The DEA results also vary widely depending on whether the returns to scale are assumed to be constant or variable (e.g., Wadud and White, 2000). Differences in estimates from the DEA and stochastic frontiers are also usually attributed to heterogeneity in characteristics of data, choice of inputs and output variables, errors arising from measurement and specification, and estimation procedures (Mortimer, 2002). Some studies found substantially different mean efficiency scores from these techniques (for instance, Bauer *et al*., 1998; Reinhard *et al*., 2000), while others obtained nearly similar mean TE estimates from both approaches (see for example, Latruffe *et al*., 2004; Mulwa *et al*., 2009a; Jef *et al*., 2010). However, as noted by Odeck (2007), the DEA approach might erroneously categorise all DMUs operating with extreme input-output quantities as efficient, when there are insufficient comparable units. For comprehensive reviews on the DEA methodology, the reader is referred to Charnes *et al*. (1995), Cooper *et al*. (2000) and Ray (2004).

Typically, the selection of which analytical model to apply in measuring efficiency is influenced by the characteristics of the production process, degree of stochasticity, number of outputs and possibility of aggregation, and the researcher's own preference (Herrero, 2005). Generally, less variability of estimates (*i.e., statistical efficiency*) is desirable for precision of inferences and accuracy in prediction or policy applications (Greene, 2003). Considering the limitations of DEA, unobserved randomness in farm decision-making behaviour, and cognisant of the existence of statistical noise, the present study prefers the stochastic frontier approach (SFA). For effective policy action, it is important to explain variations in output, more so in production systems of most developing countries, such as Kenya, which are usually vulnerable to many external influences, such as unpredictable weather and disease outbreaks.

3.3.2 Stochastic production frontier

The independent research by Aigner *et al*. (1977) and Meeusen and Van den Broeck (1977) were instrumental in providing a break-through for parametric analysis of how policy variables (e.g., management) might influence the production process. They proposed a stochastic frontier production function, which separates the error term into technical inefficiency effects and random variations due to statistical noise. This decomposition of the error term into technical inefficiency and pure statistical noise is the distinctive feature between the classical production function (Equation 1) and the stochastic frontier model. By separating the effect of stochastic noise from that of inefficiency, the SFA allows hypotheses to be tested regarding the production structure and extent of inefficiency, unlike the DEA (Coelli *et al*., 2005). Furthermore, the SFA is more suitable for TE estimation in single-output production processes or multi-output situations where it is reasonable to aggregate all outputs into one measure (Herrero, 2005).

Suppose we have k groups or production systems in the cattle industry. The stochastic production frontier can be specified as:

$$Q_n = f(X_n, \beta) + \varepsilon^* \qquad (9)$$

where Q_n is the output of the n^{th} farm

X is the vector of inputs used by the n^{th} farm

β is a vector of production input parameters to be estimated

ε^* is a composite disturbance term given by:

$$\varepsilon^* = v - u \qquad (10)$$

where v is a symmetric random error representing effects of statistical noise (including measurement errors, variables omitted in the production function and other unobserved factors or those outside a farmer's control e.g., disease and weather).

It is assumed that v is independent and identically distributed (IID) as a normal random variable with zero mean and variance σ_v^2, i.e., $v \sim N(0, \sigma_v^2)$ (Aigner *et al*., 1977). Farm-specific technical inefficiency in production is typically assumed to be captured by u, which is a non-negative random variable. The u is assumed to be IID half-normal, i.e., $u \sim |N(0, \sigma_u^2)|$ (Jondrow *et al*., 1982) and it follows that (Aigner *et al*., 1977):

$$\sigma^2 = \sigma_v^2 + \sigma_u^2 \tag{11}$$

Although u can also assume exponential or other distributions, the half-normal distribution is preferred for parsimony because it entails less computational complexity (Coelli *et al*., 2005). Furthermore, the alternative two-parameter Gamma-normal distribution is not suitable because it entails identification problems, requires very large samples for estimation, and it is sometimes difficult to maximise the log-likelihood function (Ritter and Simar, 1997). The u is independent of the v-term and it measures the TE relative to the stochastic frontier. When data are expressed in logarithm form, u is a measure of the percentage by which a particular observation or farm fails to achieve the frontier, ideal production rate (Greene, 2003).

Following Battese and Corra (1977), the variation of output from the frontier due to inefficiency is defined by a parameter gamma (γ) given by:

$$\gamma = \frac{\sigma_u^2}{\sigma^2}, \text{ such that } 0 \le \gamma \le 1 \tag{12}$$

The stochastic frontier for the k^{th} production system can be specified as:

$$Q_{nk} = f(X_{nk}, \beta_k)\exp(v_{nk} - u_{nk}) \tag{13}$$

In order to obtain asymptotically efficient estimators, equation (13) can be estimated through the maximum likelihood approach (Coelli, 1995). The estimation can be undertaken either in one-step or as a two-stage process. The single-stage approach involves simultaneous estimation of TE parameters and factors that might explain inefficiency (i.e., inefficiency effects) in one stochastic frontier equation. The double-step estimation method, on the other hand, entails determination of TE levels in a stochastic frontier, followed by a separate regression of variables associated with the estimated efficiency levels. However, the two-stage procedure is not preferred because the use of TE estimates from stage-one as the dependent variable in the second step violates the assumed IID property of *u*, introduces bias, and leads to inconsistent estimates of the inefficiency effects (Kumbhakar *et al.*, 1991; Battese and Coelli, 1995). An overview of the stochastic frontier method can be found in Kumbhakar and Lovell (2000) and Greene (2008).

Subsequent discussions in this section consider a stochastic frontier in which inefficiency effects are included. Let $u = Z\delta$, where Z is a vector of factors that influence the technical inefficiency of farms, while δ is a vector of inefficiency parameters to be estimated. The stochastic frontier for each production system (Equation 13) can be re-written as follows:

$$Q_{nk} = f\left(X_{nk}, \beta_k\right)\exp\left(v_{nk} - Z_{nk}\delta\right) \tag{14}$$

There are arguments in the literature (for instance, see Stokes *et al.*, 2007) that the requirement on the analyst to set specific assumptions on the functional form makes the SFA more prone to mis-specification, which might yield less credible results than those obtained from the deterministic DEA. Some studies (e.g., Mbaga *et al.*, 2003) also show significant differences in mean efficiency estimates across various functional forms. However, it is worthwhile to note, that the choice of a functional form is an empirical issue, and it is often a standard practice to test the applicable form on given sample data, for example using likelihood ratio (LR) tests (Coelli *et al*., 2005).

It is also recommended to check stochastic frontier results for conformity with the regularity conditions, to ensure that at least the restrictions on monotonicity and diminishing marginal products (concavity) hold at the point of approximation e.g., at the sample mean (Sauer *et al*., 2006). Although these measures of theoretical consistency have previously been ignored in the bulk of efficiency literature, recent empirical applications (e.g., Omer *et al*., 2007; Rahman *et al*., 2009) have begun to incorporate such assessments. However, the regularity conditions are unlikely to hold in some situations. For example, when data availability necessitates the use of proxy variables such as value added instead of real output (Lio and Hu, 2009), and/or as the number of inputs and outputs included in the data matrix increases (Zhu and Lansink, 2010).

The TE of the n^{th} farm with respect to the k^{th} production system frontier can be expressed as the ratio of observed output (Equation 14) to that expected maximum level from the use of available inputs (assuming any deviation is pure noise, i.e., the classical production function in equation 1) (Boshrabadi *et al*., 2008):

$$TE_{nk} = \frac{f(X_{nk}, \beta_k)\exp(v_{nk} - Z_{nk}\delta)}{f(X_{nk}, \beta_k)\exp(v_{nk})} = -Z_{nk}\delta \qquad (15)$$

There is a vast empirical literature on the SFA, involving the use of either cross-sectional or panel data. Some of the stochastic frontier applications with cross section data in agriculture include Dawson (1987), Sharma *et al*. (1999), Okike *et al*. (2004), Jabbar and Akter (2008), and Liu and Myers (2009). Selected empirical applications of the SFA on panel data include the investigation of TE in beef cattle farms (Iraizoz *et al*., 2005; Hadley, 2006; Barnes, 2008), and other agricultural enterprises (Battese and Tessema, 1993; Lio and Hu, 2009; Zhu and Lansink, 2010).

The stochastic frontier given by equation (14) allows comparison of farms operating with similar technologies. However, farms in different environments (e.g., production systems) do not always have access to the same technology. Assuming similar technologies when they actually differ across farms might result in erroneous measurement of efficiency by mixing technological differences with technology-specific inefficiency (Tsionas, 2002). Various alternatives have been proposed in the literature to account for differences in technology and production environment. These are discussed in the following section.

3.3.3 Methods to address technology differences in efficiency estimation

There are five possible approaches that can be applied to measure technology-related variations in TE between different groups. These are discussed as follows.

3.3.3.1 Continuous parameters method

There are different versions of stochastic frontiers whereby the cross-farm heterogeneity can be modelled as a continuous parameter variation. Van den Broeck *et al*. (1994) and Koop *et al*. (1997) introduced Bayesian stochastic frontiers that use Monte Carlo integration or Gibbs sampling techniques to assess the influence of exogenous or non-conventional factors on either the production function (common efficiency distribution) or inefficiency component (varying efficiency distribution). The main advantages of the Bayesian approach are that it provides point and interval estimates of TE, exact finite-sample results can be obtained, and the estimation implicitly allows conformity with economic theory. However, as noted by Balcombe *et al*. (2007, p. 8), '*…the choice of what is or is not exogenous is open to interpretation…*'. This might present the analyst with difficulties, for instance in defining not only what constitutes a technology, but also whether technology is an input or an inefficiency variable. Moreover, Bayesian frontier analysis entails many restrictions, e.g., the inefficiency term is assumed to be exponentially distributed, regularity conditions are imposed on the data and an informative prior value must be chosen for the median of the efficiency distribution. These requirements increase complexity in the estimation, and also reduce the ability to capture the 'true' characteristics of the sample data (Coelli *et al*., 2005).

Tsionas (2002) proposed a random coefficient stochastic frontier model in which the absolute farm-specific efficiency is separated from technological differences across farms using Bayesian analysis involving Gibbs sampler with data augmentation algorithm. This approach avoids confusion between technological differences and technology-specific inefficiency. However, it entails a restrictive exponential assumption on the inefficiency term. In addition, the model specification in Tsionas (2002) requires all regression parameters to be random at the same time. Huang (2004) extended this model by proposing a flexible stochastic frontier where only a subset of parameters are random while the rest remain fixed, and the inefficiency measure is assumed to follow a gamma distribution with the shape parameter not necessarily being an integer. But, the flexibility in the gamma functional form entails computational complexity given that many parameters have to be estimated (Coelli *et al*., 2005).

Greene (2005a), on the other hand, proposed two alternative panel data estimators in stochastic frontiers: the *true random effects* model, which assumes that there is a specific random term to account for heterogeneity in each farm (see applications in Abdulai and Tietje, 2007, and Farsi and Filippini, 2008); and a *true fixed effects* model, where each farm is assumed to have a fixed parameter that is correlated with other variables included (Greene, 2005b). However, these approaches are suited to panel rather than cross sectional data, which are used in the present study.

3.3.3.2 Nonparametric stochastic frontier

In order to address heterogeneous technologies, Kumbhakar *et al*. (2007) proposed a nonparametric stochastic frontier based on local maximum likelihood approach. This encompasses anchoring a parametric model in a nonparametric way by first deriving asymptotic properties of the general case estimator, and then using the results to construct a stochastic frontier model. The convoluted error term (comprising inefficiency and noise) is assumed to be a sum of a half-normal and a normal random variable. This model has been applied by Serra and Goodwin (2009), but entails much computational complexity and is associated with the limitations of nonparametric approaches mentioned earlier (see section 3.3.1).

3.3.3.3 Predetermined sample classification

Some studies classify data into various groups based on *a priori* information, and then separate frontiers are estimated for each group. This approach is the most popular method in the literature, in accounting for technology differences (see for example, Okike *et al*., 2004; Newman and Mathews, 2006; Rahman *et al*., 2009; Zhu and Lansink, 2010). However, considering that each frontier measures individual farm performance relative to the best technology in a particular industry, the separate frontiers cannot be compared because technologies might not be identical across the farms (O'Donnell *et al*., 2008). In addition, the use of group-specific dummy variables requires large samples and does not explain within-group variations.

3.3.3.4 Latent class stochastic frontier

An alternative approach that has elicited some empirical interest in recent literature is to use the latent variable theory to classify the data into segments or groups, based on unobservable (latent) characteristics depicted by the data (McCutheon, 1987) and then estimate a frontier for each group in one stage. This approach is referred to as latent class modelling (LCM) and involves joint determination of the number of groups and assignment of individuals to any of the groups in a probabilistic fashion, based on the latent segmentation variables. The main advantages of the LCM over the alternatives are that it entails use of statistical tests to choose the appropriate number of groups that realistically fit the data, and it allows use of inter-group information to explain similarities and differences, for instance in technology across groups (Alvarez and Corral, 2010).

The LCM concept has been applied in the literature, for example to investigate: market preferences (Kamakura and Russell, 1989; Bucklin and Gupta, 1992; Gupta and Chintagunta, 1994), transportation mode choices (Bhat, 1997), preferences for indigenous cattle breeds (Ruto *et al*., 2008) and preferences for agri-environment schemes (Ruto and Garrod, 2009). Applications of the LCM in stochastic frontier analysis are still few and include studies in agriculture (e.g., O'Donnell and Griffiths, 2006; Alvarez and Corral, 2010), the banking sector (e.g., Orea and Kumbhakar, 2004) and transport (e.g., Barros, 2009). However, the LCM method is not preferred for analysis of TE in the present study because it is mainly suited to panel data estimation.

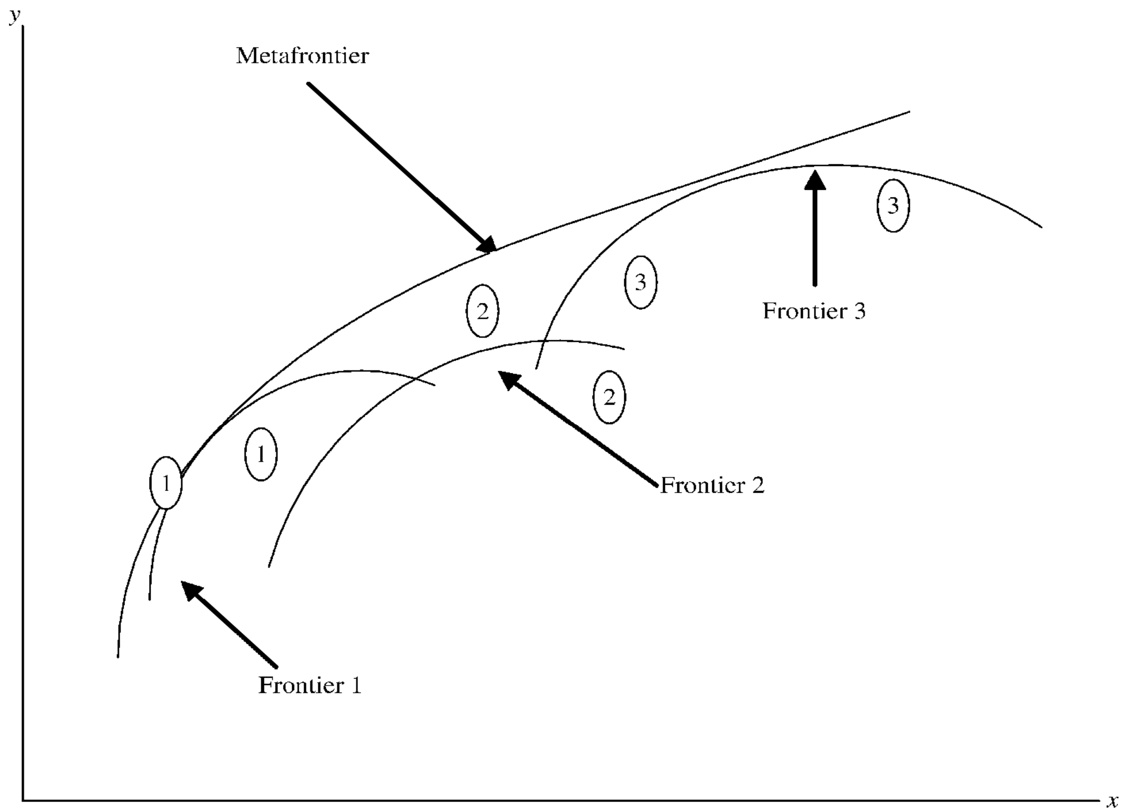
3.3.3.5 Metafrontier

In the last decade, a new approach of accounting for technology variations in both cross section and panel data through metafrontier estimation has been developed in two formats: DEA-metafrontier and stochastic metafrontier. The DEA-metafrontier method can be considered as a 'double mathematical programming' approach since it involves LP analysis in the first stage, followed with either a quadratic programming (QP) or another LP equation to optimise parameters obtained from the first estimation stage. This approach has been applied in a few studies (e.g., Mulwa *et al*., 2009b; Kontolaimou and Tsekouras, 2010). But, this method has the limitations of non-parametric techniques mentioned earlier.

In order to capture variations in technology within and between production systems, Battese and Rao (2002) proposed the use of a stochastic metafrontier production function to measure efficiency and technology gaps of firms producing in different technological environments. This approach is implicitly underpinned by two distinct data-generating mechanisms; one that explains deviations between observed outputs and group frontiers, and another that explains deviations between observed outputs and the metafrontier. However, the above method is limited because some points on the estimated metafrontier may lie below points on the estimated group frontiers. In order to address this limitation, Battese *et al*. (2004) defined the metafrontier as a smooth function that envelops the explained (deterministic) components of the group stochastic frontier functions.

Thus, the metafrontier function captures the highest possible output level (y) attainable, given the input (x) and common technology in the industry (Figure 6). Output levels for producers who are efficient both in respective group frontiers (e.g., frontier 1) and in the entire industry lie on the metafrontier. Frontiers 2 and 3 fall below the metafrontier; this implies that they represent efficient production in the groups/production systems, but not so for the industry.

Figure 6: Metafrontier illustration



Source: Adapted from Battese *et al.* (2004).

The metafrontier proposed by Battese *et al.* (2004) is estimated by specifying a single data-generating process, which explains deviations between observed outputs and the maximum possible explained output levels in the group frontiers (i.e., it is constructed from the same data generated for individual frontiers). The stochastic metafrontier estimation involves first fitting individual stochastic frontiers for separate groups and then optimising them jointly through an LP or QP approach. This technique is preferred in the present study over the other approaches discussed earlier because it allows hypotheses tests, enables estimation of technology gaps for different groups and accommodates both cross-sectional and panel data (Villano *et al.*, 2010). Following O'Donnell *et al.* (2008), the stochastic metafrontier equation can be expressed as:

$$Q_n^* = f(X_n, \beta^*) \qquad n = 1,2,\ldots N \qquad (16)$$

where $f(.)$ is a specified functional form; Q^* is the metafrontier output; and β^* denotes the vector of metafrontier parameters that satisfy the constraints:

$$f(X_n\beta^*) \geq f(X_n\beta_k), \text{ for all } k = 1, 2, \ldots K \tag{17}$$

A metafrontier may be considered as the boundary of an unrestricted technology set; while group stochastic frontiers can be defined as the boundaries of restricted technology sets (restrictions here imply limitations in economic infrastructure and production environment). According to equation (17) the values of the metafrontier are no less than the deterministic functions associated with the stochastic frontier models for the different production systems in the analysis (i.e., the metafrontier dominates all the individual frontiers when considered as a group of frontiers). Thus, the metafrontier is related to the metaproduction function concept defined by Hayami and Ruttan (1971, p. 82) as '…*the metaproduction function can be regarded as the envelope of commonly conceived neoclassical production functions*'. In order to satisfy the above condition (Equation 17), an optimisation problem is solved, where the sum of absolute deviations (or the sum of squared deviations) of the metafrontier values from the group frontiers are minimised. The optimisation problem is usually expressed as (Battese *et al*., 2004):

$$\begin{aligned} &\min \sum_{n=1}^{N} \left| \ln f(X_n, \beta^*) - \ln f(X_n, \beta_k) \right| \\ &s.t. \ln f(X_n, \beta^*) \geq \ln f(X_n, \beta_k) \end{aligned} \tag{18}$$

The standard errors of the estimated metafrontier parameters can be obtained through bootstrapping or simulation methods.

In terms of the metafrontier, the observed output for the n^{th} farm in the k^{th} production system (measured by the stochastic frontier in equation 14) can be expressed as:

$$Q*_{nk} = \exp(-Z_{nk}\delta).\frac{f(X_n,\beta_k)}{f(X_n,\beta^*)}.f(X_n,\beta^*)\exp(v_{nk}) \quad (19)$$

where $\exp(-Z_{nk}\delta) = TE_{nk}$ (see equation 15), and the middle term in equation (19) represents the technology gap ratio (TGR) that can be expressed as:

$$TGR_n = \frac{f(X_n,\beta_k)}{f(X_n,\beta^*)},\ 0 \le TGR \le 1 \quad (20)$$

The TGR measures the ratio of the output for the frontier production function for the k^{th} group or production system relative to the potential output defined by the metafrontier, given the observed inputs (Battese and Rao, 2002; Battese *et al*., 2004). Values of TGR closer to 1 imply that a farm in a given production system is producing nearer to the maximum potential output given the technology available for the whole industry. For instance, a value of 0.99 suggests that the farm produces on average 99 percent of the potential output, assuming all farmers use a common technology. Thus, the TGR provides an indication of farmers' performance relative to the dominant technology in the entire industry. Technologies in this study comprise the type of cattle breed, breeding method and feeding methods.

The notion of TGR defined in equation (20) depicts the gap between the production frontier for a particular production system or group frontier and the metafrontier (Battese *et al*., 2004). However, a confusion of terminology arises because an increase in the (technology gap) ratio implies a decrease in the gap between the group frontier and the metafrontier. Further, it is important to expand the definition of TGR to account for constraints placed on the potential output by the environment, and interactions between the production technology and the environment. Accordingly, recent literature uses meta-technology ratio (MTR) or environment-technology gap ratio (ETGR), rather than TGR (Boshrabadi *et al*, 2008; O'Donnell *et al*., 2008). Subsequently, the TGR is referred to as MTR in this study.

The MTR considers environmental limitations on the production technology. Generally, the potential for productivity gains from use of a given technology (e.g., cattle breed or breeding method) varies across production systems, depending on natural environmental constraints such as rainfall distribution (which determine feed quality and availability) and relative disease incidence. Further, human influences on the production environment, for example, skewed distribution of extension services, and veterinary drugs and advisory services, market information and general infrastructure across production systems or spatially (e.g., rural vs. peri-urban) might affect the ability of farmers to achieve the highest production potential of a given technology. In addition, O'Donnell *et al*. (2008) note that potential gains from technology sets differ among farms because of differences in available stocks of physical, human and financial capital such as type of machinery, and the size and quality of labour force.

The TE of the n^{th} farm relative to the metafrontier (TE^*_n) is the ratio of the observed output for the n^{th} farm relative to the metafrontier output, adjusted for the corresponding random error such that:

$$TE_n^* = \frac{Q_{nk}}{f(X_n, \beta^*)\exp(v_{nk})} \tag{21}$$

Essentially, following equations (14), (19), and (20), the TE^*_n can be expressed as the product of the TE relative to the stochastic frontier of a given production system and the MTR:

$$TE_n^* = TE_{nk}.MTR_n \tag{22}$$

Both estimates of TE and MTR are useful for design of programmes that target performance improvement. The TE estimates can inform changes to management and structure of farms. MTRs provide insights on necessary changes in technology and production environment (O'Donnell *et al*., 2008).

Empirical applications of the stochastic metafrontier are still very few. Some of these include estimation of TE and technology gaps in agriculture (Boshrabadi *et al*., 2008; Chen and Song, 2008; O'Donnell *et al*., 2008; Villano *et al*., 2010; Wang and Rungsuriyawiboon, 2010). Other applications of the stochastic metafrontier approach involve studies that assess TE in garment firms (Battese *et al*., 2004), healthcare-foodservice operations (Matawie and Assaf, 2008), electronic firms (Yang and Chen, 2009), and electricity distribution firms (Huang *et al*., 2010). The present study contributes to the literature through application of the stochastic metafrontier to investigate TEs and MTRs in various beef cattle production systems.

3.3.4 Assessing the determinants of metafrontier efficiency estimates

The estimation of efficiency parameters is useful to policy. Further, it is important to explain variations in the efficiency levels, so as to provide insights on variables that can be readily altered by management in order to improve efficiency. In stochastic frontiers such variables are normally included directly in the single-stage estimation process mentioned earlier (see Equation 14 in section 3.3.2). However, there is no provision for incorporating possible determinants of efficiency (i.e., inefficiency effects) in the input-out metafrontier equation that follows a deterministic programming approach (see Equation 18). Therefore, after computing the metafrontier TE scores, a two-limit Tobit model (Tobin, 1958) has been proposed in the literature as a suitable approach for investigating the determinants of the metafrontier efficiency measures.

In the two-limit Tobit model, the observed data on the dependent variable is censored from above and below (Greene, 2003). This is applicable to the present study, considering that TE scores are usually bounded between 0 and 1 (Bravo-Ureta and Pinheiro, 1997). The two-limit Tobit model can be specified as (Wooldridge, 2002):

$$\theta^{k*} = Z\delta + e$$

$$\theta^{k*} = \{(0\, if\ \theta^{k*} < 0); (\theta^{k*} if\ 0 < \theta^{k*} < 1); (1\, if\ \theta^{k*} > 1)\} \quad (23)$$

where θ^{k*} and θ^{k} are the latent and observed values of the metafrontier TE scores, respectively; Z denotes the vector of socio-demographic and other independent variables assumed to influence efficiency; δ is a vector of inefficiency parameters to be estimated; and e is the random term.

Generally, Tobit models have been extensively applied in the literature. These include for example, in the investigation of marketing contract decisions (Katchova and Miranda, 2004), milk sales issues (Holloway *et al*., 2004), livestock market participation (Bellemare and Barrett, 2006) and land market transactions (Rahman, 2010). Further, some studies have applied two-stage DEA-Tobit models to analyse determinants of agricultural efficiency (e.g., Featherstone *et al*., 1997; Rakipova *et al*., 2003; Latruffe *et al*., 2004; Fletschner *et al*., 2010).

In addition, there are cases where a stochastic frontier-Tobit approach has been used (see for example, Nyagaka *et al*., 2010). However, within a stochastic metafrontier framework, there are very few empirical applications of the two-limit Tobit model (Chen and Song, 2008 is an exception). The present study contributes to the literature by applying the two-limit Tobit to analyse factors that might influence TE measures (derived from stochastic metafrontier estimation) in beef cattle production systems in Kenya.

3.4 Summary

In this chapter, discussions have been presented on a review of the production theory and approaches for measuring efficiency. Generally, it was noted that there is extensive literature on production efficiency. But, most of the published research focuses on crops and other enterprises than beef cattle farms. The need to check conformity of efficiency measures with theoretical requirements was also highlighted.

Various strengths and weaknesses of both parametric and non-parametric methods were discussed, as well as situations in which each approach might be more suitable or useful considerations that may favour the choice of one approach over the other. The stochastic metafrontier method was found to be suitable for investigating TEs and MTRs in the present study.

Finally, various techniques of investigating determinants of efficiency have been critically reviewed, and it was concluded that the application of a two-limit Tobit model in stochastic metafrontier estimation would be a contribution to the literature. This is the approach adopted in the present study. In the next chapter, various non-market valuation approaches are reviewed, and their suitability for analysis of preferences for Disease Free Zones (DFZs) is assessed.

Chapter Four

4. Review of Non-market Valuation and Choice Modelling

4.1 Introduction

Economic valuation of non-market goods or services e.g., Disease Free Zones (DFZs) is useful in order to facilitate a more informed policy design process. However, such goods or services cannot be valued using standard market-based techniques due to lack of directly observed data on people's buying and selling behaviour for non-market commodities. This chapter reviews the main approaches suggested in the literature for valuation of goods or services that are typically not traded in conventional markets.

There are five sections in this chapter. In section 4.2, various revealed preference (RP) and stated preference (SP) techniques are discussed, with a critical assessment of their applicability to the present study. The choice experiment (CE) method, design criteria, some necessary considerations for design selection, design generation process and important dimensions are described in section 4.3. Commonly applied discrete choice models in studies of this kind are discussed in section 4.4, while a summary of some of the key points highlighted in this chapter is presented in section 4.5.

4.2 Non-market valuation approaches

Non-market goods or services can be valued by use of cost-based approaches or demand-side methods. Cost-based techniques include those that assess the replacement costs, restoration cost, relocation cost or amount of payments needed to provide the goods or services (Bateman, 1994). But since the cost-based approaches do not show the value that consumers attach to the products, demand-side techniques of valuation are preferred (Madureira *et al.*, 2007). The demand-side methods are broadly classified into RP approaches and SP methods.

The RP methods involve indirect valuation of non-market products using actual consumer choices in related or surrogate markets where similar items are traded. The RP methods are based on the assumption that an individual's utility function or preference can be inferred from their observed choice behaviour on the available alternatives (Samuelson, 1938). Some of the RP approaches include:

i. Travel cost method: typically used to estimate recreational values by assuming that the amount of time and travel expenses incurred to visit a site reflect the implicit prices of goods and/or services at the site. Some recent applications of this approach include Gurluk and Rehber (2008) and Baerenklau *et al*. (2010);

ii. Hedonic pricing approach: usually applied to assess the implicit price of an attribute by comparing the market values of two or more products that only differ with respect to the specific attribute. The comparisons are based on observation of the behaviour of buyers and sellers regarding the price. For example, it can be used for valuing the negative externalities of a quarry or a land fill site by comparing the prices that people would be willing to buy or sell two houses that are similar in all aspects, except that one is near or away from the quarry or land fill site. A few empirical applications of this method include Gao and Asami (2007), and Jim and Chen (2010);

iii. Averting behaviour technique: involves investigating the price that people attach to various situations by observing and valuing measures/interventions that they are prepared to take in order to avoid the situation (see for example, Hojman *et al*., 2005).

On the other hand, goods or services for which there is no related or surrogate markets can be valued through direct elicitation of consumer preferences in hypothetical scenarios, i.e., the SP approaches (Louviere *et al*., 2000; Bateman *et al*., 2002). Currently, DFZs do not exist in

Kenya and the valuation of farmers' willingness or preference to comply with them is a new concept that can be considered in a hypothetical market scenario through the SP methods.

The SP techniques are relatively superior to RP methods in two perspectives. First, unlike RP methods that only measure *ex-post* changes in use and option values, the SP approaches allow complete valuation through *ex-ante* assessment and analysis of use and non-use values of goods and services or attributes. Second, the hypothetical context in which SP methods are applied enables flexibility in designing different varieties of a product. This allows the researcher to capture people's preferences for different product or service options and make necessary adjustments before they are introduced into the actual market (Madureira *et al*., 2007). However, SP outcomes face criticism in terms of reliability and validity. Lack of actual markets presents a challenge in obtaining replicable measurements and unbiased responses that are consistent with economic theory, prior experience and real events (Pearce *et al*., 2002). In order to overcome these shortcomings, Carson *et al.* (2001) suggested that the nature of the product being valued must be clearly explained to the respondents, including appropriate mechanisms of delivering it to the public, and a realistic expectation of payment created.

There are two forms of SP methods: contingent valuation (CV) and choice modelling (CM). In the CV method, people are directly asked to state the maximum amount of money they would be willing to pay (WTP), or the minimum amount that they would be willing to accept (WTA) as compensation, for a hypothesized improvement in, or worsening of, a selected attribute, for a good or service (Mitchell and Carson, 1989). On the other hand, CM is a collection of survey-based methods that measure people's preferences for goods or services by using attributes or characteristics to form choice sets containing various alternatives or profiles. In the CM approach, respondents can be asked to rank or rate the choice alternatives (representing combinations of attributes); a process known as conjoint analysis (CA).

Alternatively, the CM may involve a discrete choice experiment (CE) whereby the respondents are asked to state the most preferred alternative from a set of options (Louviere, 2001). The CE technique was originally developed by Louviere and Hensher (1982) and Louviere and Woodworth (1983) in transport economics and marketing literature, respectively. The CE is anchored on two important microeconomic principles. First, it is based on Lancaster's theory of value, which postulates that a consumer's total utility function is separable into preferences for specific components (attributes) of the good or service, rather than measuring satisfaction from the aggregate product package. Thus, preferences for goods/services are a function of the attributes that characterise those goods/services instead of the goods/services themselves (Lancaster, 1966). The second important premise, on which CE rests, is the random utility theory. In this framework, utility is considered to be unobservable (to the analyst), i.e., a random variable, which can be measured as a probability that rational consumers make observable choices of goods or services from which they obtain the highest utility in any given choice set (Thurstone, 1927; McFadden, 1973; Manski, 1977). The randomness arises from the effects of unobserved alternative attributes, latent individual characteristics or taste variations, and measurement errors (Ben-Akiva and Lerman, 1985).

The CE is preferred over the CV method because of the following reasons (Hanley *et al*., 2001): it enables estimation of trade-offs that respondents make between individual components or attributes of a good/service (i.e., marginal values of changes in product or service characteristics) rather than the good/service *per se*; it captures more information by allowing respondents to express preferences over a range of attribute levels and prices; response difficulties such as protest bids and strategic behaviour associated with CV may be minimised in CE by indirectly estimating WTP from the ratings, rankings or choices made on alternative attribute bundles rather than seeking explicit WTP values in a survey; and the CE provides an opportunity to obtain more information from a relatively smaller sample size through repeated responses from the same respondent, on a panel of choice tasks. However, compared to the CV method, application of CE may involve more cognitive burden when the choice sets are complex or too many attributes and levels are included. In addition, estimates of total economic value from CE surveys may not be equal to the sum of partworths. Garrod and Willis (1999) show that independent valuation and summation (IVS) of attributes as in CEs is prone to bias; overestimation of attribute values when they are substitutes or undervaluation of complementary attributes. Therefore, it is important to ascertain the contextual validity of total economic values obtained from a CE by comparing them with estimates from other methods under similar situations (Hanley *et al*., 2001).

Both CV and CE are sensitive to the way a study is designed and implemented, and may suffer from response bias. The choice of survey questions, attributes and how they are presented to respondents are therefore important in both approaches (Hanley *et al*., 2001). Further, Bennett and Blaney (2003) suggest that WTP estimates from CV studies should be treated with caution due to biases such as differences in how respondents interpret survey contexts and possible influence of imaginary responses to WTP questions.

In addition, the CE enables measurement of specific as well as total values of multiple attributes in a good, service, policy or programmes; and the method can be applied to analyse benefit transfers, given its ability to separate values of individual characteristics (Hanley *et al*., 1998; Bateman *et al*., 2003). Furthermore, unlike RP techniques (e.g., hedonic pricing and travel cost methods), the CE can be used to elicit values of existing goods/services in surrogate markets or where there are no markets; it is applicable in capturing economic benefits of goods/services that are yet to be introduced or marketed. The approach also obviates two principal limitations of RP data – lack of variation in attribute levels in a single cross-section and multicollinearity among attributes (see Bennett and Birol, 2010 for details).

Choice experiments have been extensively applied to value a wide range of goods/services. These include assessment of quality changes in environmental attributes (e.g., Adamowicz *et al*., 1998; Garrod and Willis, 1999; Hanley *et al*., 2001; Willis *et al*., 2002; Alvarez-Farizo *et al*., 2007), wildlife population control for cattle disease prevention (Bennett and Willis, 2007), consumer preferences for beef steak attributes (Tonsor *et al*., 2005), and food safety aspects (Loureiro and Umbeger, 2007). In addition, the CE has been used to estimate farmers' preferences for genetic attributes of indigenous livestock (e.g., Roessler *et al*., 2008; Ruto *et al*., 2008; Kassie *et al*., 2009), rural landscape improvements (Campbell *et al*., 2008a & 2009), farmers' preferences for agricultural development policy (James, 2010), and cow-calf producer preferences for alternative voluntary traceability systems (Schulz and Tonsor, 2010). There are also many applications in transport economics (e.g., Leitham *et al*., 2000; Washbrook *et al*., 2006; Masiero and Hensher, 2010) and health economics (for example, Andersson and Lyttkens, 1999; Hanson *et al*., 2005; Kiiskinen *et al*., 2010).

Generally, much of the empirical literature on CE entails applications in developed country contexts; there is limited focus on developing countries. A recent documentation of some of the few CE studies undertaken in developing countries can be found in Bennett and Birol (2010).

The CE can be considered as a '… *structured method of data generation*' (Hanley *et al*., 1998, p. 415). It involves selection of attributes and their levels, experimental design, formation of choice sets and measurement of preferences in surveys (Pearce *et al*., 2002). Attributes are salient features or characteristics that describe a product. Proper identification of relevant attributes is necessary through a combination of a review of previous studies and the use of exploratory surveys that might entail focus group discussions (FGDs) with key informants on the issue at hand. Conventionally, a monetary value (in terms of cost or price) is normally included as an additional attribute to enable measurement of economic trade-offs between choice attributes and money, considering the opportunity cost of resources (Hanemann, 1984).

The selection of attributes must ensure that those included in the CE design exhaustively describe the good or service to be analysed and also reflect real preferences in a practical context (Boxall *et al.*, 1996). Furthermore, the attributes chosen must readily fit within the realms of policy control, besides bearing potentially significant influence on the probability of observed choice behaviour (Ruto and Garrod, 2009).

A notable development is in the use of CEs to inform the design of policies or programmes in which attributes are defined in terms of different components or aspects of policy design, rather than characteristics of the goods themselves. Applications of CEs in policy design include assessment of preferences for wild goose conservation (Hanley *et al.*, 2003) and transferability of benefits of water quality improvements between various sites (Hanley *et al.*, 2006). Other recent policy applications include in the investigation of preferences for various standards of public rights of way (Morris *et al.*, 2009), agri-environment schemes (Ruto and Garrod, 2009; Espinosa-Goded *et al.*, 2010) and agricultural reforms (James, 2010). The present study uses the CE approach to inform policy on the design of DFZs in Kenya.

Once attributes are known in a CE, possible levels are identified to capture the realistic range over which people can typically express preferences for the attributes. The attribute levels should include current state of the product and proposed changes or new characteristics. A subsequent stage in the CE study is the experimental design, which is discussed in the following section.

4.3 Choice experiment design aspects

In the CE design stage, statistical design theory is applied to combine the attribute levels into various choice alternatives or profiles that can be presented to respondents in a choice exercise (Adamowicz *et al*., 1994). An ideal experimental design is one in which all possible combinations of the levels of all attributes are provided to the respondents (full factorial design) for a choice decision (Kuhfeld *et al*., 2005). The full factorial design allows estimation of all main effects and interaction effects, and all the effects are uncorrelated. Main effects refer to the independent influence of a change in the levels of one attribute on the choice decision, given average levels of other attributes. Interaction effects on the other hand, measure how a choice decision varies with a change in the levels of some attributes in a choice set, holding one attribute at a constant level (i.e., the effect of one factor at different levels of other factors).

In spite of their ability to measure all effects, full factorial designs are very costly and complex to implement because they entail subjecting respondents to extremely large choice sets. As a way of making choice tasks more manageable to respondents, fractional factorial designs, which are smaller subsets of the full factorial designs, are often used. In order to achieve a manageable number of profiles, only a limited number of measurable attributes and attribute levels (usually not more than four or five levels) are included in the fractional factorial design. This yields fewer choice alternatives that can be easily handled by respondents in one interview session, with less cognitive burden. Various CE design criteria are discussed in the following section.

4.3.1 Choice experiment design criteria

There is controversy in the literature about the choice of criteria to use in generating the 'best' fractional factorial experimental design. Some authors (e.g., Louviere and Hensher, 1982; Louviere and Woodworth, 1983; Louviere *et al*., 2000, Hensher *et al*., 2005) argue in support of orthogonality, while others (such as Huber and Zwerina, 1996) consider efficiency of a choice experiment design as the primary goal that should be pursued by fulfilling the orthogonality condition, alongside other design aspects such as level balance, minimal overlap and utility balance.

4.3.1.1 Orthogonality

Orthogonality is a statistical concept that means zero correlation between variables (attribute levels in the case of a choice experiment design). Although attributes and their levels can be correlated theoretically or even in a practical sense, orthogonality implies statistical independence or zero correlations between columns of the design. Orthogonal designs have three advantages: they are easy to construct; they allow independent estimation of each attribute's contribution to variations in the dependent variable; and they maximise the ability of the model to show statistically significant relationships (t-ratios) at any given sample size (Rose and Bliemer, 2009). A fractional factorial design in which all estimable effects are uncorrelated is referred to as an orthogonal array and the arrays are classified according to their resolutions or type of effects that can be estimated from them (Kuhfeld *et al*., 2005). A design is considered to have resolution 3 if only the main effects can be independently estimated from it. On the other hand, if two-factor interactions are confounded with each other, but not with the main effects, then the design is classified as a resolution 4 design (Street and Burgess, 2004). Attributes are said to be confounded if their independent effects on the choice decision are statistically inseparable. Designs that can be used to independently estimate main effects and two-factor interactions are classified as resolution 5 designs.

In order to maintain orthogonality from the design stage to the data set, all respondents in a survey should answer each row (choice set) for small designs. In the case of a large design where only a subset of rows are used in the survey, the sampling strategy applied should ensure there are an equal number of responses for each choice set. Non-design attributes such as socio-demographic characteristics should also be tested for correlations among themselves or even with design attributes, before their inclusion in the analysis. In addition, orthogonality requires equal spacing of attribute-level labels for quantitative attributes (e.g., price). This is useful not only for ensuring no correlations among attribute levels, but also to enable prediction over a range of attribute levels in a model. Qualitative attributes, on the other hand, should be coded using either design codes (0, 1, 2…*L-1*, where *L* is the number of levels present in the attribute) or orthogonal codes (e.g., -1, 1 for two levels or -1, 0, 1 for three levels; which sum up to zero when columns of all levels in one attribute are considered). The coding of qualitative attribute levels can be changed to dummy codes (0, 1) or effects codes (1, 0, -1) during analysis depending on whether a linear or non-linear model is to be estimated (Hensher *et al*., 2005).

Orthogonal designs have traditionally been applied in several previous studies (e.g., Adamowicz *et al*., 1994&1998; Leitham *et al*., 2000; Tonsor *et al*., 2005; Bennett and Willis, 2007; Ruto *et al*., 2008; James, 2010; Masiera and Hensher, 2010). Other applications of orthogonal designs, with particular reference to CE studies in developing countries, can be found in Bennett and Birol (2010).

4.3.1.2 Design efficiency

Statistical efficiency of an experimental design entails optimising the design to minimise the sample size (and cost of data collection), while generating adequate information for accurate estimation (Scarpa and Rose, 2008). Efficiency inversely depends on the variance-covariance matrix of the design; it increases as the variance decreases (implying small standard errors of the estimated parameters and hence large t-ratios). Efficient designs are considered to maximise the information from each choice situation (Rose and Bliemer, 2009). Although Kuhfeld *et al*. (2005) highlight minimum variance as a good property of coefficients in linear models derived from orthogonal designs, Scarpa and Rose (2008) argue that due to differences in the variance-covariance matrices between linear and non-linear models, orthogonal designs may not be appropriate for estimating non-linear models such as the discrete choice models. It is important to note that while the degree of efficiency varies in orthogonal designs (some orthogonal experimental designs are more efficient than others), all efficient designs are not necessarily orthogonal. For this reason, the efficiency criterion can be used to choose among orthogonal designs, but not vice versa (Kuhfeld *et al*., 2005).

Various measures can be used to compare the efficiency of any design relative to an orthogonal and efficient one:

i. *D-efficiency*: this refers to the inverse of the determinant of the variance-covariance matrix (*D-error)*. A design is said to be *D-efficient* or *D-optimal* if it has a small D-error (Kuhfeld, 2005). This implies that the data generated using such a design enables estimation of parameters with as low as possible standard errors, i.e., significant t-ratios (ChoiceMetrics, 2009);

ii. *A-efficiency*: this is given by the *A-error*, which is the trace of the variance-covariance matrix. However, this measure is rarely used in CE studies because it does not account for off-diagonal elements (covariances), but only considers variances in a matrix and thus might result in very large covariances of the parameters (Scarpa and Rose, 2008);

iii. *B-statistic*: this ranges between zero and 100 percent, and it measures the degree of utility balance of alternatives within a design (Kessels *et al*., 2004). Utility balance means equal probability of occurrence of all alternatives within choice sets (Zwerina *et al*., 2005). However, Scarpa and Rose (2008) maintain that the *B-statistic* is only a good measure of dominance among choice alternatives, but should not be used as a criterion for comparing designs.

Rose *et al*. (2009) note that efficiency criteria are often criticised for their requirement on the analyst to have some prior information on parameters of the variance-covariance matrix and the econometric model to be estimated before data are collected. This increases complexity in the design process, considering that variance-covariance matrices vary in econometric models and might influence the efficiency of designs when the models are estimated. Suggestions have been made to either assume zero values for the unknown parameters or assume that they are known with certainty and are non-zero (see Street and Burgess, 2004; Scarpa and Rose, 2008). Alternatively, Sandor and Wedel (2001) proposed the use of simulated draws or repeated trial samples to improve the efficiency of a design.

However, the suggested options for dealing with *a priori* knowledge present the analyst with cognitive difficulty in coming up with realistic assumptions on the unknown parameters; a potential source of misspecification given the absence of uniform assumptions. In addition, a very large sample size would be required for simulations; this would be impractical considering budget constraints and uncertainty on the exact sample that would ensure an efficient design.

In order to address the design problem of *a priori* knowledge on parameters, Rose and Bliemer (2009) suggest use of exploratory surveys on relatively smaller samples to obtain information, which is analysed to provide parameters for generating an initial efficient design. The design is sequentially updated through pre-test surveys before the final CE survey. Recent applications of this design method include Kerr and Sharp (2010) and, Bliemer and

Rose (2011) with initial pilot samples of 31 and 36 respondents, respectively. This is the design approach adopted in the present study.

Generally, in response to the criticism on the need for prior econometric model specification before generating an experimental design, some research has been done on efficient design construction for the basic multinomial logit (MNL) model (for instance, Burgess and Street, 2003) and continuous mixed parameter logit models (such as Sandor and Wedel, 2002). However, in the case of discrete mixed or latent class models, Ferrini and Scarpa (2007) note that the issue of efficient design construction has not been sufficiently addressed in the literature. Rose *et al*. (2009) propose a method whereby efficient designs may be generated to reflect the average formulations of the MNL and mixed logit models. But, such designs are relatively complex to generate; hence most efficient designs in the literature are based on the MNL.

Because most choice studies aim at predicting effects of changes in attributes on choice behaviour, other non-efficiency measures are suggested in the literature. These include the *G-optimality* and *V-optimality* criteria proposed by Kessels *et al*. (2006) and the *C-optimality* criterion introduced by Kanninen (1993). The *G-optimality* involves minimisation of the maximum prediction variance of a design, while the *V-optimality* criterion entails minimising the average prediction variance. The *C-optimality* measure minimises variance of parameter estimates such as the WTP coefficients.

4.3.1.3 Level balance, minimum overlap and utility balance

Other useful considerations in experimental design are level balance, minimal overlap and utility balance. The level balance criterion requires that the frequency of appearance of all levels of each attribute should be equal. Attribute level balance allows estimation of the parameters on the whole range of levels rather than a few data points (Rose and Bliemer, 2009). Minimal overlap, on the other hand, is a restriction that the attribute levels in the alternatives within each choice set must not be repeated several times (i.e., most attribute levels must vary between alternatives in a choice set). Finally, as noted earlier (see section 4.3.1.2) utility balance measures the level of lack of dominance of alternatives in a choice situation. Dominant alternatives do not permit trade-offs between all alternatives provided to the respondent; hence no information is obtained on the respondent's clear preferences. Generally, efficient designs have utility balance ranging from 70 to 90 percent (ChoiceMetrics, 2009). However, Huber and Zwerina (1996) noted that choice experimental designs rarely achieve all these criteria (orthogonality, level balance, minimal overlap and utility balance) for most attribute combinations, levels, choice alternatives and model parameter specifications. Moreover, as with orthogonality, when non-design attributes are included in the model, the efficiency of the design decreases (Bliemer and Rose, 2006).

4.3.2 Considerations in choosing experimental designs

There is no general consensus or theory on which criteria should be used in selecting experimental designs for CE studies. In addition, no study has practically tested which type of design construction method is likely to generate better results in various circumstances (Rose and Bliemer, 2008). However, Scarpa and Rose (2008) propose that the choice of a design needs to be guided by the objectives of the research. Specifically, they suggest the following criteria for various situations:

i. *D-efficiency* criterion when the research focus is to minimise standard errors and covariances of the parameter estimates. This ensures statistical significance of most parameters in the model;
ii. *S-efficiency* measure if resources are limited and sample size has to be kept at a minimum. This measure involves spreading information obtained from each choice situation in the design over all parameters and focusing on those parameters that

need larger sample sizes and are more difficult to estimate significantly. Using this measure however, requires *a priori* expert knowledge of the parameters;

iii. *C-efficiency* statistic when the study aims at estimating the WTP for various attributes;

iv. Generate several orthogonal designs and select one which addresses any of the above criteria depending on the focus of the study (e.g., small standard errors for the ratio of two parameters if the researcher's objective is to compute WTP).

Generally, empirical applications of efficient designs in CE studies are relatively few (e.g., Loureiro and Umbeger, 2007; Kassie *et al*., 2009; Bliemer and Rose, 2010; Espinosa-Goded *et al*., 2010). One potential way of contributing to the CE design literature might be to harness the strengths of both orthogonality and efficiency criteria by using these methods in a complementary manner, rather than treating them as competing approaches, as is the case in the bulk of documented applications (Bliemer and Rose, 2010). This is the approach adopted in the present study. In this case, the CE design is made for two primary reasons. First, to explain how the probability of farmers choosing certain types of DFZs would be independently influenced by various attribute levels (marginal effects); for this reason, orthogonality is necessary. The second aim of the experimental design is to estimate an economic measure of farmers' preferences (i.e., WTP or marginal rates of substitution) for each of the attribute levels. In this regard, statistical significance of most parameters in the model (and hence efficiency criterion) is crucial to enable policy inferences on preferences for various attributes of the DFZ to be made.

4.3.3 Generating choice experiment designs

Construction of choice designs typically begins with identification of a starting design (orthogonal or non-orthogonal) from which an efficient one can be built. Depending on the number of attributes and their levels, the starting design can be selected from those already constructed in previous studies such as Burgess (2007), Nguyen and Liu (2008) and Xu *et al.* (2004). Alternatively, the starting designs can be constructed directly using a number of computer design programmes such as GENDEX, SAS and SPSS. Ferrini and Scarpa (2007) note that SPSS is basic software that can be used to generate linearly *D-optimal* (orthogonal and efficient for linear models) designs. However, generating efficient designs for non-linear models such as MNL requires the use of advanced software such as NGENE (ChoiceMetrics, 2009).

There are also computer programmes such as *Design of Choice Experiments* (Burgess, 2007), which can be used to test the starting design for orthogonality and efficiency, and thereafter generate larger designs. Depending on the effects to be measured (main effects or main effects and interactions), appropriate design generators can be added to the starting design in order to form choice sets (for further insights, see a list of some generators for different number of attributes and levels in Burgess and Street, 2004). However, some efficient design generation processes (e.g., Street and Burgess, 2004; Street *et al.* 2001) are limited to problems where each choice alternative has the same number of attributes, with each attribute having the same number of levels (Rose and Bliemer, 2008).

4.3.4 Choice experiment design dimensions

The key objective in CE studies is to obtain more meaningful information from respondents by presenting them with choice tasks that are realistic, comprehensible and manageable from their perspective, besides these exercises addressing pertinent policy and/or research issues (Beharry-Borg and Scarpa, 2010a). The ability of a respondent to complete a choice task and provide consistent responses depends on the dimensionality of the CE design, amongst other factors (DeShazo and Fermo, 2002). Design dimensions include: the number of choice alternatives to be evaluated, number of attributes used to define the alternatives, number of levels used to describe each attribute, the range of levels defined for each attribute, and the number of choice situations or tasks presented to each respondent (Caussade *et al*., 2005).

Generally, it is posited that an increase in the amount of information contained in a CE exercise can make choice tasks considerably more complex for respondents to process, especially if the information is superfluous with less desirable attribute descriptions. Consequently, respondents may adopt various coping strategies, for instance: when there is information overload, they may use some simplified, albeit relevant, choice heuristic where they only consider a portion of the information provided in the choice set (i.e., there might be attribute non-attendance); there could also be a tendency to consider more attributes if there are only a few attribute levels that greatly differ; respondents frame attributes around base or reference levels and are more likely to process more attributes when attribute levels vary considerably from the base levels; when some attributes are thought to be similar in the respondent's perspective, a cancellation and re-packing (aggregation) strategy (which is unobservable) is utilised by the respondents to process choice decisions in such cases; too many choice sets may lead to accumulation of response fatigue and errors; and generally, individual socio-economic characteristics may influence respondents' choice behaviour, for instance non-attendance may occur when desired attributes/contexts are excluded (or non-desired ones are included) in the design (Hensher, 2006).

Complex choice tasks might also produce inconsistent choices and less reliable estimates of WTP trade-offs (Lusk and Norwood, 2005; Hensher and Rose, 2009). Further, lexicographic preferences (i.e., the tendency for respondents to rank choice alternatives based on a few most preferred or least preferred attributes, while ignoring all other differences between the alternatives) violates the continuity axiom and leads to biased estimates that are non-compensatory (inappropriate or lack of trade-offs) (Swait, 2001; Foster and Mourato, 2002).

A number of studies have explored various approaches for addressing some of the above problems. For example, DeShazo and Fermo (2002) suggest that the complexity of choice sets may be minimised at the CE survey design stage by using an optimal number of alternatives, attributes and correlation structures between the alternatives. Further, Caussade *et al.* (2005) propose that optimal CE design dimensions should include between four to six attributes, three to five alternatives, and not more than nine or ten choice situations or tasks, amongst other considerations. There are also studies that focus primarily on investigating potential approaches for modelling attribute non-attendance, for instance use of follow-up questions on the respondent's choice process (for details, see for example Campbell *et al*., 2008b; Scarpa *et al*., 2009). In the present study, follow-up questions were used to improve the CE design process. Further, 'warm-up' questions were included in the survey to gauge respondents' perception on the relative importance of all attributes, prior to their participation in the CE exercise.

In CE surveys, respondents are usually presented with two or more choice alternatives and asked which option they prefer. Considering that not all respondents may prefer the attribute-based choice alternatives presented in the survey, a *status quo* or even no-choice option is normally included to allow flexibility (for instance through inclusion of an opt-out option rather than a forced choice). This ensures that the choice set is collectively exhaustive and therefore consistent with demand theory, given that it is impractical to provide a full range of alternatives (Hanley *et al*., 2001). Further, Breffle and Rowe (2002) argue that although the appropriateness of a *status quo* depends on the application, its inclusion should add information or contribute to reduced measurement error in the estimation of trade-offs between attributes. The *status quo* option may be included in the design if there are clearly defined attributes to describe it. Alternatively, it might be adjoined (imposed) as an additional alternative in the survey stage, especially when the baseline situation represents absence of a good, service or policy under investigation (see for example, Espinosa-Goded *et al*., 2010). This is applicable to the case of DFZs, which currently do not exist in Kenya.

As noted by Street and Burgess (2007), whether the *status quo* option is initially included in the design or imposed later, a design retains optimality except that there is usually some little loss in the design efficiency. It is also important to ensure that all information included in a CE survey is relevant to the policy question at hand, and that the good/service being valued is correctly 'unpacked' into constituent attributes/levels that capture the context of the study in an un-biased manner, without overemphasising either the positive or negative aspects that might influence responses (Hensher, 2006). The analytical methods for CE data are discussed in the next section.

4.4 Choice experiment analytical framework

Discrete choice analysis involves situations in which the dependent variable is a qualitative response (i.e., choice among finite set of alternatives) rather than a continuous mathematical measure as in ordinary regression. The primary task in such cases is to specify and estimate a model that would explain the probability of occurrence of the qualitative response or choice event of interest.

The appropriate model for qualitative responses depends on the range of possible values for the dependent variable. Binary choice models can be applied in situations where the possible outcomes for the dependent variable are dichotomous (e.g., a yes or no). On the other hand, when the qualitative response has a probability of occurrence over a range exceeding two options, multinomial choice models are suitable (Greene, 2003).

4.4.1 General overview of utility theory and choice modelling framework

In discrete choice modelling, consumer preferences are assumed to follow standard axioms of choice (for instance, transitivity, stability and monotonicity). Preferences are said to be transitive if consumers are able to compare and rank products or services, and always choose one with the highest utility. The stability axiom indicates that there is at least some time lapse before consumer preferences change. Preferences are described as monotonic because rational consumers are expected to make the best choices (i.e., a product or service is chosen *iff* it is as good as itself) (see Varian, 1992 for details on utility theory).

The choice set is considered to be mutually exclusive, collectively exhaustive and finite (McFadden, 1981). Mutual-exclusivity means that the choice alternatives must be distinct so as to allow respondents to compare all alternatives provided in a choice set and be able to show unique preference for each alternative, *but pick one and only one* in each choice task. The exhaustiveness property implies that the choice set must include a full range of alternatives over which a typical respondent would be expected to express preference. Moreover, the finiteness requirement addresses the practicality of the choice situation, by ensuring that each respondent is provided with a manageable number of alternatives and choice sets.

Each choice alternative is associated with a given level of utility, which is assumed to have two components that can be expressed as (Manski, 1977):

$$U_{in} = V_{in} + \varepsilon_{in} \qquad (24)$$

where U_{in} is the utility derived by individual n from alternative i, V_{in} is the deterministic (systematic) component of utility, and ε_{in} is the stochastic or random part of utility (respondent's preferences that are known to the respondent but are unobservable to the researcher).

The random part of the utility function accounts for variations in the choice behaviour, which might be due to the following factors (Ben-Akiva and Lerman, 1985):

i. Unobservable taste variations between individuals;
ii. Unobservable features and idiosyncratic situations or disturbances that influence people's choices;
iii. Errors made in measurement of the observable factors;
iv. Specification errors in model estimation, for example the inclusion of irrelevant variables, omission of important variables or problems with the functional form.

On the other hand, the deterministic component of utility is considered to be a function of the observable attributes of the choice alternatives and individual-specific characteristics of the respondent such as age and education, i.e., a conditional indirect additive utility function that can be expressed as a linear-in-parameters equation:

$$V_{in} = X_{in}\beta \tag{25}$$

where X is a vector of observable attributes, while β are the unknown parameters of the observable attributes and a series of alternative specific constant (ASC) terms to be estimated. The inclusion of an ASC accounts for the systematic component of a potential *status quo* effect. Thus, the ASC captures the average effects on utility from attributes not included in the X vector (Scarpa *et al*., 2005). However, the suitability of an ASC in a model should be viewed with caution; preference should be given to significance of attributes if the research aims to estimate WTP. Moreover, the ASC does not provide any meaningful information to policy (besides a general indication of possible programme adoption), in situations where the *status quo* option describes absence of the good/service e.g., DFZs; hence it can be excluded for parsimony. Further, Hensher *et al*. (2005) suggest that the ASC is more appropriate in labelled choice situations, where it might represent a base alternative with defined attributes.

Given a choice set (C) of alternatives, random utility theory assumes that a rational individual randomly sampled from the relevant population will pick an alternative i that yields a higher utility than all other alternatives j in a choice set C, ($U_i > U_j$; $i \neq j$). The utility of alternative i is unobservable (to the analyst) because of lack of information on the individual's true utility function. The researcher can instead measure the probability that the choice decision occurs, by observing $Y_{in} = 1$ if i is selected (0 otherwise), implying that (Adamowicz *et al*., 1994; Boxall *et al*., 1996):

$$\Pr(in) = \Pr\{V_{in} + \varepsilon_{in} \geq V_{jn} + \varepsilon_{jn}; \forall i \neq j \in C\}$$

$$\text{or } \Pr(in) = \Pr\{(V_{in} - V_{jn}) > (e_{jn} - e_{in})\} \qquad (26)$$

Equation 26 is a general choice model from which several discrete choice models can be derived depending on the assumptions made on the distribution of the random component ε_{in}. For example, a multinomial probit model would be appropriate where the researcher assumes that the error term follows a multivariate normal distribution. An identically and independently distributed (IID) structure of extreme value type I, or the assumption that the error differences between the chosen and non-chosen alternatives have a logistic distribution, yields the conditional or MNL model (McFadden, 1973). On the other hand, a distribution that assumes some behavioural relationship depicted in the data and the prevailing choice circumstance, in addition to the IID assumption, gives rise to the random parameters logit (RPL) model (Train, 2003).

It is important to note that extension of the ordinary least squares (OLS) regression through a linear probability model (LPM) is inappropriate for discrete choice analysis due to the resulting non-normality and heteroscedasticity of the disturbance terms. In addition, the conditional expectation of LPM is not bounded between zero and one; this violates the probability distribution theory and might yield parameter estimates that are outliers. Probit models are also rarely used in discrete choice studies, due to difficulties in evaluating multiple integrals for the normal distribution (Greene, 2003).

The next section examines the commonly applied discrete choice models in empirical literature; particularly the MNL and its variants such as the RPL and the latent class model (LCM) mentioned earlier (see section 3.3.3.4).

4.4.2 Multinomial logit model

The logit model, which was originally introduced by Luce (1959), is preferred to linear or probit functional forms because the logit has a closed form, which entails less complexity in computation than other expressions. The MNL specification assumes a *Gumbel* (extreme value type I) distribution where the location parameter (mean) is zero and μ is the scale parameter. The probability that individual *n* chooses alternative *i* from the choice set is given by (McFadden, 1973):

$$\Pr(in) = \frac{\exp(\mu V_{in})}{\sum_{j \in C} \exp(\mu V_{jn})} \tag{27}$$

The scale factor μ is assumed to equal 1 so that the *β's* can be identified. As μ tends to zero, the probability of choosing the alternative with the highest predicted utility approaches one. On the other hand, as μ tends to infinity the probabilities of all choices tend to equality; i.e., the probability distribution of choices becomes uniform. The scale parameter may thus be interpreted as a measure of the error or lack of precision in the respondent's choices.

Substituting V_{in} from equation (25) into (27) yields the MNL (conditional on alternative *i* being chosen by individual *n*):

$$\Pr(in) = \frac{\exp(X_{in}\beta)}{\sum_{j \in C} \exp(X_{jn}\beta)} \tag{28}$$

Equation (28) is commonly referred to as the conditional logit model to differentiate it from other variants of the MNL.

If one of the attributes in the deterministic utility function (i.e., the *X* vector) is cost, the respondents' marginal WTP or '*part worth'* for specific characteristics of the choice options can be computed as (Hanemann, 1984):

$$WTP = -1 * \left(\frac{\beta_k}{\beta_p} \right) \tag{29}$$

where β_k is the estimated coefficient for an attribute level in the choice set and β_p is the marginal utility of income given by the coefficient of the cost attribute. The part worth (also called implicit prices) for a discrete change in an attribute (or attribute level) provides a measure of the relative importance that respondents attach to attributes within the CE design. Thus, it represents the marginal rate of substitution (MRS) between the attributes and money.

The MNL assumes independence from irrelevant alternatives (IIA), i.e., the ratio of the choice probabilities of any two alternatives (e.g., $\Pr_{in}/\Pr_{jn}$) is considered to be unaffected by other alternatives in the choice set (Luce, 1959; Ben-Akiva and Lerman, 1985). The IIA property is based on the assumption that the error terms are independent and homoscedastic. An important implication of the IIA condition is that removal or introduction of irrelevant alternatives from (into) the choice set does not alter the relative odds of choosing *i* over *j*, and has no systematic influence on any parameter changes that may occur (Hausman and McFadden, 1984).

In order to account for heterogeneity in preferences, individual-specific characteristics (e.g., income and age) can be included in the MNL model as interaction variables with the choice attributes. Note that the individual-specific factors can not be included as separate variables because they do not vary across choice alternatives and hence fall out of the probability estimation. In the case of different production systems, separate MNL models can be estimated for each system or interaction terms of production system and choice attributes can also be used.

Goodness of fit in non-linear models such as the MNL is usually measured by adjusted pseudo-R^2 denoted by ρ^2.

$$\rho^2 = 1 - \frac{LM_u - F}{LM_r} \tag{30}$$

where LM_u is the value of log likelihood in the full model (unrestricted model where all independent variables are included), while LM_r is the value of log likelihood in the restricted model, where all parameters (except the constant term) are set equal to zero; and F is the number of parameters estimated in the unrestricted model. Domenich and McFadden (1975) noted that ρ^2 in the range of 0.2 to 0.4 is comparable to the value of adjusted R^2 of 0.7 to 0.9 in conventional OLS regression models.

Despite its mathematical simplicity of estimation, the MNL model has quite restrictive assumptions, which may not realistically portray the choice making process by consumers when faced with choice tasks on various alternatives of goods and services. Three main draw-backs of the MNL include (Train, 1998):

i. The IIA assumption, which forms the foundation of MNL framework, imposes unrealistic substitution patterns between choice alternatives by predicting proportionate changes in choice probabilities of some alternatives if there is a change in attributes of one alternative within a choice set. Through the IIA restriction, the MNL fails to account for varying levels of substitution (and even complementarities) that may actually be observed between choice alternatives.

ii. People with different observed characteristics (e.g., age, income and education) are assumed to have homogeneous taste parameters. This restriction ignores the fact that tastes/preferences are unobservable to the researcher and that they are rarely the same even among individuals with identical socio-demographics. In addition, Swait and Bernardino (2000) noted that some variability might be expected in consumer preferences due to individual-specific decision rules employed by respondents to process choice tasks. Boxall and Adamowicz (2002) argue that the common practice of addressing this weakness by interacting individual characteristics and attributes in MNL models is limited because it requires *a priori* selection of the main socio-demographic characteristics to include and that it can only allow inclusion of a few individual-specific variables in order to maintain model parsimony. Multicollinearity is often a challenge when too many interactions are included. Moreover, results of the models tend to be very sensitive to the way in which parameters and individual-specific characteristics are interacted (Breffle and Morey, 2000). It is also worthwhile to note, that interactions between socio-demographic characteristics and choice attributes or ASCs may only incorporate observed heterogeneity in the analysis, but cannot account for unobserved heterogeneity in the MNL models (Train, 2003).

Imposing an assumption of preference and response homogeneity when, in fact, there is heterogeneity results in biased and inconsistent parameters and choice probability estimates (Chamberlain, 1980). Accounting for taste heterogeneity is important because it enables estimation of unbiased and consistent models, and it improves the accuracy and reliability of analytical results (Greene, 2003). In addition, incorporating and understanding heterogeneity provides useful information on the distributional effects and other policy impacts of resource use and management decisions (Boxall and Adamowicz, 2002). These insights would enable policy makers to design suitable programmes for differentiated customer needs and interests in the society.

iii. The MNL model imposes independence of unobserved factors over time or choice situations, for instance in repeated choice tasks. Through this, the MNL violates consumer axioms of transitivity and stability of choices. Ideally, rational individuals would be expected to show some consistency in their patterns of preference in repeated choice tasks. In a nutshell, choice tasks can be considered as a learning process characterised by correlation of decisions across time (i.e., in the process of repeated choices, respondents are expected to gain more knowledge or experience and are likely to utilise information gained from previous choice tasks in making their subsequent choices).

Due to the above shortcomings of the standard MNL, more flexible specifications (e.g., RPL and LCM) are preferred in the literature.

4.4.3 Random parameter logit model

The RPL model, also known as mixed logit, was introduced by Boyd and Mellman (1980) and Cardell and Dunbar (1980). In the RPL specification, individual preferences are assumed to be heterogeneous and continuously distributed random variables for the entire population. Thus, the RPL accounts for taste heterogeneity by allowing model coefficients of the observed variables to vary randomly over individuals (Train, 1998). This flexibility eliminates the restrictive IIA property and allows approximate representation of any substitution pattern exhibited by the data. In the RPL model, the inclusion of, or change to, an alternative affects the ratio of the probabilities of any other two alternatives in the choice set (Morey and Rossman, 2003). In addition, when the unobserved individual-specific parameters are allowed to vary, correlation is induced between choice alternatives (and over time) in the random component of utility. The RPL specification captures this correlation and allows efficient estimation when there are repeated choices by the same individuals (Revelt and Train, 1998; McFadden and Train, 2000). The benefit of allowing correlation over choice alternatives is that two pair-wise choices (one from each of two individuals) provide more information than two choices from the same individual (Morey and Rossman, 2003).

Following Revelt and Train (1998), the utility obtained by individual *n* from alternative *i* in choice situation (or time period) *t* is expressed as:

$$U_{\text{int}} = \beta_n X_{\text{int}} + \varepsilon_{\text{int}} \tag{31}$$

where X_{int} is a vector of observable variables, β_n is an unobserved coefficient vector for each decision maker and varies in the population with a density function $f(\beta_n | \theta)$ whereby θ are the parameters of this distribution. The ε_{int} is an unobserved random term assumed to be IID type I extreme-value. Conditional on β_n, the probability that individual *n* chooses alternative *i* in choice situation *t* is given by the standard MNL model (slight modification of equation 28):

$$L_{\text{int}}(\beta_n) = \frac{\exp(\beta_n X_{\text{int}})}{\sum_{j \in C} \exp(\beta_n X_{jnt})} \tag{32}$$

In order to measure the unconditional probability of alternative *i* being chosen (relaxing the IIA assumption), the integral of the conditional probability is obtained for all possible values of β_n, which are a function of the parameters of the distribution of β_n:

$$Q_{\text{int}}(\theta) = \int L_{\text{int}}(\beta_n) f(\beta_n | \theta) d\beta_n \tag{33}$$

Maximum likelihood estimation of equation (33) requires information on the probability of each sampled individual's sequence of observed choices.

Let *i(n,t)* denote the alternative chosen by individual *n* in choice situation *t*. The probability of individual *n*'s observed sequence of choices (conditional on β_n) is simply the product of standard MNL models, assuming that the individual tastes, β_n, do not vary over choice situations for the same individual in repeated choice tasks (but are heterogeneous over individuals):

$$G_n(\beta_n) = \prod_t L_{\text{int}}(\beta_n) \tag{34}$$

The unconditional probability for the sequence of choices made by individual *n* is expressed as follows:

$$P_n(\theta) = \int G_n(\beta_n) f(\beta_n|\theta) d\beta_n \tag{35}$$

Two sets of parameters are noteworthy in this expression: β_n is a vector of parameters specific to individual *n* (representing the individual's tastes, which vary over people). On the other hand, θ are parameters that describe the density of the distribution of the individual-specific parameters β_n (for instance, θ represent the mean and covariance of β_n). The objective in RPL is to estimate the θ. This is usually done through simulation of the choice probability (because the integral of equation 35 cannot be computed analytically due to the lack of a closed mathematical form). The log-likelihood function is specified as:

$$LL(\theta) = \sum_n \ln P_n(\theta) \tag{36}$$

The $P_n(\theta)$ is approximated by a summation over randomly chosen values of β_n. For a selected value of the parameters θ, a value of β_n is drawn from its distribution and $G_n(\beta_n)$, i.e., the product of standard MNL models, is computed. Repeated calculations are done for several draws and the average of the $G_n(\beta_n)$ is considered as the approximate choice probability:

$$SP_n(\theta) = \left(\frac{1}{R}\right) \sum_{r=1}^{R} G_n\left(\beta_n^{\,r|\theta}\right) \tag{37}$$

where R is the number of draws of β_n, $\beta_n^{r|\theta}$ is the r^{th} draw from $f(\beta_n | \theta)$ and SP_n is the simulated probability of individual n's sequence of choices. Following Train (2003), the simulation is usually based on Halton intelligent draws, which has been shown to yield more accurate results compared to independent random draws. The simulated log-likelihood function is constructed as:

$$SLL(\theta) = \sum_n \ln\left(SP_n(\theta)\right) \tag{38}$$

The estimated parameters are those that maximise $SLL(\theta)$.

There are numerous documented applications of the RPL model, for instance see Tonsor *et al.* (2005), Kassie *et al.* (2009), Espinosa-Goded *et al.* (2010), Beharry-Borg and Scarpa (2010b) and Scarpa and Willis (2010). The RPL model is applied in the present study to evaluate preferences for DFZ attributes.

Other alternative methods for accounting for taste heterogeneity include covariance heterogeneity models, exogenous segmentation and endogenous segmentation or LCM. These are discussed briefly as follows.

4.4.4 Covariance heterogeneity models

Another set of models known as covariance heterogeneity models (CovHet models) attempt to parameterise the scale factor, μ, with individual socio-demographic characteristics (rather than impose the restriction of μ being equal to one). These models of scale heterogeneity belong to the family of heteroscedastic extreme value (HEV) models and aim at capturing differences in respondent coherence, decision-making ability or interest in the survey (Breffle and Morey, 2000).

However, criticisms are often raised on the appropriateness of CovHet models whereby individual characteristics enter the model as affecting the scale parameter rather than preference heterogeneity models in which the individual characteristics are considered to influence tastes (Boxall and Adamowicz, 2002). Moreover, the decision on whether to model preference or scale heterogeneity from a particular data set is an empirical issue that depends on the objective of the study (Kontoleon, 2003).

4.4.5 Exogenous segmentation model

The exogenous segmentation approach assumes that there exist a fixed and finite number of segments that are mutually-exclusive (each individual can only belong to one segment). The segmentation is done *a priori* based on observable characteristics (for instance, socio-demographics such as education levels, or other aspects like geographic location that theory might deem relevant in the classification). Ideally the number of segments is equal to the number of segmentation variables that are known in advance or can be predicted before the study. All individuals within a particular segment are assumed to have identical preference patterns and sensitivity (responsiveness) to choice attribute patterns. Hunt *et al.* (2005) applied both exogenous segmentation and RPL models to investigate varying setting preferences among game tourists.

However, the exogenous segmentation approach has a number of shortcomings. For instance, interpretational and estimation difficulties arise as the number of segmentation variables increase. This is because the number of segments becomes too many as more segmentation variables are used, and it is impractical to obtain adequate observations for each of the segments. In the unlikely event that sufficient degrees of freedom (large samples) exist for the estimation of many segments, the analyst has to contend with the challenge of realistically (and meaningfully) fitting the segments in the population. Further, when continuous variables such as income are used for segmentation, there is no standard rule on the threshold values for categorisation of the segments (Bhat, 1997).

4.4.6 Latent class model

The LCM approach (mentioned earlier in section 3.3.3.4) considers the population as comprising of unobservable (latent), finite and discrete segments or classes, which are heterogeneous in their preference patterns across the segments, but have homogeneous set of preferences within each segment (Wedel and Kamakura, 2000). While the RPL accounts for heterogeneity at individual-level, the LCM (also referred to in the literature as the finite mixture logit - FML) addresses differences among segments of the population (Provencher *et al*., 2002).

Endogenous segmentation (LCM) can be done using the observed discrete individual-characteristics (i.e., psychometric factors such as individual's perceptions or beliefs about the goods or services, attitudes or values, preferences on various goods or services, decision rules that link preferences with choices, and behavioural intentions for choices made) that relate to a particular situation, like in a survey (Wind, 1978; McFadden, 1986). Endogenous segmentation allows the number of latent classes to be determined by the observed preference behaviour in the data, rather than assuming that they are known in advance. The relevant number of segments is statistically determined through successive additions of a segment until a point is reached where an extra segment does not yield a significant improvement in the model fit. The endogenous segmentation technique involves joint determination of the number of segments, assignment of individuals to any of the segments in a probabilistic fashion based on the segmentation variables, and estimation of the segment-specific choice model parameters (McFadden, 1986).

Unlike the RPL where continuous distribution of parameters is assumed, in LCM the mixing distribution $f(\beta|\theta)$ is discrete with finite segment-specific parameters β_s. The log-likelihood for the LCM assuming S latent classes or segments can be expressed as:

$$LL(\theta) = \sum_{n}^{N} \ln\left[\sum_{s=1}^{S} P(s)P(y_n \mid S)\right] \tag{39}$$

where $P(s)$ is the probability that individual n belongs to segment s, while β_s denotes a vector of segment-specific coefficients, and $P(y_n|\beta_s)$ is the joint probability of a set of choices made by individual n, conditional on belonging to a given segment s. Assuming that segment membership likelihood functions are IID Gumbel across respondents and segments (with scale factor normalized to one), the probability of respondent n's membership in segment s, i.e., $P(s)$ is characterised by an MNL model (Greene and Hensher, 2003):

$$P(s) = \frac{\exp(\Re_s A_n)}{\sum_{s=1}^{S} \exp(\Re_s A_n)} \tag{40}$$

where A_n are the observed individual characteristics that enter the segment membership probability model, while $\Re$ is a vector of unknown class-specific parameters to be estimated.

The LCM has been applied in various studies (e.g., Bhat, 1997; Ruto *et al*., 2008; Scarpa *et al*., 2009; James, 2010; Schultz and Tonsor, 2010). It is worthwhile to note that empirically, either the RPL or LCM could be used to assess preference heterogeneity. There are no theoretical considerations to choose one over the other (Greene and Hensher, 2003). Where data permits, comparative studies can be undertaken using both methods (e.g., Ruto and Garrod, 2009). In the present study, the RPL is applied to investigate preferences for DFZs.

4.5 Summary

This chapter has laid out the theoretical framework and modelling techniques for valuation of non-market goods/services. It was noted that the CE method is more expedient for analysis of preferences for DFZs that are not yet in the market and would therefore not be possible to evaluate using RP methods. The CE approach is also preferred over other SP methods because, amongst other advantages, it enables estimation of trade-offs for different components (or attribute levels) of a good/service rather than the good/service *per se*.

The main strengths and weaknesses of various CE design criteria were assessed, and it was concluded that a complementary application of orthogonal and efficient designs would possibly contribute to the CE literature. In addition, application of optimal design dimensions suggested in the literature would help to refine CE tasks, reduce complexity to respondents and improve consistency of responses from the surveys.

Finally, a review of the analytical literature shows that both LCM and RPL approaches could be applied in the estimation of parameters; the choice between the two methods is an empirical issue, given sample data. In the following chapter, a detailed discussion is presented on the specific methodologies that were applied in this study.

Chapter Five

5. Research Methodologies

5.1 Introduction

This chapter describes specific methods used in the present study. The study is based on household survey data on cattle production and a choice experiment (CE) on farmer preferences for Disease Free Zones (DFZs). The remainder of this chapter is organised into seven sections. Study sites are described in section 5.2, while the sampling techniques applied in the study are explained in section 5.3. The data collection approaches and empirical estimation of technical efficiency (TE) are discussed in sections 5.4 and 5.5, respectively. Subsequently, the CE exercise and analysis of farmer preferences for DFZs are explained in sections 5.6 and 5.7. Finally, a summary of this chapter is provided in section 5.8.

5.2 Study sites

The study was conducted in four sites (i.e., Kajiado, Kilifi, Makueni and Taita Taveta districts) that are representative of Kenya's three main cattle production systems; nomadic pastoralism, agro-pastoralism and ranches. As noted earlier (see section 1.3 in chapter 1), the three production systems are characterised by different features. For instance, the ranchers mainly use controlled grazing system on their private land, while both the nomads and agro-pastoralists generally practise an open grazing system which often tends to cause conflicts with other land users, due to encroachment. It is important to understand how efficiency varies in the production systems, and how different grazing systems might influence preference for DFZ attributes. In addition, differences in relative disease incidence might also explain preferences for DFZ features in the three production systems. Cattle disease incidence generally varies with the level of migration and in Kenya is estimated to be 60 percent, 40 percent and 25 percent in nomadic, agro-pastoral and ranch systems, respectively (Maloo *et al*., 2001)[4].

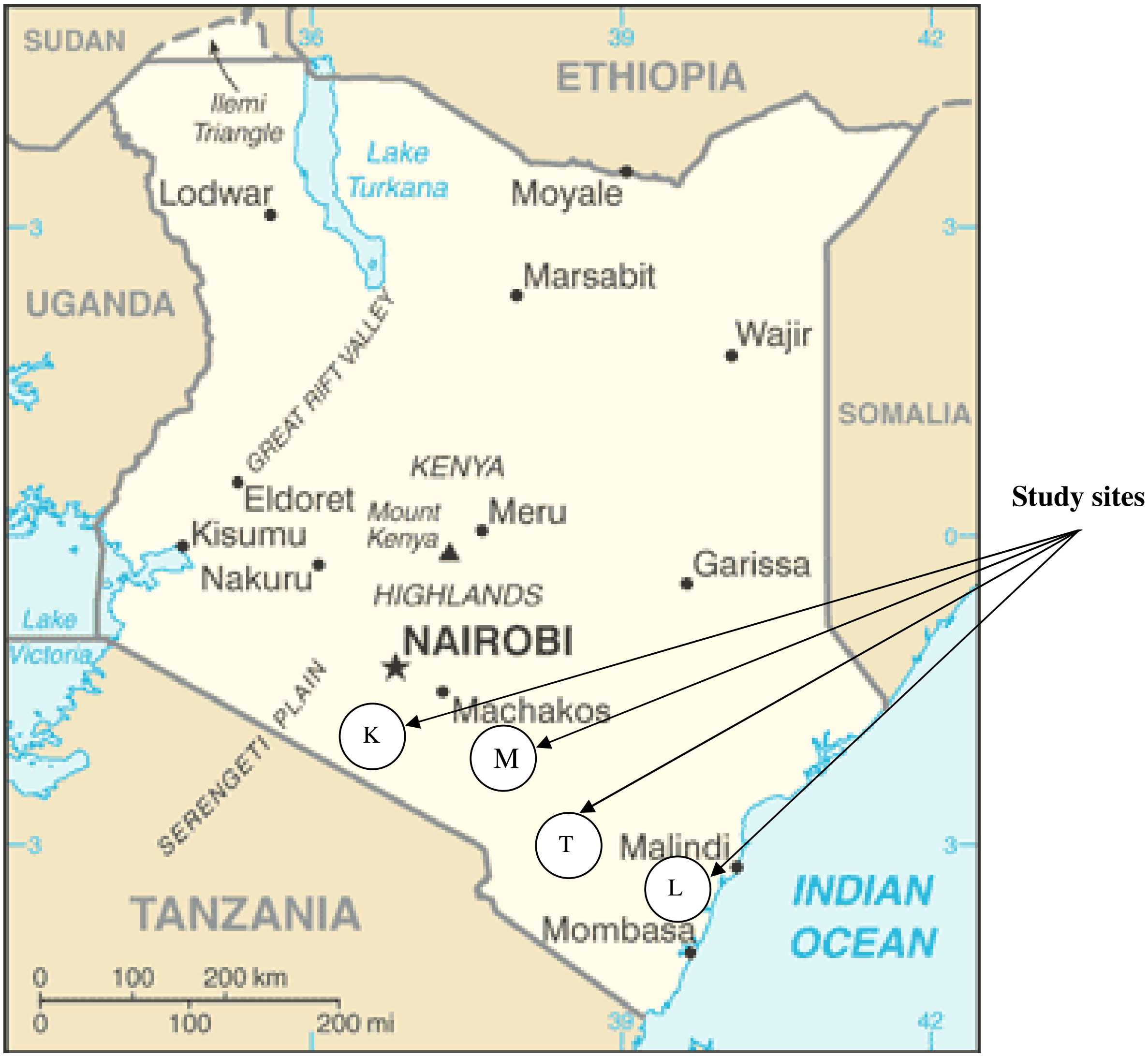
Generally, Kenya is divided into seven agro-climatic zones based on moisture index, i.e., the annual rainfall as a percentage of potential evaporation (Sombroek *et al*., 1982). Places with moisture index above 50 percent are classified as zones I, II and III, and are considered to have high potential for agriculture. Less than 20 percent of land in Kenya falls in the first three categories. The study sites represent different agro-climatic zones, but are close to each other (contiguous), hence logistically more accessible. These sites also provide an opportunity to indirectly capture farmers' views about a pilot DFZ programme that the government of Kenya plans to establish. The sites are shown in Figure 7.

Kajiado is classified into zone VI, which include semi-arid to arid rangelands. It borders the capital city, Nairobi, to the north, and the United Republic of Tanzania, to the south. The mean annual rainfall in the area ranges from 300–800mm, with a moisture index of 25–40 percent (Orodho, 2002). However, rainfall in Kajiado is highly variable within and between years, and there are frequent droughts in the area (Thornton *et al*., 2007). Due to the relatively drier and hot weather in Kajiado, the area is mostly utilised for livestock production, especially nomadic pastoralism, with very limited crop farming. In addition, more than 50 percent of Kenya's wildlife outside national parks is found in this area. Kajiado also serves as a migratory corridor for the world's largest natural animal migration; the annual seasonal movement of about 1.5 million wildebeests between Maasai Mara and Serengeti national parks, in Kenya and Tanzania, respectively (Republic of Kenya, 2008b). It is important to understand preferences for DFZ attributes (including compulsory fencing) among nomadic

[4] The relatively high cattle disease incidence in Kenya's pastoralist systems is consistent with estimated levels in the entire east African region, where for instance, the annual prevalence of Foot and Mouth Disease (FMD) is estimated to vary from 15 percent to 50 percent (Rufael *et al*., 2008).

pastoralists, most of who are found in Kajiado and might experience losses from diseases transmitted by wild animals.

Figure 7: Distribution of the study sites in Kenya



Note: The letters K, L, M and T denote the four study sites; Kajiado, Kilifi, Makueni and Taita Taveta, respectively.

Source: Adapted from World Atlas (2011b).

Kilifi is a semi-humid region (zone III) within Kenya's coastal strip near the Indian Ocean. It has an annual rainfall between 760–1,300mm and moisture index of about 65 percent. The area is mainly characterised by ranches and tree-crops including coconuts, cashew nuts and mangoes (Republic of Kenya, 2008c). Kilifi has a generally wet vegetation and hot climate. **Makueni** is a semi-arid area (zone V), with average rainfall of 500–760mm and 40 percent moisture index annually. In this area, there is some dry-land irrigated crop farming focusing on production of fruits and vegetables (Republic of Kenya, 2008d). Finally, **Taita Taveta** is a coastal hinterland, classified as semi-humid to semi-arid (zone IV). On average, this site is estimated to have 500–750mm of annual rainfall and about 50 percent moisture index (Republic of Kenya, 2008e). Generally, Makueni is a transition zone sandwiched between very dry parts of Kajiado and relatively wetter coastal sites. Both Makueni and Taita Taveta are characterised by more agro-pastoralists than nomads and ranchers.

Kajiado enjoys proximity to the Kenya Meat Commission (KMC) which is based in Nairobi, and processes beef destined for high-value domestic and a few export markets. Also, Kilifi and parts of Taita Taveta are closer to the port of Mombasa, which serves as a gateway for live animal exports from Kenya. Therefore, these sites are generally considered to have relative geographic advantage to potential market outlets. It is envisaged that increased efficiency and safety of beef production in these areas might offer considerable benefit to the Kenyan economy. During the survey, nomads were selected from Kajiado (zone VI), agro-pastoralists from Makueni and Taita Taveta (zones IV and V), and ranchers from Kilifi (zone III).

5.3 Sampling techniques

The relevant target population for the study were cattle farmers in the sites mentioned above. In order to gain insights on the general distribution of cattle in the study sites, key informant interviews were held with officials in the Ministry of Livestock Development in Kenya.

Following these consultations, a threshold number of cattle was set as a criterion to guide selection of farmers in each of the three production systems. These were at least 5, 15 and 40 cattle in agro-pastoralism, nomadic pastoralism and ranches, respectively. Establishing thresholds was useful to ensure cost-effectiveness in the survey, considering the expansive nature of the study sites and general variations in the number of cattle kept.

Once the target population has been identified, it is important to determine a representative sample, given that it would be too costly and time consuming to survey the entire population. Sample representativeness aims at enhancing the accuracy and reliability of sample estimates for predicting population parameters. Another important issue is the sampling frame. This is the list of all units or elements in the target population, from which information is sought. A sampling frame may be available in some cases, while in other instances it may be completely lacking due to inadequate record keeping or persistent changes in the distribution of elements in the target population (e.g., death/movement of cattle or farmers). Whether a sampling frame exists or not, it is important to choose the sample in a way that minimises sampling error and sample selection bias. Sampling error arises from large variations between different subsets in a target population; this might be addressed by choosing a subset with average characteristics of the target population. In contrast, sample selection bias (or non-reponse bias) occurs due to omission of key groups from the sample or their refusal to participate in the survey.

Sampling can be done using probabilistic or non-probabilistic techniques. Probability sampling is based on statistical theory, while the non-probabilistic methods are anchored on other criteria such as convenience of reaching the site, subjective judgement of importance of certain elements or individuals (purposiveness) and quota restrictions. Some of the probability sampling approaches include simple random sampling, systematic sampling, stratified sampling, cluster sampling and multi-stage sampling. In simple random sampling, each unit in the sample frame has an equal chance of being included in the sample. Systematic sampling involves selection of sample units at uniform intervals from an ordered list (e.g., every 5^{th} household). In both stratified and cluster sampling methods, the sampling frame is classified into categories (commonly referred to as strata and clusters, respectively). The difference is that for stratified sampling, a random sample is selected from each stratum, while in cluster sampling, random samples are drawn from randomly selected clusters. In multi-stage sampling, more than one method is employed at two or more successive stages to obtain the final sample (Cochran, 1977).

The optimal sample size for a study increases as the number of subgroups in the population increase, if a higher degree of precision (less sampling error) is desired, and when there is much variation in characteristics of interest in the study. In multiple choice situations, the minimum sample size can be obtained by dividing the total number of choice alternatives by the number of choice sets that are to be presented to each respondent (Bateman *et al.*, 2002). Alternatively, the sample size for CEs can be determined as follows (Orme, 1998):

$$500 * \frac{L}{J.T} \tag{41}$$

where L is the largest number of levels for any of the attributes, J is the number of choice alternatives and T is the number of choice situations in the design. For instance, in the present study where $L = 3$, $J = 3$ and $T = 4$, the sample size would be 125 respondents.

Further, in order to ensure more robust estimates from CE data, Hensher *et al.* (2005) suggested that a minimum sample of 50 respondents should answer the least preferred choice alternative. The present study sought a suitable sample size for both CE and TE analysis. In TE studies, the sample size depends on the number of parameters to be estimated (and the functional form chosen). A Cobb-Douglas model requires fewer degrees of freedom compared to the translog form, which includes additional parameters for squared variables and cross-products (Coelli *et al*., 2005).

A multi-stage cluster (area) sampling approach (Horppila and Peltonen, 1992) was used in the present study. This method is appropriate in situations where the population is scattered over a large geographic area and there is no comprehensive list of the sampling units or sampling frame (as is the case in Kenya). Further, multi-stage cluster (area) sampling is preferred due to its relative convenience, economy and efficiency compared to other sampling techniques. Moreover, the use of probability methods such as random sampling to derive the final sampling units improves the precision of the estimates, ensures representativeness and permits hypothesis tests (Allen *et al*., 2002). Within the four districts, smaller administrative units (divisions) were randomly selected (using a random number table) from lists of all divisions in these districts, taking into account the general distribution of cattle in the study area. Subsequent stages involved a random selection of a sample of locations, from which a number of smaller units (sub-locations) were selected. The primary sampling units for the survey were therefore forty sub-locations. Systematic random sampling was used to select individual respondents for study. The data collection methods and sample size used are discussed in the following section.

5.4 Data collection methods

Data were collected through household surveys and CE involving face-to-face interviews. The face-to-face interviews were preferred to other survey modes (e.g., mail surveys, telephone interviews and computer-based surveys) because of a generally poor communication infrastructure in the study area, e.g., limited internet connectivity and inadequate postal and telephone coverage, which preclude the use of other survey methods. Face-to-face interviews enable clarification of questions and probing of respondents for accurate answers in the survey, provide higher response rates (about 70 percent or better), allow use of visual aids and enable collection of more data (Bateman *et al*., 2002). Further, face-to-face interviews are considered to be a suitable survey method in a developing country context because, '…*this mode can ensure that the correct member of the household responds to the survey, and well-trained enumerators can explain the information and choice occasions appropriately, assisting those who are illiterate/who do not understand in order to minimise any biases*' (Bennett and Birol, 2010, p. 302). With the assistance of seven experienced local interviewers who were trained prior to the surveys, the data were gathered using a two-part questionnaire comprising cattle enterprise information and CE, questions (see Appendix 1). The questionnaire was administered in local languages between July and December 2009. The household survey and questionnaire structure are described in this section, while the CE exercise is discussed in detail in section 5.6.

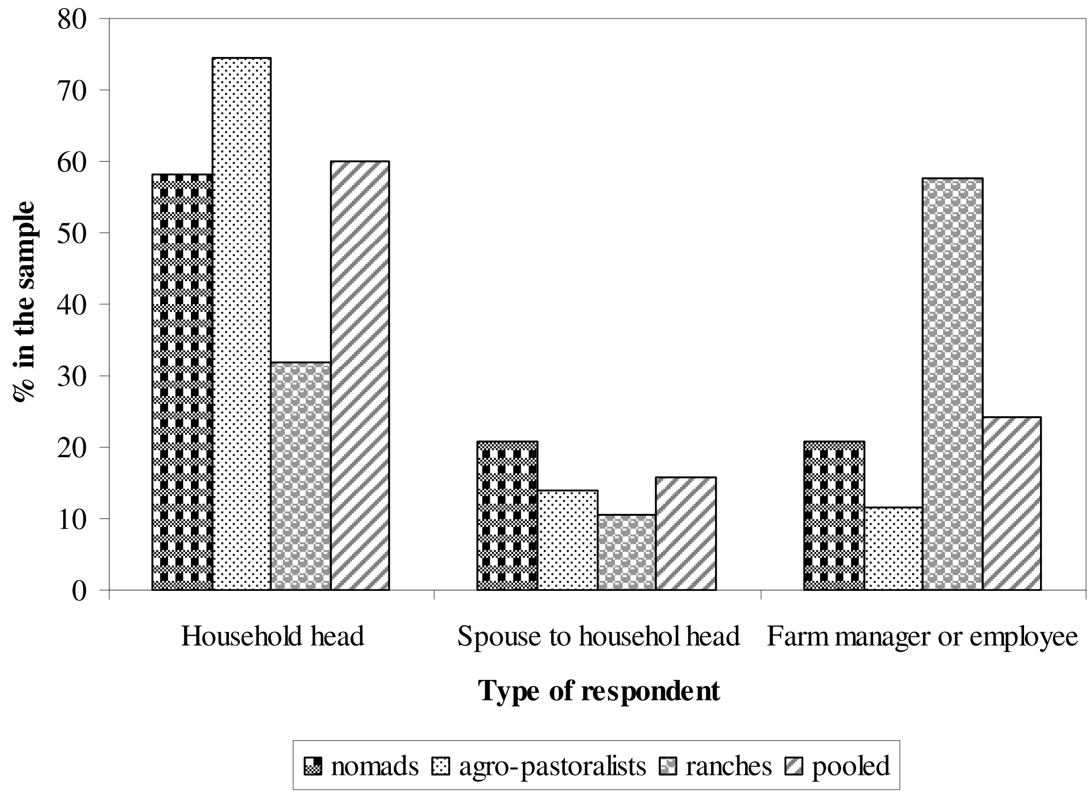
During the survey, a random route procedure (for example first left, next right, and so on) was followed by the interviewers to select every fifth or tenth farmer, in sparsely or densely populated sub-locations, respectively. Only households that had kept cattle for a continuous period of at least one year prior to the survey were eligible for inclusion in the sample and only one person was interviewed in any selected household. Further, in order to obtain reliable information, the interviewee/respondent was defined as an adult (18 years and above) who normally makes farm decisions (e.g., household head or his/her deputy, farm manager or other farm employee).

In each household visited, a brief introduction was given to the potential respondent on the purpose of the survey. The individual's suitability for the interview was then ascertained through a short informal preliminary discussion on the household's cattle keeping history, minimum age requirements for inclusion in the sample and their involvement in decision-making on the farm. Thereafter, permission to commence interview was sought from the eligible respondent and he/she was assured of the confidentiality of their responses. An indication of the likely duration of the interview (not more than 2 hours) was also given to the eligible respondents. Generally, about 95 percent of the households approached accepted to participate and completed the survey. Appropriate replacements were randomly made (i.e., next farm left or right) for those who either declined or dropped out in the course of the survey.

In total, 313 farmers, including 66 ranchers, 110 nomadic pastoralists and 137 agro-pastoralists, were interviewed. Generally, most respondents interviewed comprised household heads; three-quarters for agro-pastoralists and more than half for nomads, while more than half of the respondents in ranches were farm managers or other farm employees (Figure 8). A relatively smaller proportion of respondents across the three production systems were spouses of the household head. Further, it was noted that on average, the respondents interviewed usually spent about 90 percent of their time on the farm; hence they should be expected to be relatively well-informed about the farm operations[5]. Therefore, it is reasonable to conclude that the data collected are of sufficient quality and should be relevant to the issues under investigation in this study.

[5] Computations from the survey responses on respondents' relative monthly availability on the farm indicated that nomads, agro-pastoralists and ranchers, respectively, usually spend about 96 percent, 91 percent and 86 percent of the time on the farm. For nomads, the farm almost exclusively refers to a livestock enterprise.

Figure 8: Composition of survey respondents



The survey questionnaire was structured into twelve main sections covering broad issues such as household enterprises, cattle output, inputs, services and markets (see Appendix 1). Some of the main variables captured in the data included: relative importance of cattle and other enterprises to household income; cattle inventory in the past twelve months; production inputs such as on-farm and purchased feeds, paid and unpaid labour, veterinary supplies and advisory services, and fixed inputs; cattle breeding methods; access to extension and market services; and household socio-demographic characteristics. The analytical methods used to investigate farmers' TE are discussed in the following section.

5.5 Technical efficiency analysis

5.5.1 Measurement of variables

This section discusses how the variables used in TE analysis were measured and the necessary computations/transformations that were made in the data. In studies of this kind, beef output would be considered as the dependent variable, while a number of inputs (e.g., herd size, feeds, veterinary costs, fixed costs etc.) are included as regressors in the model. However, due to measurement difficulties, previous studies have used proxy variables, for example, value-added (Featherstone *et al*., 1997; Iraizoz *et al*., 2005) or physical weights of cattle (Rakipova *et al*., 2003). However, such data are not available in the present study. Therefore, this study follows the revenue approach recently applied in the literature (Hadley, 2006; Abdulai and Tietje, 2007; Gaspar *et al*., 2009) and defines output as:

$$Q_{n(k)} = \frac{\sum_{r}^{R} yp}{t} \tag{42}$$

where $Q_{n(k)}$ is the annual value of beef cattle output of the n^{th} farm in the k^{th} production system (measured in Kenya shillings; Kshs); r denotes any of the three forms of cattle output considered, i.e., current stock, sales or uses for other purposes in the past twelve-month period; y is the number of beef cattle equivalents[6]; p is the current price of existing stock or average price for cattle sold/used during the past twelve months; and t is the average maturity period for beef cattle in Kenya, which is four years (Republic of Kenya, 2008a). The output prices used are average prices for all markets per site; this possibly controls for differences associated with various market types and ensures that TE measures are attributable to farmers' managerial abilities.

[6] Beef cattle equivalents were computed by multiplying the number of cattle of various types by conversion factors (Hayami and Ruttan, 1970; O'Donnell *et al*., 2008). Following insights from focused group discussions with key informants in the livestock sector in Kenya, the conversion factors were calculated as the ratio of average slaughter weight of different cattle types to the average slaughter weight of a mature beef bull. The average slaughter weight of mature bull, considered to be suitable for beef in Kenya, is 159 kg (FAO, 2005). The estimated conversion factors were: 0.2, 0.6, 0.75, 0.8 and 1, for calves, heifers, cows, steers and bulls, respectively.

The main inputs discussed here are: herd size (proxy for capital in the classical production function), feeds, veterinary services, depreciation, labour, land and other inputs. The beef cattle herd size was computed as the average number of cattle kept in the past twelve months, adjusted with the relevant conversion factors.

In order to capture the approximate share of feeds from different sources in each production system, the quantities of purchased and non-purchased (or on-farm) feeds were first adjusted with the average annual number of dry and wet months, respectively, in each district (Orodho, 2002; Lukuyu *et al*., 2009). Assuming one price in a given locality (Chavas and Aliber, 1993), average feed prices were computed using prices from district annual reports and recent surveys (e.g., Lukuyu *et al*., 2009), after validation with research staff at the Kenya Agricultural Research Institute (KARI). Both purchased and non-purchased feeds were then converted to improved feed equivalents by multiplying the respective feed quantities by the ratio of their prices (or opportunity costs) to the average per unit price of improved fodder. Thus, the total annual improved feed equivalent was computed as:

$$\{\varphi(p_f * d) + s(n_p * w)\} \tag{43}$$

where; φ and s denote, respectively, the ratio of prices of purchased and non-purchased feed to that of improved fodder; p_f and n_p represent the average quantities of purchased and non-purchased feeds, respectively, in kilogrammes per month; d is the approximate number of dry months (when purchased feeds are mainly used), while w is the length of the wet season (when farmers mostly use on-farm or non-purchased feeds) in a particular area.

As noted earlier (see section 5.2), cattle disease incidence generally varies with the level of sedentarisation (Maloo *et al*., 2001). Also, it is assumed that lower disease incidence in a given production system is partly due to greater investment in veterinary management. Accordingly, the annual cost of veterinary advisory services and drugs was derived by multiplying the monthly expenditure on these items by the estimated proportion of time in a year (number of months) when veterinary costs are incurred.

Depreciation costs on fixed inputs were based on the straight line method[7], assuming a 10 percent salvage value following discussions with relevant officials in the Ministry of Livestock Development. Also, following the key informant discussions, the useful economic life for small farm equipment (e.g., a wheel barrow) and large machinery (e.g., vehicles and tractors) was set at 5 years and 10 years, respectively. The depreciable value of an asset was based on the proportion of time that it was used in the cattle enterprise. Labour costs comprise both paid and unpaid labour; the latter valued using the average minimum farm wage in a particular district. The labour costs were adjusted with the share of cattle income in household income. Similar adjustments were applied to other incidental variable costs, such as fuel and electricity bills.

Additionally, land was measured as farm size adjusted with the corresponding share of cattle income in the household income. However, the farm size was found to be highly statistically correlated with amount of feeds used in agro-pastoralism. Further, nomads generally migrate with cattle and there was no evidence that they use their *owned* land as a direct input in the cattle enterprise. Therefore, it was difficult to establish *owner-occupancy* on land with respect to cattle production or to measure other expenditure (except feed costs) on temporary secondary land. Moreover, at the time of the survey there were no taxes on unutilised land in Kenya. Consequently, the use of imputed land rent as an input (see for example, Hadley, 2006; Barnes, 2008) was not suitable for this study. Further, use of a dummy variable to indicate presence of land (e.g., Iraizoz *et al*., 2005) was not appropriate in this case due to lack of variation, given that all farmers sampled had some land. In the literature, Featherstone

[7] Depreciation costs were computed as: (Initial cost minus approximate salvage value)/estimated useful life.

et al. (1997) and, Ceyhan and Hazneci (2010) include farm size as a possible determinant of TE in the inefficiency model, rather than as an input in cattle production. This is the approach adopted in the present study.

5.5.2 Empirical estimation of technical efficiency

The parameters of the stochastic frontiers for the production systems were estimated using the Cobb-Douglas[8] specification:

$$\ln Q_{n(k)} = \beta_{0(k)} + \sum_{i=1}^{4} \beta_{i(k)} \ln X_{ni(k)} - Z\delta_{n(k)} + v_{n(k)} \tag{44}$$

where $Q_{n(k)}$ is the annual value of beef cattle output;

X_{ni} represents a vector of inputs where X_{n1} is the beef herd size, X_{n2} is feed equivalent and X_{n3} is the cost of veterinary services, while X_{n4} is a *Divisia* index calculated as (Boshrabadi *et al*., 2008)[9]:

$$X_{n4(k)} = \prod_{i=1}^{3} C_{ni(k)}^{\alpha_{ni}} \tag{45}$$

where $\alpha_{ni(k)}$ represents the share of the i^{th} input in the total cost for the n^{th} farm in the k^{th} production system;

$C_{n1(k)}$ = depreciation costs, insurance and taxes on farm buildings, machinery and equipment (Kshs);

$C_{n2(k)}$ = cost of labour (Kshs);

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[8] A likelihood ratio (LR) test (Coelli *et al*., 2005) with an LR statistic of 3.58 compared with the chi-square critical value of 18.31 at 5 percent level and 10 degrees of freedom did not support rejection of the null hypothesis that the Cobb-Douglas model provided a better fit to the data than an alternative translog model. The LR statistic was calculated as -2{ln(LR_1) – ln(LR_0)}, where LR_1 is the log-likelihood of the Cobb-Douglas model while LR_0 is the log-likelihood of the translog model. Degrees of freedom refer to the difference in the number of parameters estimated in the two models, i.e., the restrictions imposed.

[9] The *Divisia* index is a proxy variable used to possibly account for the effects of inputs that were not found to be individually statistically significant (e.g., depreciation, labour etc.). Initially, the model was estimated with depreciation, labour and other costs as separate inputs but these were insignificant though with the expected positive sign, and were consequently consolidated into the *Divisia* index to improve the model fit.

$C_{n3(k)}$ = other costs, e.g. fuel, electricity, hire/maintenance of machinery, market services, purchase of ropes, branding etc. (Kshs);

Z denotes the vector of socio-demographic and other independent variables assumed to influence efficiency; v represents statistical noise and δ is a vector of inefficiency parameters to be estimated.

Intuitively, a negative sign on δ in equation (44) implies that the corresponding variable has a positive influence on TE (Brummer and Loy, 2000). The log-likelihood function for the half-normal model is expressed as (Greene 2003):

$$\log L = n\log\varpi - \frac{n}{2}\log\frac{2}{\Pi} - \frac{1}{2}\sum_{n=1}^{N}\left(\varpi Q_n - \varsigma' X_n\right)^2 + \sum_{n=1}^{N}\log\Phi\left[-\lambda\left(\varpi Q_n - \varsigma' X_n\right)\right] \tag{46}$$

where $\varpi = \frac{1}{\sigma}$, $\varsigma = \varpi\beta$, $\lambda = \frac{\sigma_u}{\sigma_v}$, $\sigma = \sqrt{\left(\sigma_u{}^2 + \sigma_v{}^2\right)}$ and $\Phi(.)$ is the probability density function in the standard normal distribution. The parameters of the stochastic frontiers were obtained by maximising the log-likelihood function (Equation 46) using FRONTIER version 4.1c software (Coelli, 1996b). Metafrontier estimation (Equation 18 in section 3.3.3.5) and bootstrapping of standard errors were undertaken in SHAZAM version 10 (Whistler *et al*., 2007), while LIMDEP version 9.0/NLOGIT version 4.0 (Greene, 2007) was used for the Tobit analysis (Equation 23 in section 3.3.4). The log-likelihood function for the two-limit Tobit model is expressed as (Wooldridge, 2002):

$$\log L\left(\delta, \sigma_{tm} \mid \theta^k, Z, L_0, L_1\right) = \Big\{ \prod_{\theta^k = L_0} \Phi\left(\frac{L_0 - \delta' Z}{\sigma_{tm}}\right);$$

$$\prod_{\theta^k=\theta^{k*}} \frac{1}{\sigma_{tm}}\phi\left(\frac{\theta^k - \delta' Z}{\sigma_{tm}}\right);$$

$$\prod_{\theta^k = L_1}\left[1 - \Phi\left(\frac{L_1 - \delta' Z}{\sigma_{tm}}\right)\right] \Big\} \tag{47}$$

where Φ and ϕ are the standard normal cumulative and density functions respectively; and σ_{tm} denotes standard deviations in the Tobit model. As defined earlier in equation (23), θ^{k*} and θ^{k} are the latent and observed values of the metafrontier TE scores, respectively. The subscripts 0 and 1, respectively, are the lower and upper limits of TE scores.

The model commands or codes used in the estimation of the stochastic frontiers and metafrontier are summarised in Appendix 2 and 3, respectively. Results on TE estimation are presented and discussed in chapter six.

As mentioned earlier, the CE section on DFZs also formed an important part of the survey questionnaire. The CE exercise is described in detail below.

5.6 Choice experiment on disease free zones

5.6.1 Current state of cattle disease control in Kenya

As mentioned earlier (see sections 1.3 and 1.4 in chapter 1), cattle farmers in Kenya frequently face outbreaks of notifiable diseases, especially Foot and Mouth Disease (FMD) and Rift Valley Fever (RVF) that spread quickly across farms. In 2006/2007, nearly 30 percent of the national herd was lost within a period of 6 months due to occurrence of these two diseases (Otieno, 2008). Although liberalisation of veterinary service provision in Kenya in the 1990s opened the way for the entry of private service providers alongside government veterinarians, farmers' access to these services remain limited due to high cost. Further, there is a generally inadequate coverage of veterinary advisory services in remote and marginal areas where most pastoralists live (Leonard and Ly, 2008).

In addition, most farmers (except ranchers) practise open grazing on communal or individually-owned pasture lands, road sides, forests and sometimes encroach in wildlife reserves and other people's croplands. This often results in conflicts between cattle farmers and crop farmers or other land users. Recently, many conflicts arising from encroachment of private or public protected land by pastoralists have led to confiscation of cattle or penalties such as fines (Obunde *et al*., 2005). The uncontrolled movement of animals also contributes to faster spread of diseases across farms and regions. Therefore, DFZs are proposed in the present study as an important zoo-sanitary intervention.

5.6.2 Features of the proposed disease free zones

This study conceptualises DFZs to have two types of attributes or features; compulsory and optional. The compulsory attributes are those that must be adhered to by all farmers in a DFZ and all other people living in the neighbourhood (but not necessarily members of the DFZ), in order to prevent spread of diseases. Inclusion of compulsory features in the DFZ accords with the view that some form of coercion is necessary in order to enforce public policy (Olson, 1965). The compulsory features include:

a) Farmers in a DFZ would be required to practise a controlled grazing system in order to prevent transmission of diseases across farms. The controlled grazing could be done by individual farmers on their private grazing land or a group of farmers could develop pasture for communal grazing. Thus, open grazing on roadsides, forests and other unconfined areas outside the DFZ would not be allowed.

b) Farmers would be required to monitor and report any disease outbreak in their herds promptly. They would also be expected to maintain consistent animal health records (showing dates of disease occurrences and treatments) for their cattle. These records together with notes from the veterinary service providers would be useful for regular evaluation of progress in the DFZs.

c) The minimum duration for membership in a DFZ would be five years; thereafter a farmer would be free to renew participation for another five years or withdraw from the scheme[10]. Farmers who pull out of the scheme would be required to sell all their cattle to the scheme and would not be allowed to keep cattle for a subsequent period of five years.

d) No animal movement would be allowed from or into a DFZ during a disease outbreak.

e) Farmers would be required to slaughter and discard all infected cattle during disease outbreak.

f) A penalty would be imposed on farmers who fail to comply with prescribed practices in a DFZ. This could be in form of a fine involving compulsory purchase/auction of all cattle owned by a member, and the member being consequently banned from keeping cattle in the area for a period of five years.

In addition, the DFZ would have some optional (but important) features or attributes that farmers would choose at levels they preferred. Optional or voluntary features are the ones that enter the CE design. These features enable individuals with diverse interests to reach consensus or exercise collective action, which Ostrom (1990) notes is necessary when individuals face a common problem such as cattle disease that may threaten their collective livelihoods. In this study, policy-relevant DFZ features/attributes were selected from a combination of an extensive review of the literature on DFZ implementation in other countries (see section 2.5 in chapter 2), in-depth interviews of key officials instrumental in policy implementation at the Ministry of Livestock Development in Kenya, and focus group discussions (FGDs) with farmers. The use of participatory research methods such as FGDs in the assessment of farmers' needs prior to programme design may help to capture diverse views and enhance the relevance and acceptability of development programmes (Merrill-Sands and Collin, 1994; Kassam, 1997), such as DFZs.

[10] Five-year duration is consistent with short-term national development planning or policy cycle in Kenya.

Two FGDs, each comprising a representative mix of 12 farmers across the three production systems, were held in July 2009 in a logistically central site, i.e., at the Kenya Agricultural Research Institute (KARI), Kiboko station in Makueni district. The FGDs were conducted using a check-list questionnaire (see Appendix 4). It was noted in the FGDs that, generally, farmers loose a considerable size of their herds due to disease outbreaks. Further, participants in the FGDs expressed dissatisfaction with existing disease control measures, but there was relatively low awareness on DFZ programmes. This therefore meant that there was need to provide more information to respondents in the subsequent survey, regarding DFZs.

Following guidelines proposed by Bateman *et al*. (2002) the FGDs were also used to validate important attributes identified and their levels for inclusion in the CE. Five DFZ attributes were selected for the CE design from the validation exercise:

i. *Training* would be provided on disease monitoring, record keeping and pasture development, to farmers who are willing to join the DFZ and require capacity-building on these skills. Farmers could choose DFZ alternatives that have a training component or those without. Provision of skills would improve compliance with compulsory rules on reporting and confined grazing. Farmers' demand for training would also help to indirectly evaluate their satisfaction with the current livestock extension service provision.

ii. *Market support* would be provided at two levels: information on market prices and buyers, or the information plus facilitation or linkage (for instance, through registration, guarantee or endorsement) to access sales contract opportunities in some local and export markets. Alternatively, no market support may be provided. However, enhancing market access is considered as an important strategy that would enable farmers to earn better incomes, recover money spent on DFZs and sustain their long term participation in the programme.

iii. In order to participate in the scheme, farmers would be expected to pay *annual membership fees (cost) per animal*. Regular payment is necessary in order to enhance continuity of service provision. The fee could be paid once annually or through monthly or quarterly instalments depending on an individual farmer's preference. By paying the fee, farmers would be guaranteed veterinary drugs and services at all times without any extra charges. The fee would also be used to finance other operational costs.

iv. Cattle would be *labelled* with an identification number in order to allow traceability in each DFZ for faster disease control. The identification number could include unique codes that describe the cattle type only (breed, size, sex, and colour) or the cattle type and the owner's personal identity number. The labelling would be done using relatively considerate identification methods such as ear tagging, as opposed to other techniques such as ear notching, freeze branding and fire branding that are generally considered to violate animal welfare (Phillips *et al*., 2009)[11]. Adherence to animal welfare is an important legislative requirement and a key concern to consumers in main beef export markets (Bennett and Blaney, 2003), such as the European Union (EU), where Kenya has a preferential quota. Therefore, promoting farmer compliance with better traceability methods would possibly improve access to high value markets (Schultz and Tonsor, 2010). Moreover, farmer compliance with 'humane methods' of cattle labelling is important to avoid loss of livestock

[11] For details on other important aspects of animal welfare, see for example, Chilton *et al*. (2006).

incomes, given that increased media coverage of 'animal welfare-unfriendly' handling practices generally leads to reallocation of consumer expenditure to non-meat food (Tonsor and Olynk, 2011).

v. In case of a fatal disease outbreak, farmers who adhere to all prescribed practices in the DFZ would be *compensated* some value of the cattle lost (i.e., 10 percent, 25 percent or 50 percent). The minimum compensation is set at 10 percent to encourage participation (considering that currently there is no compensation for any disease-related losses), while 50 percent is considered as the best upper limit. Higher levels of compensation may lead to problems such as moral hazard and adverse selection (i.e., relatively high disease-risk farmers would generally have a tendency to seek more compensation than those facing less disease-risks). This would necessitate extremely expensive premium that many farmers may not be willing (and able) to pay[12]. Moreover, the maximum level of compensation proposed in this study (50 percent of the value of cattle lost) is consistent with the allowable domestic farm support measures in articles 7 and 8 of Annex 2 (the green box) in the WTO Agreement on Agriculture (AoA). In the AoA, compensation of farmers for losses of income or livestock from natural disasters e.g., disease outbreaks, should not exceed 70 percent (WTO, 1995b).

The inclusion of both compulsory and optional features in the DFZ programmes provides an enhanced level of responsibility through mutual agreement by the key stakeholders (Harden, 1968; Feeny *et al*., 1990) in livestock policy, i.e., government and farmers. This may help to achieve what Blandford (2010) describes as a balance between regulation and voluntary

[12] Relatively lower levels of compensation (ranging from 5 percent to 25 percent) had been proposed in the study (see Appendix 4), but these were adjusted following suggestions from the FGDs.

participation (or minimum consensus necessary for decision making in the absence of full collective action), in order to improve the acceptability, enforcement and implementation of the programme.

5.6.3 The choice experiment design

Following recommendations from the FGDs, three levels were used for each of the five DFZ attributes, except training for which only two levels were used (Table 2). In CE design, different experimental procedures can significantly influence the accuracy of the results (Lusk and Norwood, 2005). Generally, it is important to use an experimental design approach that maximises an efficiency criterion (such as *D-efficiency*), or equivalently, minimises an error criterion such as the *D-error*. A design is said to be *D-efficient* or *D-optimal* if it has a sufficiently low *D-error* or yields data that enable estimation of parameters with low standard errors (see Scarpa and Rose, 2008 for details).

Given the large geographical scope of the study and the cost of surveys of this kind, sample size was also an important issue. To increase sampling efficiency, the study focused on maximising the *D-optimality* through a two-stage design procedure (Bliemer and Rose, 2010). First, a conventional fractional factorial orthogonal design was generated from the attributes selected and applied in a preliminary survey of 36 farmers to obtain prior coefficients. The *priors* were then used in the second stage to generate an efficient design, which could be applied to estimate both main effects and interaction effects. The design had a relatively good level of *D-optimality* (i.e., *D-efficiency* measure of 85 percent).

Table 2: Attributes included in DFZ choice experiment design

DFZ attribute	Attribute levels
Training	No Training
	Training is provided
Market support	No market support
	Market information is provided
	Market information is provided and contract sale is guaranteed
Compensation	10 percent of the value of cattle lost
	25 percent of the value of cattle lost
	50 percent of the value of cattle lost
Labelling of cattle	No labelling
	Labelling cattle without owner's identity
	Labelling cattle with owner's identity
Annual membership fee per animal (in Kenyan shillings; Kshs)*	150
	300
	450

* On average, 75 Kenyan shillings (Kshs) were equivalent to USD$1 at the time of the survey. Lower levels of membership fee (Kshs 50-150) were initially proposed (see Appendix 4), but these were subsequently adjusted considering suggestions from the FGDs.

In addition, the design had a relatively good utility balance (i.e., a *B-estimate* of 77 percent). This indicates that there was an insignificant likelihood of dominance by any alternative in the choice situations. Essentially the design fulfilled the minimum threshold (*B-estimate* of 70 percent) required for utility balance in efficient designs. Note that many CE designs rarely achieve good *D-efficiency*, utility balance and orthogonality at the same time (Huber and Zwerina, 1996). The statistical software NGENE (ChoiceMetrics, 2009) was used to generate the design (see Appendix 5, for details on the CE design syntax). This study is one of the few applications in the literature involving the use of more recent and robust software to obtain an efficient CE design, especially for modelling a choice problem in a developing country.

The final design had 24 paired choice profiles that were randomly blocked into six choice sets, each with four choice tasks. Respondents were randomly assigned to one of the six choice sets. Each choice task consisted of two alternatives (A and B) and a baseline alternative (C) in which all DFZ attributes were set at the 'zero' level. When making choices, respondents were asked to consider only the attributes presented in the choice tasks and to treat each choice task independently. An example of a choice set presented to respondents is shown in Figure 9.

An important objective in the design of CEs is to ease the choice tasks for respondents. As noted in section 4.3.4, a number of studies have investigated the influence of CE design dimensions (particularly number of attributes/level, number of alternatives and choice situations) on respondents' ability to choose. Overall, the design generated in this study is in line with the optimum CE design dimensions discussed in Caussade *et al*. (2005). Pilot testing of the CE questionnaire was conducted through face-to-face interviews of a further 36 farmers to refine its wording and format. The pilot survey showed that respondents could comfortably manage at least four choice tasks.

Figure 9: Example DFZ choice set

I would like to request you to choose your most preferred type of DFZ from the following three alternatives.			
DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C (*baseline or status quo*)**
Training	Training	No training	No training
Market support	No market support	Market information and contract	No market support
Compensation	25%	10%	No compensation
Labelling	Cattle and owner	No labelling	No labelling
Annual membership fee (Kshs)	150	450	No membership fee
Which ONE would you prefer?			

Some important issues in DFZ implementation are briefly highlighted in the following section, while the CE survey is subsequently discussed in section 5.6.5.

5.6.4 Potential considerations in implementation of disease free zones

In a practical implementation context, each DFZ would consist of three or four villages where most people keep cattle (i.e., to facilitate economies of scale in cost sharing), use a common water source e.g., a river or borehole, and are willing to comply with the DFZ scheme. It is envisaged that each DFZ would be implemented through a management committee including farmers' representatives and other stakeholders, e.g., livestock production officers. The committee would, for instance, identify competitive (public or private) providers of services, such as training, and pay for those services from its account. Further, in consultation with local administrators (e.g., local county officers) and veterinarians, the committee would monitor movement of cattle into or out of the DFZ (for example, through a clearance permit system) to prevent disease transmissions. In addition, the management committee would be expected to facilitate mechanisms for resolution of disputes between DFZs, or with non-members.

The government (for example, through departments of livestock development, water and irrigation) and development partners would be expected to support the implementation process in various ways. This might include for instance, providing additional funding for fencing of the DFZ, and investments in alternative water sources to prevent migration of farmers and their cattle during severe droughts that often occur in some parts of Kenya.

This study builds on the literature of existing DFZs in other countries, by suggesting provision of training and market support to farmers. Further, a compensation scheme that is supported by a membership fee is introduced as a way of enhancing sustainability in terms of continued ability to finance the operations of the DFZs in the long-run. This is possibly a more realistic approach, given that governments in developing countries such as Kenya are unlikely to be able to provide full funding for DFZs. Thus, the study provides for sustainability of the DFZs through what Ostrom (1990) describes as collective action, and enables reduced reliance on government or development partners. It is also important to note that the minimum membership duration is suggested as a possible deterrent to moral hazard. Otherwise, farmers might be tempted to withdraw from the scheme if compensation is made before they complete payment of the annual membership fees.

5.6.5 Choice experiment survey

The CE exercise was preceded by some 'warm-up' questions and a brief introduction on the proposed DFZ to prepare the respondents for the choice tasks. The initial 'warm-up' questions sought to investigate the respondents' perceptions on the relative importance of cattle diseases to farming and their level of satisfaction with current disease control programmes (using a Likert scale, where 1 = strongly disagree, while 5 = strongly agree). Additional preliminary questions included investigation of disease mitigation strategies used by the respondents in previous severe outbreaks, and their awareness of DFZs in general (see section J in Appendix 1, for details).

The farmers' responses to the 'warm-up' questions showed that generally, they considered cattle diseases to be a serious problem to farming, but were dissatisfied with the existing disease control measures. Further, although there was a relatively low awareness on DFZs (less than 20 percent of the respondents), respondents across the three productions indicated that a DFZ would be a 'very important' intervention to them (Table 3). A higher proportion of nomads sold/slaughtered cattle or moved to other 'safer' areas during previous severe disease outbreaks. On the contrary, two-thirds of agro-pastoralists and ranchers did not sell/slaughter or move cattle away during disease outbreaks, but sought veterinary services. Considering limited veterinary service provision, and lack of 'better' options to reduce spread of diseases in the event of an outbreak, it should be expected that generally farmers would show a preference for DFZs. Overall, the farmers' responses to the 'warm-up' questions offer an indication that their subsequent choice behaviour in the CE survey would be more realistic and should possibly reflect their interest in DFZs.

Table 3: Farmers' perceptions on cattle disease control measures

Variable	Nomads (n=110)	Agro-pastoralists (n=137)	Ranchers (n=66)	Pooled sample (n=313)
Relative perception that cattle diseases are a serious problem to farming*	3.8[a]	3.6[a]	3.7[a]	3.7
Relative satisfaction with current disease control programmes*	1.9[a]	2.3[a]	2.3[a]	2.2
Other options undertaken (in addition to seeking veterinary services) to manage previous severe disease outbreaks (% of farmers):				
Sold cattle	43.6[a]	16.8[b]	21.2[b]	27.2
Slaughtered	5.5[b]	13.9[a]	7.6[b]	9.6
Moved cattle to other areas	14.5[a]	2.2[b]	7.6[b]	7.7
Did nothing	36.4[b]	67.1[a]	63.6[a]	55.5
DFZ awareness	18.2[b]	10.2[c]	39.4[a]	19.2
Overall relative importance of DFZ attributes**	2.7[a]	2.6[a]	2.7[a]	2.7

Notes: * 1 = strongly disagree, 2 = disagree, 3 = undecided, 4 = agree, 5 = strongly agree.

** 1 = not important, 2 = important, 3 = very important.

[a,b,c] Different letters denote significant differences (at 10 percent level or better) in variables across the production systems in a descending order of magnitude.

Following insights from the FGDs (e.g., slow pace of response and tendency to recall previous responses), adequate information was provided in the survey to enable respondents to understand the CE exercise and be able to make independent and reliable choices in each situation based on their preferences. The short introduction that was provided in the CE section to the respondents highlighted the purpose of the proposed DFZ, and both voluntary and compulsory features were clearly explained to them using a card[13]. Each respondent was then presented with a series of four choice sets (see Figure 10 for illustration), randomly chosen from one of the six blocks of choice sets from the CE design, and asked to choose the most preferred option in each case. A complete list of all the blocks/panels of choice sets used in the CE survey is provided in Appendix 6.

Figure 10: Example panel of choice sets (block 1) used in the choice experiment survey

Choice set number 1

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	No training	Training is provided	No training
Market support	Market information	Market information and contract	No market support
Compensation	50%	50%	No compensation
Labelling	Cattle and owner	No labelling	No labelling
Annual membership fee (Kshs)	450	150	No membership fee
Which ONE would you prefer?			

Choice set number 2

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	No training	Training is provided	No training
Market support	No market support	Market information	No market support
Compensation	50%	10%	No compensation
Labelling	Cattle and owner	No labelling	No labelling
Annual membership fee (Kshs)	150	300	No membership fee
Which ONE would you prefer?			

[13] A detailed introduction to DFZs and features that were explained to respondents on the card are provided in section J of Appendix 1.

Choice set number 3

DFZ Attribute	Alternative A	Alternative B	Alternative C
Training	Training is provided	No training	No training
Market support	Market information	Market information	No market support
Compensation	50%	10%	No compensation
Labelling	No labelling	Cattle and owner	No labelling
Annual membership fee (Kshs)	450	450	No membership fee
Which ONE would you prefer?			

Choice set number 4

DFZ Attribute	Alternative A	Alternative B	Alternative C
Training	Training is provided	No training	No training
Market support	Market information and contract	Market information	No market support
Compensation	10%	50%	No compensation
Labelling	No labelling	Cattle and owner	No labelling
Annual membership fee (Kshs)	450	150	No membership fee
Which ONE would you prefer?			

Note: Following recommendations by ChoiceMetrics (2009), all choice sets obtained from the CE design were applied in the survey without any alteration, in order to maintain optimality in the design dimensions.

Overall, the entire survey questionnaire including the CE exercise took about one and a half to two hours to complete. On average, each interviewer was able to conduct three interviews per day, and the entire survey was conducted from July to December 2009. Responses to all questions were filled in the questionnaire directly during the survey. Empirical analysis of the CE data is discussed in the following section.

5.7 Analysis of farmer preferences for disease free zones

In the CE survey, each respondent was presented with a series of *T=4* choices. Each choice situation provided a respondent a choice between *J=2* alternatives (plus a baseline option). Thus, the three alternatives that the respondent faced in a particular choice occasion comprised two DFZ policy options described in terms of key design attributes (training, market information, compensation, etc.) and the option in which none of the attributes was made available.

The RPL model discussed in section 4.4.3 (see the commands in Appendix 7) was applied in the CE analysis because it was found to fit the sample data better than the MNL and LCM. Up to 100 Halton intelligent draws were utilised in the simulations (Train, 2003). Trade-offs between DFZ attributes and money, i.e., marginal WTP for discrete changes in each attribute, were computed following equation (29) in section 4.4.2. Confidence intervals for the marginal WTP (at 95 percent level) were also calculated using standard errors of the WTP measures, estimated through the delta method in LIMDEP version 9.0/NLOGIT version 4.0 software (Greene, 2007).

Subsequently, the overall WTP or a compensating surplus (CS) welfare measure was derived for different policy scenarios associated with multiple changes in attribute levels as (Hanemann, 1984):

$$CS = \frac{-1}{\beta_p}(V_1 - V_0) \tag{48}$$

where V_1 represent the value of indirect utility associated with attributes of the DFZ scenario under consideration, while V_0 is the indirect utility of the baseline scenario of no DFZ. Finally, the possible influence of TE on preferences for DFZ attributes was investigated using the RPL model. The CE results on farmer preferences for DFZs are discussed in chapter seven.

5.8 Summary

This study collected survey data comprising information on cattle production and responses to a CE on farmers' preferences for DFZs. The DFZs were envisaged to have both compulsory and voluntary features, which were identified through a combined review of the literature, FGDs and expert consultations. A *D-optimal* procedure was used in the CE design. The survey questionnaire was validated through a pilot exercise and subsequently administered through face-to-face interviews of a representative multi-stage sample of farmers in the three main cattle production systems in Kenya, spread over four areas.

Cobb-Douglas stochastic frontiers were applied to estimate TE, while a stochastic metafrontier was employed to investigate technology gaps across farms. In addition, a Tobit model was used to assess determinants of TE with respect to the metafrontier. Further, preferences for DFZ attributes and various possible policy scenarios were estimated using the RPL model. Some suggestions on implementation of DFZs are also offered in this chapter. The results of the study on TE are presented and discussed in the next chapter, while CE findings are explained in chapter seven.

Chapter Six

6. Results on Technical Efficiency Estimation

6.1 Introduction

The main objective of this study is to investigate farmers' technical efficiency (TE) and willingness to comply with Disease Free Zones (DFZs). Results presented in this chapter address two specific objectives, which include:

i. to measure farm-specific TE in different production systems;

ii. to analyse the determinants of farmers' TE.

The discussion of results in this chapter is organised as follows. Sample characteristics from the survey are described in section 6.2. The production structure is discussed in section 6.3. Estimates of TE and meta-technology ratios (MTRs) are presented in section 6.4. Further, possible determinants of TE are discussed in section 6.5. A summary of this chapter is provided in section 6.6. Subsequently, results on farmer preferences for DFZs are discussed in chapter seven.

6.2 Farmer characteristics

Descriptive results on some of the sample characteristics are shown in Table 4. On average, ranchers have larger herds and farms than the nomads and agro-pastoralists. Both nomads and ranchers depend more heavily on cattle as the main source of income and tend to keep indigenous (local) cattle breeds such as the *Zebu* and *Boran*, which are relatively well adapted to dry and hot areas (e.g., Kajiado and Kilifi) where most farmers in the two systems live. In contrast, the agro-pastoralists have a majority of exotic and crossbreeds. The ranchers have significantly higher average monthly household incomes.

Table 4: Sample characteristics from the survey

Variable	Nomads (n = 110)	Agro-pastoralists (n = 137)	Ranchers (n = 66)	Pooled sample (n = 313)
Average cattle herd size	53.1^{b}	11.4^{c}	150.9^{a}	55.5
Average farm size (acres)	84.1^{b}	9.5^{b}	426.5^{a}	123.6
Access to livestock extension services in the past year (% of farmers)	49.1^{b}	35.8^{c}	77.3^{a}	49.2
Access to veterinary advisory services in the past year (% of farmers)	50.0^{b}	51.8^{b}	87.9^{a}	58.8
Percentage of farmers who derive more than half of income from cattle (specialisation)**	78.2^{b}	36.5^{c}	93.9^{a}	63.3
Main cattle breed is indigenous (% of farmers)	68.2^{a}	27.0^{c}	54.5^{b}	47.3
Monthly income above Kshs 20,000 (% of farmers)*	22.7^{b}	15.3^{b}	84.8^{a}	32.6
Average age of respondent (years)	38.6^{b}	42.4^{a}	42.1^{a}	41.0
Rural location (% of farmers)	83.6^{a}	65.7^{b}	72.7^{b}	73.5
Dependence on both crops and other livestock (% of farmers)	31.8^{a}	38.7^{a}	7.6^{b}	29.7
Dependence on off-farm income (% of farmers)	25.5^{a}	24.8^{a}	24.2^{a}	24.9
Average distance from farm to main market (Kilometres)	11.6^{b}	4.8^{b}	41.0^{a}	14.9
Percentage of farms with manager	8.2^{b}	7.3^{b}	75.8^{a}	22.0
Main market is abattoirs and not open air market (% of farmers)	49.1^{c}	64.2^{b}	77.3^{a}	61.7
Access to prior market information in the past year (% of farmers)	26.4^{b}	19.7^{b}	68.2^{a}	32.3
Sale of cattle on contract (% of farmers)	16.4^{b}	24.8^{b}	53.0^{a}	27.8
Transport arrangements are included in market contract, in addition to price (% of farmers)	38.9^{b}	47.1^{b}	66.7^{a}	53.4
Use of controlled cattle breeding method (% of farmers)	58.2^{b}	79.6^{a}	68.2^{b}	69.6
Average household size	8.5^{a}	6.3^{b}	6.0^{b}	7.0
Gender (% of male farmers)	66.4^{b}	67.2^{b}	87.9^{a}	71.2
Membership to any development group (% of farmers)	67.3^{a}	65.0^{a}	54.5^{a}	63.6

^{a,b,c} Different letters denote significant differences (at 10 percent level or better) in variables across the production systems in a descending order of magnitude.

* On average, 75 Kenyan shillings (Kshs) were equivalent to USD$1 at the time of the survey.

** Other studies e.g., Hadley (2006) also defined specialisation as the proportion of household income derived from a particular enterprise. Further, based on the distribution of income, the 50 percent criterion is used in order to maintain a reasonable sample in each category.

Only a quarter of farmers in the three systems depend on off-farm income. This is partly consistent with the observation that, a few pastoralists near peri-urban areas are gradually diversifying their activities into wage labour or small businesses, due to rapid population growth and the concomitant pressure on resources, such as water and grazing land (Thornton *et al.*, 2007). Further, one-third of the farmers, including a smaller proportion of ranchers, depend on both crops and other livestock, besides the cattle enterprises. For nomads, a higher proportion of this comprise dependence on other livestock e.g., sheep and goats (shoats), with very limited *if any* share of crops.

There is no significant difference in the average age of agro-pastoralists and ranchers, but generally farmers in both categories are slightly older than the nomads. Over 60 percent of all farmers, including three-quarters of the nomads, are found in rural areas. The nomads have significantly bigger households than agro-pastoralists and ranchers. On average, there is a fairly similar level of involvement in development groups by farmers across the three systems. More than half of farmers in all the production types are male, with ranchers having the smallest proportion of females.

Currently, ranchers benefit from relatively better access to livestock extension and veterinary advisory services, and most of them have farm managers (see Table 4)[14]. A higher proportion of agro-pastoralists use controlled cattle breeding, which involves use of artificial insemination (AI) or planned and monitored natural breeding rather than random natural breeding. This is consistent with the observation that the more commercially-oriented farmers (i.e., ranchers and agro-pastoralists) prefer cattle breeding strategies that target market and/or profitability requirements, e.g., faster growth and higher gains in live weight, while the

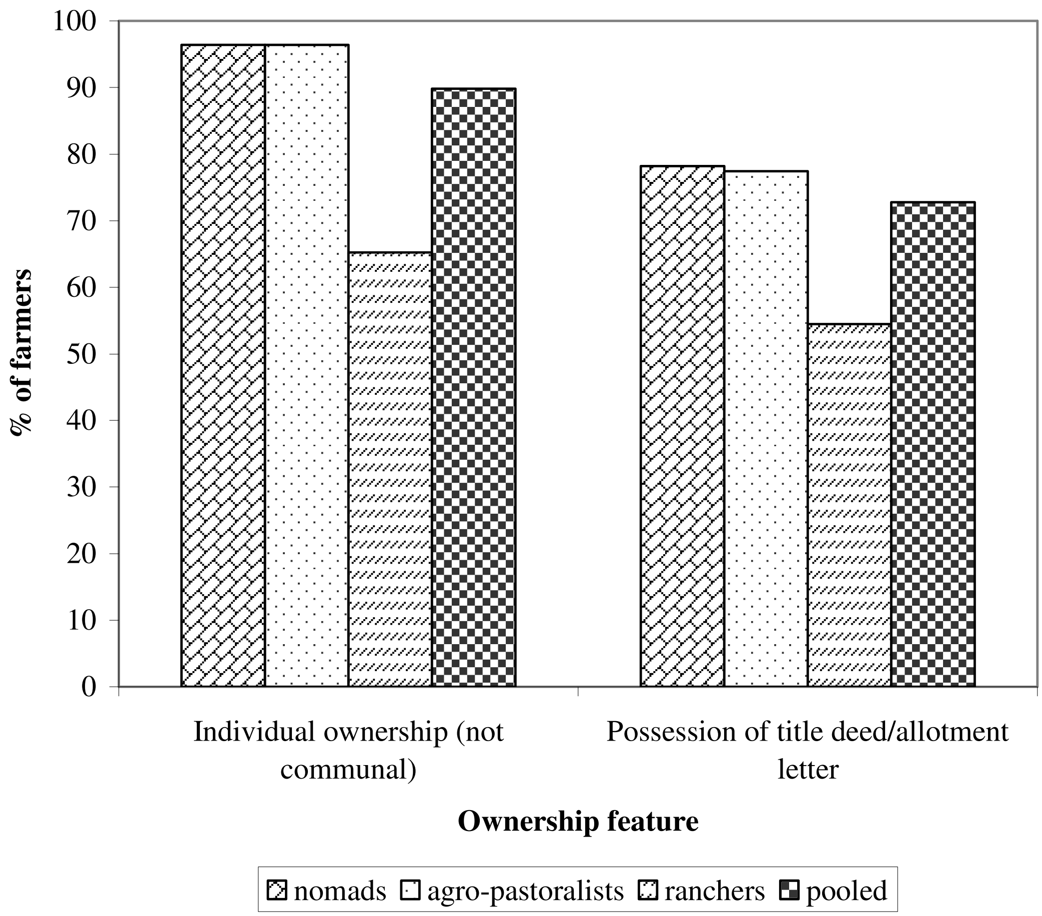
[14] Half of the nomads and agro-pastoralists, and one-third of ranchers with access to extension and veterinary services, usually obtain these from government as opposed to private providers. However, the service provision is less frequent; two-thirds of nomads and agro-pastoralists and 40 percent of ranchers obtain extension services less than once a month. A majority of the farmers indicated a preference to have extension visits at least once a month (Appendix 8).

relatively less-commercialised nomads mainly focus on cattle survival traits such as drought resistance, hardiness and disease tolerance (Gamba, 2006). Generally, the use of controlled cattle breeding (especially AI service) is important for improving genetic distribution, reducing the risk of disease transmission, reducing inbreeding and avoidance of breeding of immature heifers or old cows. Moreover, use of AI service can enable farmers to control animal sex ratio in the herd; higher male-female beef animal ratio is generally preferred because male animals have relatively faster growth rates and are considered to be more efficient in meat production (Berry and Cromie, 2007; Valergakis *et al*., 2007).

As noted earlier, the ranchers have relatively larger farms. Generally, they use most of their land to grow fodder (see Table 5 in section 6.3). On the contrary, there is no evidence of investment on land by the nomads; perhaps they might be using it for speculative purposes on rent, considering that there is a growing demand for real estates in Kenya. Most agro-pastoralists and nomads have individual land ownership with relatively secure tenure (possess either a title deed or allotment letter). About 40 percent of ranchers, however, have group-owned land without secure tenure (Figure 11). Most of these farms were previously large-scale government or private landholdings that have only been sub-divided recently, either to address group ranch management problems or to provide long-term access to younger members (Thornton *et al*., 2007).

However, as noted by Lengoiboni *et al*. (2010), the existing land laws and property rights in land administration in Kenya tend to focus on ownership and control of land, but are inadequate in serving pastoralists' temporal and spatial access rights. For instance, there is relatively limited government investment on development of water resources in nomadic pastoral areas. Perhaps this might have a bearing on pastoralists' motivation to develop their land, for example, by growing pasture and/or conserving it from degradation; most land owned by the nomads is very dry and fallow. Generally, as noted by Deininger (2010), Kabubo-Mariara *et al.* (2010) and Oluoch-Kosura (2010), improved land tenure and access rights (e.g., through land registration) are important prerequisites for long-term and ecologically beneficial land-related investments, technology adoption and productivity enhancement.

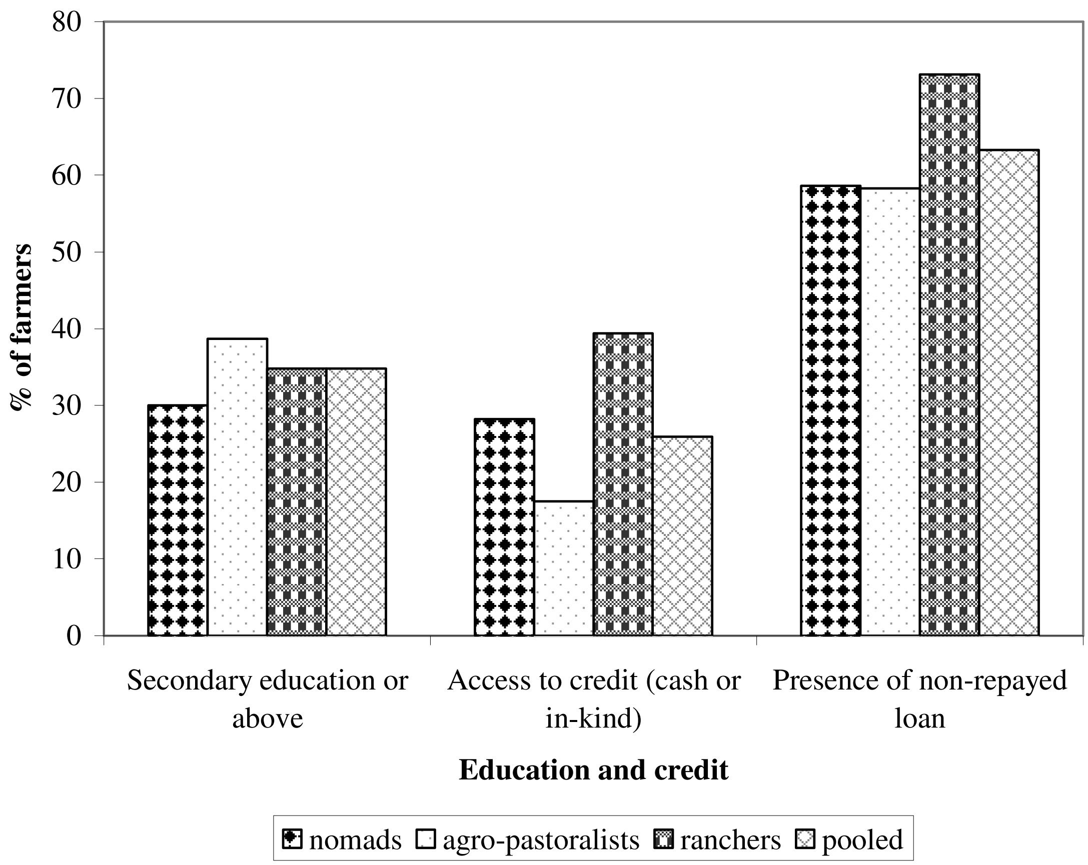
Figure 11: Land ownership type



Across all three production systems, less than 40 percent of respondents have formal education at the secondary level or above. Further, only a quarter of farmers have access to credit, but agro-pastoralists have the least. Of these, more than half of the nomads and agro-pastoralists, and nearly three-quarters of ranchers are yet to repay all the loans (Figure 12).

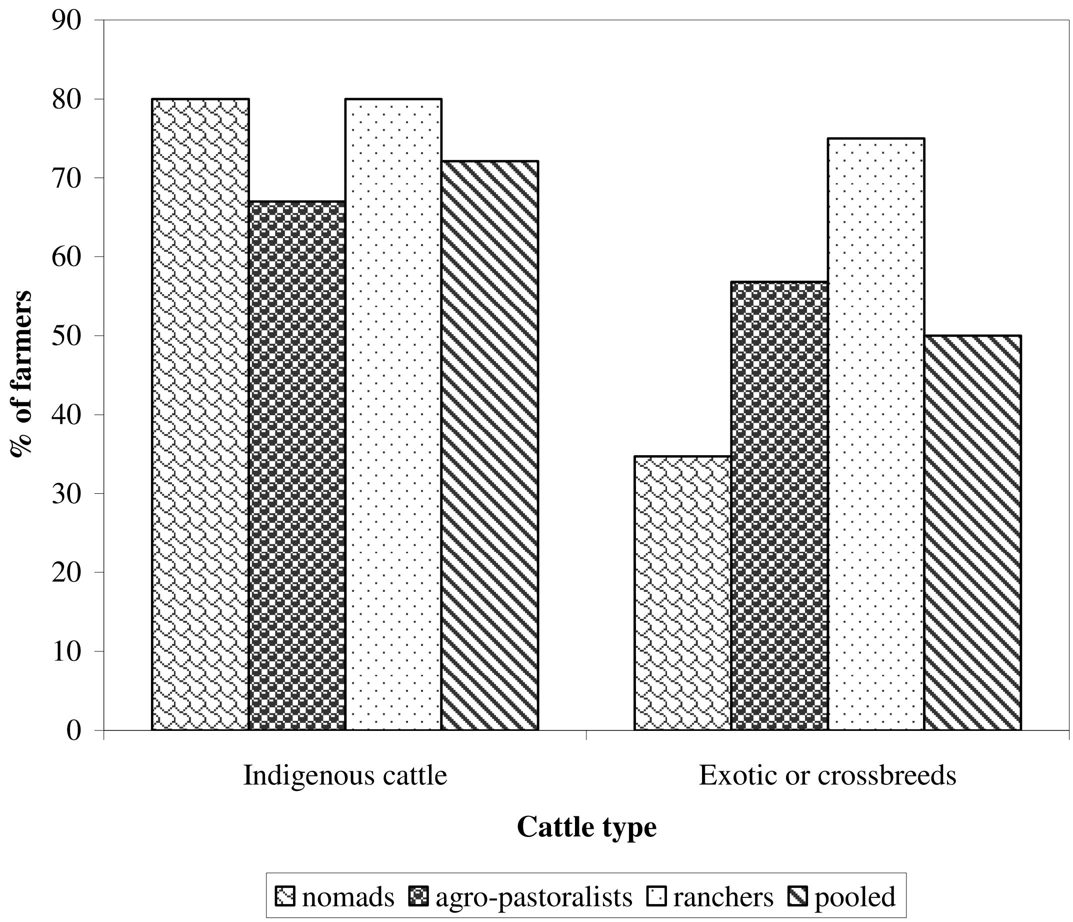
The credit referred to here, includes any loan received in the past year, either in cash form or in-kind (e.g., livestock feeds) from formal lending institutions such as banks or informal sources, including friends and relatives.

Figure 12: Farmers' formal education and access to credit



In terms of main market outlet, between a half (nomads) and three-quarters (ranchers) of farmers opt for abattoirs (e.g., Kenya Meat Commission – KMC) in preference to open air markets, neighbours or other channels (see Table 4). Across all three production systems, a higher proportion of farmers use abattoirs for their indigenous cattle than for their exotic and crossbreeds; this difference is most noticeable for the nomads (Figure 13). On average, ranchers sell in distant outlets compared to the nomads and agro-pastoralists. As noted by Omiti *et al*. (2009) and Shilpi and Umali-Deininger (2008) improving market infrastructure (e.g., provision of appropriate market information and contract opportunities) and enabling farmers to access the markets are important for enhanced commercialisation, and would possibly improve their incomes and livelihoods. In Kenya, the present study shows that only one third of beef cattle farmers (mostly ranchers) have access to prior market information and sell on contract. Further, two-thirds of the contracts for ranchers, and about half for agro-pastoralists, usually include transport arrangements besides price agreements; the proportion of nomads with these is relatively low (see Table 4).

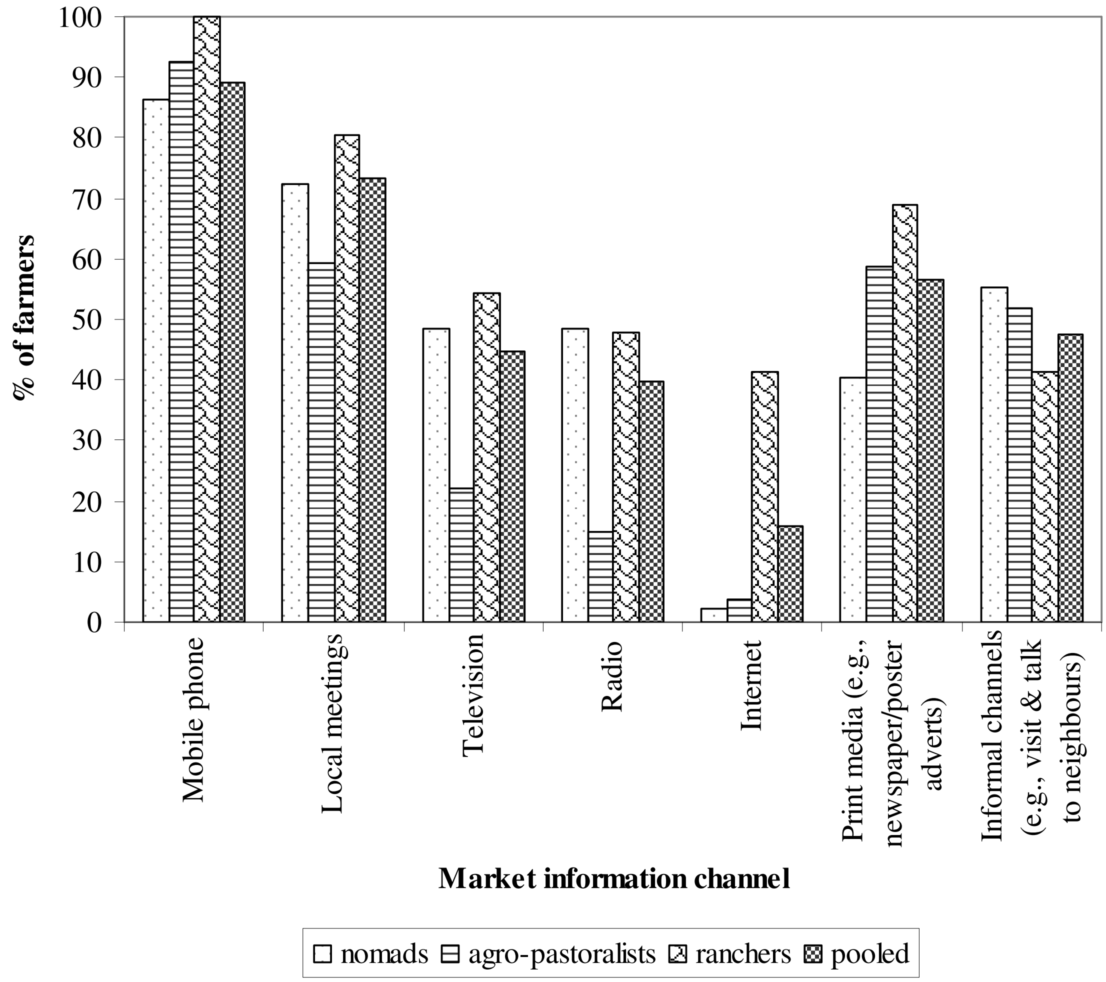
Figure 13: Use of abattoirs as market outlets for different cattle types



Generally, prior market information could offer insights to farmers' decisions, including the choice of market outlets and when to sell their output. In the present study, only a few farmers receive prior market information, as mentioned earlier. Further, the frequency of access to market information is generally low. More than half of the farmers, including eighty-five percent of the agro-pastoralists, receive prior information once a month or less (Appendix 8). These farmers mainly obtain the information by use of mobile phones and through attendance in local development meetings (Figure 14).

There is a relatively low use of internet as a source of market information in the pooled sample, perhaps due to general poor internet connectivity in most remote areas of Kenya and the high cost of access. However, the nomads' relatively high access to information from television and print media (mostly roadside posters) is to be expected, considering that they are less sedentary and often graze cattle in public places, including shopping centres where they might have a chance to get free information from these channels.

Figure 14: Use of various channels by farmers to obtain prior market information



On average, farmers across the three production systems perceive the mobile phones and informal channels (e.g., visiting and talking to a neighbour or friend) to be ‘very important’ sources of market information. All the rest are viewed to be ‘important’. However, nomads and agro-pastoralists do not consider the internet as an important channel (Appendix 8), perhaps due to low access.

A relatively higher proportion of nomads and ranchers have access to fairly good roads (from farm to main market) than the agro-pastoralists. Finally, there are no significant differences in the length of farmers’ experience in cattle production across the three systems; the average for the pooled sample is fourteen years (Appendix 8).

Results on the production structure are presented in section 6.3. Further, estimates of TE and MTRs are provided in section 6.4, while possible determinants of TE are discussed in section 6.5.

6.3 Production structure

This section provides a discussion of production inputs and the estimated production parameters.

6.3.1 Production inputs

The main production variables for the beef cattle enterprise are summarised in Table 5. On average, ranchers use more inputs (i.e., herd size, equipment, labour, feeds and other inputs) and produce the highest output. Nomads and agro-pastoralists use significantly lower amounts of improved feeds and invest less in professional veterinary services than ranchers. Further, farmers (especially the nomads) in remote areas of Kenya with limited access to professional veterinary services prefer community-based and/or self-administered herbal animal health services (Irungu *et al*., 2006). The agro-pastoralists have the highest unpaid labour component; perhaps, this might be one of their strategies to reduce costs due to greater enterprise diversification, compared to the other farm types.

Consistent with their less-sedentary nature, the nomads use the least amount of on-farm feeds (which might be from naturally-growing pasture in their temporary abodes or possibly donations from sedentary farmers; there is no evidence to indicate that nomads invest in fodder cultivation). However, nomads have higher total depreciation costs than agro-pastoralists, because almost all of them possess portable cattle equipment such as dip sprayer, chaff cutter, dehorning and castration equipment[15].

[15] Generally, agricultural input cost components in Kenya vary widely among farmers due to differences in type and level of input usage. For example, livestock feeds might account for 60–80 percent of livestock production costs in some farms, depending on the intensity of production (Republic of Kenya, 2007).

Table 5: Average annual output and inputs

Variable	Nomads (n = 110)	Agro-pastoralists (n = 137)	Ranchers (n = 66)	Pooled sample (n = 313)
Value of beef cattle output (Kshs)*	135,960.88[b]	37,807.35[c]	579,155.08[a]	186,452.20
Beef cattle equivalents (herd size)	35.78[b]	7.67[c]	112.11[a]	39.57
Depreciation costs (Kshs)	7,277.52[b]	2,535.36[c]	228,042.32[a]	51,752.92
Veterinary costs (Kshs)	17,256.00[b]	14,911.36[b]	145,036.36[a]	43,173.85
Paid labour costs (Kshs)	33,547.45[b]	10,648.10[c]	128,511.52[a]	43,548.79
Unpaid labour costs (Kshs)	37,219.09[b]	47,751.82[a]	35,286.36[b]	41,421.73
Total labour costs (Kshs)	70,766.55[b]	58,399.93[c]	163,797.88[a]	84,970.51
Improved feed equivalent of purchased feeds (Kg)	5,848.31[b]	3,331.05[c]	14,161.88[a]	6,499.53
Improved feed equivalent of on-farm feeds (Kg)	218.90[c]	4,004.59[b]	18,441.52[a]	5,718.36
Total improved feed equivalents (Kg)	6,067.21[b]	7,335.64[b]	32,603.40[a]	12,217.89
Cost of other inputs, e.g. market services, branding, dehorning, etc. (Kshs)	17,943.28[b]	5,338.99[c]	189,863.38[a]	48,677.91

[a,b,c] Differences in the superscripts denote significant differences (at 10 percent level or better) across the production systems.

* On average, 75 Kenyan shillings (Kshs) were equivalent to USD$1 at the time of the survey.

Partial input shares are computed to provide *a priori* indication of differences in production technologies across the three production systems (Table 6). Generally, the ratios of expenses on veterinary services and labour in total value of output are relatively larger than those of other inputs. Further, a relatively higher proportion of labour cost in the pooled sample and for nomads and agro-pastoralists, comprise imputed cost of unpaid labour. Due to this, the total cost of labour for agro-pastoralists and in the pooled sample appears higher than the average value of output. There is no significant difference in the share of paid labour cost across the three production systems. Agro-pastoralists have the highest share of veterinary cost, unpaid labour cost and feeds per unit of output. Depreciation and cost of other inputs (e.g., market services) per unit of output are highest in ranches, while nomads use less on-farm feeds and have the lowest per unit veterinary expenses. Finally, the ranchers have the lowest per unit unpaid labour cost and they use relatively less feeds per unit output. This suggests perhaps, that the ranchers keep relatively better cattle in terms of feed conversion. Considering these differences, farmers across the three production systems might be expected to have different levels of efficiency.

Table 6: Partial input shares in output

Input per unit of output	Nomads (n = 110)	Agro-pastoralists (n = 137)	Ranchers (n = 66)	Pooled sample (n = 313)
Depreciation cost (Kshs)	0.05^{c}	0.10^{b}	0.44^{a}	0.15
Veterinary expense (Kshs)	0.18^{c}	0.58^{a}	0.40^{b}	0.40
Paid labour cost (Kshs)	0.31^{a}	0.42^{a}	0.29^{a}	0.35
Unpaid labour cost (Kshs)	0.47^{b}	1.85^{a}	0.11^{c}	1.00
All labour cost (Kshs)	0.78^{b}	2.27^{a}	0.40^{c}	1.35
Purchased feeds (Kg)	0.06^{b}	0.09^{a}	0.03^{c}	0.06
On-farm feeds (Kg)	0.003^{c}	0.14^{a}	0.04^{b}	0.07
All feeds (Kg)	0.06^{b}	0.22^{a}	0.07^{b}	0.14
Other input costs (Kshs)	0.17^{b}	0.17^{b}	0.38^{a}	0.21

[a,b,c] Differences in the superscripts denote significant differences (at 10 percent level or better) across the production systems.

6.3.2 Production parameter estimates

In this section, production function parameters are estimated using the Cobb-Douglas model, without the inefficiency factors (*Z-variables*) to allow possible use of group frontier parameters in the estimation of a metafrontier[16]. Thus, the model is initially estimated as:

$$\ln Q_{n(k)} = \beta_{0(k)} + \sum_{i=1}^{4} \beta_{i(k)} \ln X_{ni(k)} + v_{n(k)} - u_{n(k)} \qquad (44)$$

[16] Inefficiency effects are estimated and discussed in section 6.5.

where $Q_{n(k)}$ is the annual value of beef cattle output;

X_{ni} represents a vector of inputs where X_{n1} is the beef herd size, X_{n2} is feed equivalent and X_{n3} is the cost of veterinary services, while X_{n4} is the *Divisia* index;

v represents statistical noise, and u denotes technical inefficiency.

Various hypotheses are tested to establish the model fit (Table 7). The null hypothesis on poolability of the group frontiers is rejected, suggesting that there are significant differences in the input parameters, TE scores and random variations across the three production systems. This implies that differences exist in the production technology and environment, which justifies estimation of a metafrontier (Battese and Rao, 2002; Battese *et al.*, 2004). Generally, the most dominant technologies in the sample of Kenyan beef cattle farmers include the use of crossbreed cattle (53 percent of farmers) and controlled breeding method (70 percent of farmers). Agro-pastoralists have the highest proportion of crossbreed/exotic cattle (73 percent) and nomads, the least (32 percent) (see Table 4).

The agro-pastoralists operate multiple enterprises on relatively smaller farms; hence their herds mainly comprise crossbreeds either between indigenous and exotic cattle, or among exotic breeds that they might consider to offer higher returns. In contrast, nomads and ranchers mainly depend on the cattle enterprise and they keep more indigenous or crossbreeds of various indigenous cattle. Further, a relatively higher proportion of agro-pastoralists (80 percent) use controlled cattle breeding method, than both nomads and ranchers (see Table 4).

The gamma (γ) test shows that there is significant technical inefficiency in the pooled frontier and group frontiers for nomads and agro-pastoralists, but less statistically so for ranchers (Table 7).

Table 7: Hypothesis tests on the production structure

Test	Parameter restrictions	*LR* test statistic	Degrees of freedom	χ^2 critical value at 5%	Decision
Poolability of group frontiers	$H_0: \beta_k = \gamma_k = \sigma_k$	32.24	14	23.68	Reject H_0
There is technical efficiency	$H_0: \gamma_{nomads} = 0$	47.31	1	2.71	Reject H_0
	$H_0: \gamma_{agro\text{-}pastoralists} = 0$	10.15	1	2.71	Reject H_0
	$H_0: \gamma_{ranchers} = 0$	1.07	1	2.71	Accept H_0
	$H_0: \gamma_{pooled\ sample} = 0$	46.19	1	2.71	Reject H_0

Notes: The hypothesis test involving a zero restriction on the gamma (γ) parameter follows a mixed chi-squared distribution (i.e., joint test of equality and inequality, since the alternative hypothesis H_1 is stated as $0 \leq \gamma \leq 1$). Following Coelli and Battese (1996), the critical value for this distribution is obtained from the statistical table of Kodde and Palm (1986).

Consistent with assumed producer rationality (Coelli *et al.*, 2005), the estimated input parameters are all positive (Table 8). Thus, as expected for a continuously differentiable production function, the elasticities fulfil the regularity condition of monotonicity (Sauer *et al*., 2006). Monotonicity implies the production frontiers are non-decreasing in inputs (Coelli *et al*., 2005)[17]. The pooled sample results show that an increase in the application of any of the inputs would significantly increase output. Herd size is significant across the three production systems, while improved feeds are only significant in the agro-pastoralist system.

Results suggest that only the ranchers derive significant returns from investment in professional veterinary management. This is to be expected, because most ranchers sell cattle to high premium abattoirs and export-oriented market outlets e.g., the KMC, on contracts (see Table 4), which are usually characterised by stringent requirements on disease-free status. Sales contracts are important in enabling farmers to obtain steady and high income through an assured market, and reduced input and output price risks (MacDonald *et al*., 2004).

[17] In the present study, all marginal physical products (MPP) are positive at the sample mean and for all observations. Further, concavity tests are reported in Table 9.

As noted earlier (see section 5.5.2), labour, depreciation costs and other inputs that were initially found to be individually statistically insignificant were consolidated into the *Divisia* index in order to improve the model fit (Boshrabadi *et al*., 2008). Results show that increased expenditure on the inputs captured by the *Divisia* index, would lead to significantly higher output in both nomadic and ranch systems.

Input parameters that are positive but insignificant offer inconclusive results on whether greater use of inputs would increase output. However, when the objective is to measure efficiency, production frontier estimates are not the primary interest; rather, the overall predictive power of the estimated frontier and measures of TE are considered to be more important (Hallam and Machado, 1996; Wilson *et al*., 1998). Further, Dawson, (1987) notes that provided the production frontier is non-convex in inputs (i.e., non-negative input elasticities, with declining marginal productivities) then inefficiency scores for individual farms are not obscured. Moreover, while the production function estimates are important, Dawson (1990, p. 36) observes that '…*they are only a means by which measures of technical efficiency are calculated, thereby identifying relative producer performance through differential input use*'. Therefore, subsequent discussion of the production parameters is kept brief in this section, while the TE estimates are discussed in detail in section 6.4.

Table 8: Stochastic frontier and metafrontier parameter estimates

Variable	Nomads (n = 110)	Agro-pastoralists (n = 137)	Ranchers (n = 66)	Pooled frontier[18] (n = 313)	Metafrontier[Ж] (n = 313)
Constant (β_0)	8.37***	8.39***	8.02***	7.64***	8.28***
	(0.264)	(0.371)	(0.469)	(0.155)	(0.001)
Beef herd size (β_1)	0.89***	0.89***	0.90***	0.88***	0.90***
	(0.021)	(0.041)	(0.045)	(0.017)	(0.000)
Feed equivalents (β_2)	0.03	0.05**	0.02	0.06***	0.03***
	(0.022)	(0.025)	(0.029)	(0.015)	(0.000)
Veterinary cost (β_3)	0.04	0.02	0.08*	0.08***	0.06***
	(0.026)	(0.029)	(0.041)	(0.016)	(0.000)
Divisia index for other	0.02**	0.01	0.02*	0.02***	0.02
costs (β_4)	(0.009)	(0.013)	(0.014)	(0.007)	(0.013)
σ^2	0.29***	0.17***	0.13***	0.22***	
	(0.046)	(0.032)	(0.048)	(0.024)	
γ	0.99	0.81	0.75	0.88	
Log-likelihood	-15.32	-18.32	-4.64	-63.91	

Notes: statistical significance levels: ***1%; **5%; *10%. Corresponding standard errors are shown in parentheses.

[Ж] standard errors for the metafrontier parameters were computed through bootstrapping (Freedman and Peters, 1984).

The sum of input elasticities in the group frontiers for nomads (0.98) and agro-pastoralists (0.97) are slightly below unity, while for ranchers, and in the pooled frontier, the sum of input elasticities marginally exceed one (1.02 and 1.04, respectively), indicating that on average the constant returns-to-scale (CRS) property of the Cobb-Douglas specification is appropriate. This is further corroborated by the metafrontier estimation, where the sum of input elasticities is 1.01. As expected for a ‘smooth envelope’ curve (Battese and Rao, 2002), the metafrontier parameters are generally similar to average values of the group frontier parameters.

[18] A pooled model with group-specific dummies (for production systems) gave similar results as the separate production system estimation (i.e., ranchers are relatively efficient while nomads and agro-pastoralists are less efficient). For parsimony, the group frontiers are presented rather than a pooled model with dummies.

In addition to monotonicity, another important regularity condition in the production theory, is the fulfilment of concavity test. The concavity test requires that second order derivatives of production parameters (i.e., slope of the marginal physical product, MPP, curve) should be negative. Thus, the marginal productivity for each input must be diminishing at least at the sample means (Sauer *et al.*, 2006). In the present study, both regularity conditions are fulfilled for all inputs (though with an insignificant parameter for the marginal product of herd size), implying that farmers are rational in use of inputs (Table 9).

Table 9: Second-order derivatives of production parameters

Change in variable	Nomads (n = 110)	Agro-pastoralists (n = 137)	Ranchers (n = 66)	Pooled sample (n = 313)
Beef herd size	-0.14ψ	-0.09	-0.19	-0.002
(∂MPP$_1$)	(1.47)	(1.08)	(1.56)	(0.042)
Feed equivalents	-0.29***	-0.29***	-0.37***	-0.18***
(∂MPP$_2$)	(3.17)	(3.45)	(3.15)	(3.18)
Veterinary cost	-0.38***	-0.50***	-0.36***	-0.17***
(∂MPP$_3$)	(4.21)	(6.65)	(3.10)	(3.11)
Divisia index for other	-0.38***	-0.53***	-0.39***	-0.15**
costs (∂MPP$_4$)	(4.24)	(7.18)	(3.42)	(2.64)

Notes: statistical significance levels: ***1%; **5%; *10%. Absolute values of the corresponding t-ratios are shown in parentheses.

Ψ: $\frac{\partial MPP_{X\,i}}{\partial X_i} = \frac{\partial\left(Q\beta_{X\,i} / X_i\right)}{\partial X_i} < 0$, where Q is output, X$_i$ denotes the i^{th} input and β is the corresponding elasticity (Coelli *et al.*, 2005).

The significance of σ^2 (see Table 8) indicates that the models are stochastic (rather than deterministic). Moreover, the values of γ imply that 99 percent, 81 percent, 75 percent and 88 percent of the discrepancies between the observed values of beef output and the frontier output for nomads, agro-pastoralists, ranchers and in the pooled sample, respectively, can be attributed to failures within the farmers' control. Furthermore, as shown in Table 10 (section

6.4), the shortfall of all mean TE scores from 1 confirms the presence of technical inefficiency[19]. This implies that there is scope to improve efficiency in the utilisation of resources.

6.4 Technical efficiency and meta-technology estimates

Estimates of TE scores and MTRs are presented in Table 10. With respect to the estimated pooled frontier, nomads have the lowest mean TE (0.71), with highest standard deviation (SD) of 0.14; while ranchers have the highest mean TE (0.77), with lowest variation (SD = 0.12). Generally, this shows that less-sedentary farmers (nomads) are likely to be less efficient than their sedentary counterparts, perhaps due to various factors including differences in long-term investments such as pasture development (see Table 5). The mean TE across all production systems is estimated to be 0.74. The TE scores measured with respect to production system frontiers exhibit a similar pattern as those measured relative to the pooled frontier. The estimated mean TE across all the production systems in this case is also about 0.74.

The mean MTR in the pooled sample is 0.93, implying that, on average beef farmers in Kenya produce 93 percent of the maximum potential output achievable from the available technology (crossbreed cattle). Further, 98 percent of farmers across the three production systems have MTR estimates below 1, indicating that they use the available technology sub-optimally. Perhaps, this can be partly explained by the view of Diagne (2010) that low rates of adoption or poor use of agricultural technologies in sub-Saharan Africa is largely due to lack of awareness on the technologies and/or how to use them. The average MTR is highest in ranches (0.96) and lowest in the agro-pastoralist system (0.91). Nomads have a mean MTR of 0.94.

[19] Significance of technical inefficiency, however, depends on the gamma tests (see Table 7). Generally, technical inefficiency exists in all the three production systems, but at a less-significant level in the ranches.

Table 10: Technical efficiency and meta-technology ratios

Model		Nomads	Agro-pastoralists	Ranchers	Total
TE w.r.t. the pooled frontier*					
	Mean	0.711[b]	0.749[a]	0.774[a]	0.741
	Min	0.328	0.275	0.442	0.275
	Max	0.972	0.945	0.954	0.972
	SD	0.141	0.133	0.121	0.135
TE w.r.t. production system frontiers*					
	Mean	0.681[b]	0.767[a]	0.792[a]	0.738
	Min	0.302	0.313	0.499	0.302
	Max	0.998	0.936	0.938	0.998
	SD	0.172	0.119	0.101	0.143
TE w.r.t. the metafrontier					
	Mean	0.647[c]	0.696[b]	0.763[a]	0.693
	Min	0.278	0.267	0.481	0.267
	Max	0.943	0.909	0.944	0.944
	SD	0.162	0.112	0.099	0.136
Meta-Technology ratio					
	Mean	0.942[b]	0.907[c]	0.963[a]	0.931
	Min	0.905	0.806	0.892	0.806
	Max	1.000	1.000	1.000	1.000
	SD	0.020	0.044	0.025	0.040

Notes: * these TE scores are only reported for the completeness of analysis. The *caveat* is that they are estimated relative to different technologies (i.e., cattle breeds); hence non-comparable across the groups. Comparisons are based on the metafrontier and meta-technology estimates because these use a common industry-wide technology (crossbreeds) as the reference point.

[a,b,c] Differences in the superscripts denote significant differences (at 10 percent level or better) across the production systems.

The lower MTR for agro-pastoralists and nomads could be explained by their relatively higher use of unpaid labour (mostly family members, who might be lacking specific cattle management skills). Further, the purchased feeds used by agro-pastoralists and nomads could be of low quality due to frequent distortions of feed compositions in the distribution chain (see section 2.6.1 in chapter 2). In contrast, the ranchers employ professional managers.

Ranchers also invest relatively more in capital equipment (see higher depreciation costs in Table 5), which they might use for on-farm feed production and processing (and are likely to be able to control feed quality); hence they have a higher average MTR.

Nomads' relatively higher MTR than agro-pastoralists perhaps can be partly explained by the notion of *catching-up or convergence to best practice* (Rao and Coelli, 1998). This stipulates that, on average, farmers who conventionally operate below the technology frontier might be expected to adopt technologies at a relatively faster rate than those who produce near the frontier. In addition, ranchers and nomads have relatively low variation in MTRs (SD is 0.02 and 0.03), perhaps because both groups keep indigenous breeds or their crosses, while the agro-pastoralists have more crossbreeds of indigenous and exotic cattle. Compared to the indigenous breeds, exotic breeds are generally less adapted to drier conditions where most beef cattle in Kenya are reared. The maximum estimated MTR is 1 in all three production systems, which means that the group frontiers are tangent to the metafrontier (Battese *et al*., 2004); it was found that 2 percent of farmers in the sample (at least one farm from each production system) indeed produce on the metafrontier. This suggests that in order to achieve further productivity gains (for the small proportion of technology-optimal farmers) it is important to provide a relatively better technology (cattle breed). Generally, this might entail provision of a relatively adaptable and affordable cattle breed and possibly promotion of skills-sharing on optimal technology use among Kenyan beef farmers.

As expected, the mean TE estimates relative to the metafrontier are consistently lower than production system frontier estimates. This further confirms that generally there is potential to improve production efficiency, given the existing technologies. Results show that the distribution of metafrontier TE scores follows the same pattern as in the pooled and production system frontiers; nomads have the lowest mean TE (0.65) with largest variation

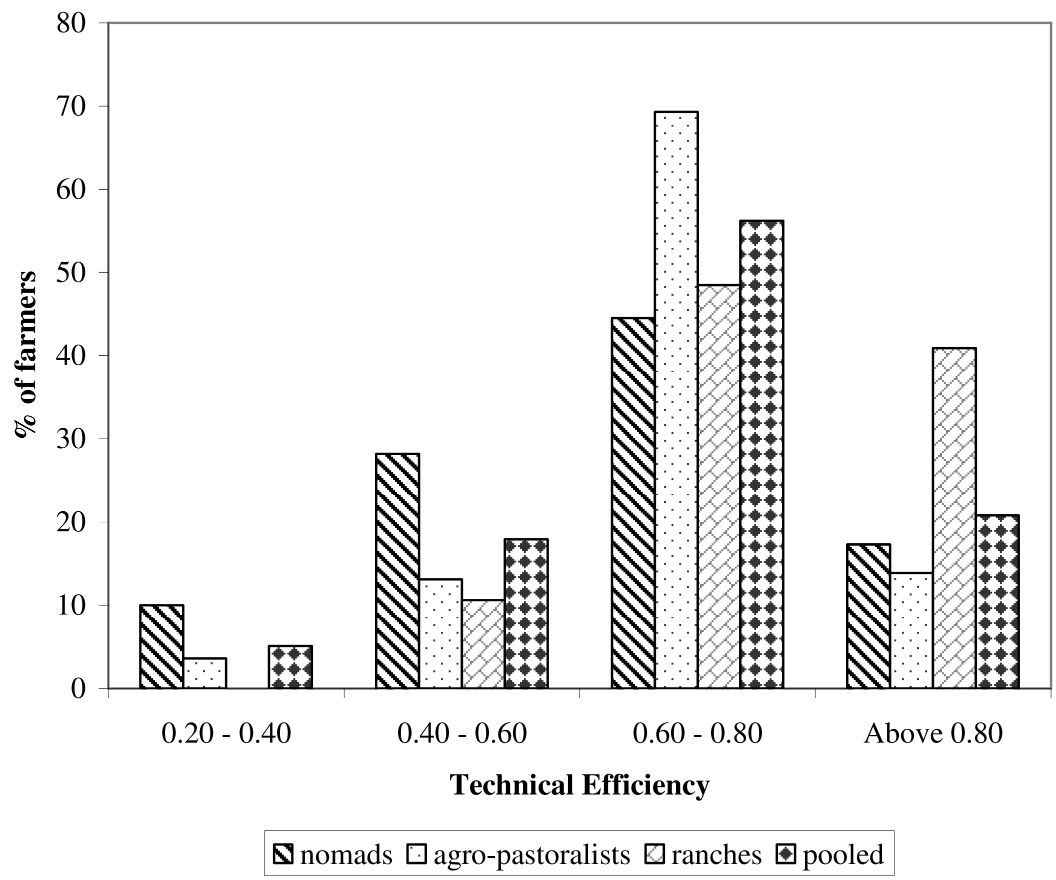
(SD = 0.16), while ranchers have the highest mean (0.76) and smallest variation (SD = 0.10). It is important to note that a relatively larger MTR does not necessarily imply higher TE, considering that other factors (besides technology) in different production systems might influence farmers' ability to achieve the maximum potential output.

The nomads' low TE perhaps suggests that they are largely unable to adjust input levels optimally as a result of limited institutional capacity to provide them with requisite services such as appropriate training or livestock extension. Moreover, the nomads' relatively low average TE could be due to the high proportion of indigenous breeds that nomads keep (often associated with low market value) and their susceptibility to disease risks because of limited access to veterinary advisory services (see Table 4). Furthermore, the nomads might be expected to be less efficient because they are more likely to be prone to large losses (in stock numbers and quality) during severe droughts, due to their less-sedentary nature and low investment in pasture development. For instance, in the year preceding the survey they lost about a quarter of their herd size due to drought (Appendix 8). Agro-pastoralists depend more on crops and other enterprises, and thus invest relatively less in cattle production inputs; hence they might be expected to have low TE. In contrast, the ranchers' high mean efficiency could be associated with generally high investment in cattle production services, use of more skilled managers and better access to market information.

Across the three production systems, the mean TE relative to the metafrontier is estimated to be 0.69, suggesting that policies targeting optimal resource utilisation could improve beef production in Kenya by up to 31 percent of the total potential, given existing technologies and inputs. These results show that, generally, Kenyan beef farmers are less efficient compared to their counterparts in developed economies (albeit under different technologies, production environments and estimation approaches). For instance, the mean TE scores for beef cattle farmers were estimated to be 0.95 in Australia (Fleming *et al*., 2010), 0.78 in Kansas, USA (Featherstone *et al*., 1997), 0.92 in Louisiana, USA (Rakipova *et al*., 2003), 0.84 in Spain (Iraizoz *et al*., 2005), 0.82 in England and Wales (Hadley, 2006), 0.77 in Scotland (Barnes, 2008) and 0.92 in the Amasya region of Turkey (Ceyhan and Hazneci, 2010). However, the estimated average TE of beef cattle farmers in the present study is perhaps more comparable to those of farmers in other enterprises in Kenya, such as maize (TE = 0.71) and potato (TE = 0.67) (Liu and Myers, 2009; Nyagaka *et al*., 2010). Further, a recent study in the agro-pastoral site showed that the average cost efficiency for dairy farmers was 0.76 (Kavoi *et al*., 2010).

The estimated metafrontier TE scores are generally heterogeneous within and across the production systems. For example, a higher proportion of farmers in the nomadic system have TE scores below 0.6, while most agro-pastoralists have scores between 0.6 to 0.8, and a large proportion of ranchers have scores above 0.8 (Figure 15). This further confirms that nomads are the least efficient. Overall, more than half of the farmers have scores between 0.6 to 0.8; the pooled mean TE is also in this range.

Figure 15: Distribution of metafrontier technical efficiencies



Compared to the TE scores, the MTRs seem to be narrowly spread (0.81 to 1.00) (see Table 10). This might imply that, on average, farmers learn and adopt some technologies from their counterparts across the production systems. For instance, about two-thirds of farmers in the pooled sample use controlled breeding, which is one of the main technologies in cattle production. Further, about 60 percent of farmers (nomads and ranchers) keep relatively similar crossbreeds of indigenous cattle. The estimated TE scores, however, are relatively more widely distributed across the production systems (0.27 to 0.94 in the metafrontier) perhaps due to differences in farm characteristics that influence efficiency other than the MTRs. Some of the factors that might influence TE are empirically investigated in the following section.

6.5 Determinants of technical efficiency

Besides estimating TE scores, another key objective of TE analysis is to explain possible sources of inefficiency, commonly referred to in the literature as inefficiency effects (Coelli *et al*., 2005). In this study, possible determinants of TE were investigated by inclusion of various socio-economic and technology-related variables in the estimation. The selection of variables for the inefficiency model started with a test of multicollinearity through computation of variance inflation factors (VIF) for each of the descriptive variables discussed in section 6.2. This involved estimation of 'artificial' ordinary least squares (OLS) regressions between each of the farm characteristics as the 'dependent' variable with the rest as independent variables[20]. Since all the independent variables exhibited $VIF_i<5$, it was concluded that there was no multicollinearity and therefore all these variables were eligible for inclusion in the model estimation (Maddala, 2000).

The next stage involved estimation of a pooled stochastic frontier where all the descriptive variables were included in the *Z-vector* as possible determinants of inefficiency. The model was estimated as shown earlier (see equation 44, section 5.5.2), and is restated here for ease of reference as:

$$\ln Q_{n(k)} = \beta_{0(k)} + \sum_{i=1}^{4} \beta_{i(k)} \ln X_{ni(k)} - Z\delta_{n(k)} + v_{n(k)} \qquad (50)$$

where $Q_{n(k)}$ is the annual value of beef cattle output;

X_{ni} represents a vector of inputs where X_{n1} is the beef herd size, X_{n2} is feed equivalent and X_{n3} is the cost of veterinary services, while X_{n4} is the *Divisia* index;

[20] VIF for each regression is calculated as: $VIF_i = \dfrac{1}{1-R_i^2}$,

where R_i^2 is the R^2 of the artificial regression with the i^{th} independent variable as a 'dependent' variable. The VIFs are shown in Appendix 9. The use of VIFs accounts for joint correlations between a given variable, and many others, in a single equation; and hence can generally be considered as a more robust test for multicollinearity than the alternative partial correlation method.

Z denotes the vector of socio-demographic and other independent variables assumed to influence efficiency; v represents statistical noise and δ is a vector of inefficiency parameters to be estimated.

From this estimation (Equation 50), *Z-variables* that were insignificant and did not improve the overall model fit were dropped. Subsequent re-estimations were undertaken to obtain better results in terms of significance of most parameters estimated. All input parameters had the expected positive sign and were significant (with values similar to those noted earlier in Table 8, section 6.3.2). Therefore, to avoid repetition, subsequent discussion in this section focuses on the inefficiency effects.

A likelihood ratio test showed that there were significant inefficiency effects in the pooled sample and two production systems (agro-pastoralists and nomads)[21]. In a one-step stochastic frontier estimation, the parameter for inefficiency level usually enters the model as the dependent variable in the inefficiency effects component of the model; therefore a negative sign of a variable in the *Z-vector* implies that the corresponding variable would reduce inefficiency (or increase efficiency). On the contrary, a positive *Z-variable* is interpreted as potentially having a negative influence on efficiency (Brummer and Loy, 2000; Coelli *et al*., 2005). In the two-stage Tobit estimation however, conventional interpretation of regression parameters is applicable because the TE measure obtained from the optimisation process in the metafrontier estimation is used as the dependent variable in the subsequent Tobit model

[21] The values of LR statistic calculated as: $-2(L_{wt}-L_{we})$ were 30.64, 21.76 and 63.1 for nomads, agro-pastoralists and pooled sample, respectively. These values are higher than the critical chi-square value of 18.31 at 5 percent level and 10 degrees of freedom, suggesting that there are significant inefficiency effects. L_{we} and L_{wt} are values of the log likelihood functions for models with and without inefficiency effects, respectively. Degrees of freedom equal the difference in the number of parameters estimated in the model with and without inefficiency components, i.e., the restrictions imposed. Consistent with the gamma (γ) test in Table 7, the estimated inefficiency effects for the ranchers sub-sample were found to be insignificant and did not improve the model fit. Therefore, for parsimony, only the pooled stochastic frontier and metafrontier-Tobit models are presented and discussed.

(Chen and Song, 2008). Thus, positive signs of variables in the metafrontier-Tobit model imply that such variables would increase efficiency.

The estimated inefficiency effects from the stochastic frontier and the metafrontier-Tobit models are shown in Table 11. Results from both models show that use of controlled breeding method, access to market contract, presence of farm manager and off-farm income would significantly improve efficiency, while specialisation (higher dependence on beef cattle for income) would reduce efficiency. Farm size, farmer's age and peri-urban location were found to be significant in the pooled stochastic frontier, but not in the metafrontier-Tobit model. The finding on farm size contradicts that of Sharma *et al*. (1999) who showed that large farms were more efficient than small ones, due to relatively lower labour use and feed cost, per unit of output, in the large farms. Perhaps, the unexpected influence of farm size on efficiency might be attributed to lack of long-term investments on land by most Kenyan pastoralists. As a consequence, the fallow land acts as an indirect cost, for example in the form of high opportunity cost of feeds and labour to oversee grazing elsewhere.

Results show that older farmers are likely to be more efficient. Perhaps this can be explained by the suggestion by Rakipova *et al*. (2003) that such farmers are likely to have more experience in farming. Further, peri-urban location was shown to contribute significantly to inefficiency. This is to be expected, although it appears to contradict the view of Stifel and Minten (2008) that remoteness increases inefficiency through limited access to technology and infrastructure. In the present study, however, it is worthwhile to note that main grazing areas and water sources for most cattle farmers are located away from the urban centres.

Table 11: Frontier and Tobit estimates of the determinants of technical efficiency

Variable[22]	Stochastic frontier (n = 313)	Metafrontier-Tobit (n = 313)
Constant (δ_0)	-0.30	0.62***
	(0.407)	(0.031)
Indigenous breed (δ_1)	-0.26	0.01
	(0.178)	(0.016)
Controlled breeding method (δ_2)	-0.65***	0.06***
	(0.256)	(0.018)
Access to market contract (δ_3)	-0.62***	0.04**
	(0.240)	(0.017)
Farm size (δ_4)	0.0006**	-0.00002
	(0.0003)	(0.00002)
Specialisation (δ_5)	0.84***	-0.04**
	(0.281)	(0.016)
Peri-urban location (δ_6)	0.84***	-0.01
	(0.284)	(0.017)
Presence of farm manager (δ_7)	-1.27**	0.05**
	(0.527)	(0.022)
Age of farmer (δ_8)	-0.01*	0.0007
	(0.006)	(0.001)
Off-farm income (δ_9)	-0.92***	0.03*
	(0.367)	(0.017)
Beef herd size (δ_{10})	-	0.003***
		(0.0001)
Income-education interaction (δ_{11})	-	-0.04**
		(0.018)

Notes: statistical significance levels: ***1%; **5%; *10%. Corresponding standard errors are shown in parentheses.

Given the statistical differences in the production systems (for example, see Table 7), the pooled stochastic frontier is considered inappropriate for policy application; hence the

[22] Regional dummies (for study sites) were found to be highly correlated with features of the production systems, and did not improve the model fit; inclusion of the dummies leads to statistical insignificance of most parameters. Hence, farm characteristics (instead of the regional dummies) are included in the estimation because these are considered to be relatively amenable to policy action.

subsequent discussion focuses on variables that are significant in the metafrontier-Tobit estimation. Controlled breeding might be expected to increase efficiency by improving genetic quality, enhancing adaptation of cattle to environmental conditions, and ensuring optimal stocking (Wollny, 2003). Further, the finding on controlled breeding conforms to that of Kavoi *et al*. (2010) who noted that given proper management, planned crossbreeding of exotic and indigenous cattle can improve potential for higher output in relatively dry areas. As expected, results show that use of market contracts significantly improves TE. This is consistent with the view of MacDonald *et al*. (2004) that sales contracts are important in enabling farmers to obtain steady and increased income through an assured market, and reduced input and output price risks. Well-functioning contractual arrangements might also provide improved access to better inputs and more efficient production methods (Oluoch-Kosura, 2010).

Moreover, a manager with appropriate managerial capacity is considered to be a useful asset in the organisation of inputs and overall decision making in the farm (see Nuthall, 2009 for details). Therefore, availability of a professional farm manager might be expected, as shown in this study, to enhance co-ordination of farm operations and ensure better utilisation of resources. On the contrary, lack of proper management might lead to accumulation of less productive resources and less intensive use of the resources, consequently resulting in lower efficiency (Meon and Weill, 2005).

The significance of off-farm income suggests that, as noted by Alene *et al*. (2008), there might be considerable re-investment of such earnings in various farm operations by some cattle keepers in Kenya. The finding on specialisation seems to contradict the suggestion by Rakipova *et al*. (2003) that farmers who depend heavily on cattle production for their livelihoods might be more efficient. However, this result conforms to those of Hallam and

Machado (1996), Featherstone *et al*. (1997), Iraizoz *et al*. (2005) and Hadley (2006), which showed that specialised farmers were relatively less efficient due to lack of flexibility to adapt to changes in market and policy environments. Further, it is worthwhile to note that, generally, beef cattle farmers in Kenya (except ranchers) invest little on requisite capital equipment that would improve efficiency (see depreciation costs in Table 5). Moreover, nearly half of the farmers who depend more on cattle than other enterprises in east Africa (especially nomadic pastoralists) are relatively less commercialised, partly due to cultural rigidities. In addition, the pastoralists usually incur considerable disease- and drought-related losses, but have limited access to alternative economic activities for risk management (Davies and Bennett, 2007; Thornton *et al*., 2007). Therefore, it would be reasonable to expect their efficiency levels to be relatively low.

Compared to the stochastic frontier, the metafrontier-Tobit model offers an improvement in the ability to explain TE; two additional variables, i.e., beef herd size and an interaction term (for education and income) are found to be significant. Beef herd size was shown to have a positive effect on efficiency. This implies that economies of scale is important in improving beef cattle farm efficiency (Featherstone *et al*., 1997). There is a general expectation in the literature that education of a household head or main decision maker in the farm should contribute to improved efficiency. More so, the returns to formal education are considered to be higher in modernised agricultural systems, where most operations are knowledge-based, than in traditional systems (Phillips, 1994).

However, in the present study, income and formal education did not individually improve the model fit; hence an interaction variable was included in the model to possibly capture their joint influence on TE[23]. The results show that farmers with formal education and higher

[23] Only a quarter of the farmers sampled have formal education at secondary level and above, and monthly income of at least Kshs 20,000.

income are relatively less efficient. Perhaps this suggests that such farmers (especially the agro-pastoralists) are likely to invest more in, and/or pay greater attention to, 'highly profitable' enterprises other than beef cattle production. Indeed, cross tabulations of the survey data show that 52 percent of cattle farmers with formal education and higher income also keep shoats (sheep and goats). Shoats might be considered as substitutes to cattle; this suggests that some farmers could be shifting resources away from, and hence lowering efficiency in, beef cattle enterprises. Generally, rearing of shoats is often regarded as an important alternative to cattle keeping in pastoral areas, because the shoats are more resilient to droughts, have faster reproduction rates (allowing quick herd replacement) and can be easily sold to reduce losses in severe droughts (Lebbie, 2004; Huho *et al.*, 2011)[24]. Additionally, low efficiency despite possession of formal education and high income, might be partly explained by the observation that some nomads in Kenya derive considerable income from sale of livestock and part of their land to rental developers, but spend a greater share of it on consumption (e.g., food purchases), as opposed to investment on productive activities (Lesorogol, 2008).

Moreover, weak linkage between the existing formal training systems and local farmers' information needs is often considered to contribute to inappropriate and/or low use of inputs and technologies in sub-Saharan Africa (Diagne, 2010; Oluoch-Kosura, 2010); hence low efficiency. Generally, this appears consistent with the 'traditional vs. modernised system' hypothesis suggested by Phillips (1994); inability to adapt formal skills to local conditions in traditional systems results in less than optimal returns from education. Alam *et al.* (2011) also found a negative significant influence of formal education on TE, while Wadud and White

[24] As noted earlier (see section 2.6.3 in chapter 2) the relatively educated and wealthier farmers in Kenya are likely to have considerable influence on some extension programmes. It is posited that they might use such influence, for example, in favour of activities that focus on shoats than cattle, and this could perhaps explain their low efficiency in beef cattle enterprises.

(2000) found a negative, but insignificant influence, in developing country contexts[25]. Further, a producer's hands-on experience (though insignificant in this study) would generally be expected to have a relatively higher positive effect on TE than formal education (Ortega *et al*., 2004).

6.6 Summary

The sample characteristics are described and a summary of production inputs presented in this chapter. In addition, various hypotheses are tested on the production structure and regularity conditions. Further, results on MTR and TE estimates have been discussed. Generally, the average MTR was estimated to be 0.93, while the mean TE is 0.69. Ranchers were found to have relatively higher MTR and TE estimates, on average, than nomads and agro-pastoralists.

The main factors that were found to contribute positively to efficiency include: controlled cattle breeding method, access to market contract, availability of farm manager, off-farm income, herd size and farmer's age. On the contrary, farm size, total household income and formal education did not have a favourable influence on efficiency. These findings may have important implications on policies aimed at improving beef production efficiency.

Results on farmer preferences for DFZs are discussed in the following chapter.

[25] In the case of Alam *et al*. (2011), low efficiency by educated farmers in Bangladesh was attributed to their tendency to practise less professional farming because agriculture was considered to be relatively less rewarding than other economic sectors.

Chapter Seven

7. Farmer Preferences for Disease Free Zones

7.1 Introduction

This chapter presents a discussion of results on farmer preferences for Disease Free Zones (DFZs). These results are based on the random parameter logit (RPL) model (see section 4.4.3 and 5.7) and address the following specific objectives of the study:

i. to assess farmers' willingness to comply with requirements in DFZs;

ii. to estimate the possible influence of technical efficiency (TE) levels on farmers' willingness to comply with requirements in DFZs.

Farmers' preferences for DFZs are investigated in three main cattle production systems in Kenya: nomadic pastoralism, agro-pastoralism and ranches. A high proportion of farmers in each of the three production systems experience disease-related cattle losses; about three-quarters for nomads and ranchers and half for agro-pastoralists (Table 12). As a consequence, a DFZ may be a beneficial intervention. In addition, it might be expected that the high disease incidence in nomadic systems (Maloo *et al*., 2001), and the greater losses incurred by both nomads and ranchers from diseases, would lead to higher preference for DFZs by these two groups[26].

[26] For ease of reference, some of the farmer characteristics provided earlier in Table 4 are shown again in Table 12.

Table 12: Farmer characteristics from the survey

Variable	Nomads (n = 110)	Agro-pastoralists (n = 137)	Ranchers (n = 66)	Pooled sample (n = 313)
Loss of cattle from diseases (% of farmers affected in the past year)	74.5[a]	49.6[b]	72.7[a]	63.3
Access to livestock extension services in the past year (% of farmers)	49.1[b]	35.8[c]	77.3[a]	49.2
Access to veterinary advisory services in the past year (% of farmers)	50.0[b]	51.8[b]	87.9[a]	58.8
Percentage of farmers who derive more than half of income from cattle	78.2[b]	36.5[c]	93.9[a]	63.3

[a,b,c] Different letters denote significant differences (at 10 percent level or better) in variables across the production systems in a descending order of magnitude.

The RPL estimates of preference parameters for DFZ attributes are presented in section 7.2, while the analytical link between TE and preference for DFZs is subsequently investigated in section 7.3.

7.2 Random parameter estimates of preferences for disease free zones

The variables used in the DFZ analysis and their coding are shown in Table 13. A likelihood ratio test shows that parameters are not equal across production systems[27]. The utility parameters for all DFZ attributes were entered as random variables assuming a normal distribution, except the cost attribute which was specified as fixed so as to facilitate estimation

[27] The LR statistic is calculated as -2{*L*(pooled) – (*L*1+*L*2+*L*3)} where L(pooled) is the value of the log likelihood function for the pooled sample, while L1, L2 and L3 are the values of the log likelihood for the sub-samples (nomads, agro-pastoralists and ranchers, respectively). The LR statistic is distributed chi-square with degrees of freedom equal to the number of parameters estimated. The test strongly rejects the null hypothesis that the parameters are equal across the three production systems, with a LR statistic of 57.34 compared to the chi-square critical value of 18.48 at 1 percent level and 7 degrees of freedom.

of the distribution of WTP, by eliminating the risk of obtaining extreme negative and positive trade-off values (Revelt and Train, 1998).

Generally, there are other distributions that could be used to represent the random parameters, e.g., a lognormal distribution might be assumed when a coefficient is known to have the same sign for all individuals in the sample. Further, triangular distributions can be used to restrict the range of parameter values to accord with choice behavioural expectations (see for example, Campbell *et al*., 2009). Uniform distributions with (0, 1) bounds can also be used when attributes have same levels and are expressed as dummy variables. However, all distributions have a limitation in the sign of parameters and/or size of tail (s) (for details, see Hensher and Greene, 2003). Further, Train (2003, p. 142), suggests that '…*the researcher is free to specify a distribution that satisfies his expectations about behaviour in his own application*'.

Table 13: Description of variables used in the choice analysis

Variable	Description
TRAIN	Training is provided (1 = Yes; 0 otherwise)
MKI	Market information is provided (1 = Yes; 0 otherwise)
MKIC	Market information is provided and sales contract is guaranteed (1 = Yes; 0 otherwise)
COMPEN	Compensation (10%, 25% or 50%)
LABC	Label cattle only (1 = Yes; 0 otherwise)
LABCO	Label cattle with owner's identity (1 = Yes; 0 otherwise)
COST	Annual membership fee per animal in Kshs. (150, 300 or 450)*

* On average, 75 Kenyan shillings (Kshs) were equivalent to USD$1 at the time of the survey.

Considering that a DFZ is an intervention to mitigate disease losses that cattle farmers experience in Kenya, it is reasonable to expect that on average, some of them would have a positive preference for the DFZ attributes; hence a normal distribution is assumed for non-price attributes. The normal distribution is the most popular one in the literature[28]. Further, following conventional practice in most CE applications, the present study focused on the estimation of average population parameters to explain heterogeneity in preferences for the DFZ attributes[29].

Results of the RPL models for the three production systems and the pooled sample are reported in Table 14. Farmers prefer training on pasture development, monitoring and reporting of cattle diseases. This result may capture farmers' lack of satisfaction with the current livestock extension service provision systems and also corroborates the suggestion by Irungu *et al.* (2006) that livestock farmers prefer community-based animal health workers because of a high proportion of poorly trained veterinary officers in remote areas of Kenya.

As expected, preferences for the market support attributes are fully consistent with the choice axiom of transitivity; market information and contract is preferred to market information only or to no market support. The estimated coefficient for compensation is also positive, as expected, and significant. There is a higher preference for labelling cattle without, rather than with, the owner's identity. This might be due to farmers' fear of penalties (e.g., fines) that are normally imposed on those who practise open grazing and encroach on private or public protected farms. However, as noted by Schulz and Tonsor (2010), acceptance of a complete system of cattle labelling by most farmers would be useful for verification of animal health, as well as for market access purposes. The parameter estimate for farmers' annual membership fee (COST) is significant with the expected negative sign, which permits computation of trade-offs between each attribute and money.

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[28] Empirical applications of other distributions, including analysis of spatial variations in WTP can be found for example, in Hensher and Greene (2003) and Campbell *et al*. (2008a & 2009).

[29] Some studies that primarily focus on methodological development have explored the use of individual-specific parameters to investigate preference heterogeneity. For details, the reader is referred to, for instance, Huber and Train, (2001), Hensher and Greene, (2003), Louviere *et al*. (2008), and Campbell *et al*. (2008a & 2009).

Table 14: Random parameter logit estimates for DFZ attributes

Variable[30]	Coefficient (t-ratio)			
	Nomads	Agro-pastoralists	Ranchers	Pooled sample
TRAIN	4.85 (5.76)***	6.67 (5.47)***	5.11 (3.97)***	4.36 (9.69)***
MKI	3.11 (4.64)***	4.38 (5.34)***	3.27 (3.09)***	3.01 (7.83)***
MKIC	3.78 (4.90)***	5.03 (5.18)***	5.31 (3.73)***	3.50 (8.76)***
COMPEN	0.06 (3.93)***	0.06 (3.53)***	0.06 (3.05)***	0.05 (6.28)***
LABC	2.27 (2.77)***	0.46 (0.88)	1.27 (1.44)	1.17 (3.67)***
LABCO	1.43 (3.01)***	0.32 (0.66)	2.39 (3.17)***	0.98 (4.25)***
COST	-0.004 (3.27)***	-0.011 (5.14)***	-0.005 (2.91)***	-0.005 (7.21)***
Standard deviations of parameter distributions (t-ratio)				
sdTRAIN	2.58 (4.23)***	3.02 (4.02)***	2.44 (2.74)***	2.15 (7.21)***
sdMKI	0.40 (0.45)	3.13 (3.46)***	1.98 (2.19)**	1.35 (2.79)***
sdMKIC	1.52 (1.95)*	2.13 (2.86)***	2.39 (2.78)***	1.48 (3.85)***
sdCOMPEN	0.04 (2.51)**	0.03 (1.79)*	0.03 (1.05)	0.04 (3.32)***
sdLABC	0.12 (0.10)	0.31 (0.46)	0.23 (0.21)	0.17 (0.70)
sdLABCO	1.00 (1.34)	1.20 (1.63)	0.48 (0.64)	0.57 (0.18)
Log-likelihood	-179.99	-253.65	-115.12	-577.43
Adjusted pseudo-R^2	0.40	0.36	0.35	0.35
n (respondents)	110	137	66	313
n (choices)	440	548	264	1,252

Notes: statistical significance levels: ***1%; **5%; *10%. Absolute values of the corresponding t-ratios are shown in parentheses.

The estimated models for the separate production systems, as well as the pooled sample, all exhibit good explanatory power (pseudo-R^2 values between 35 percent and 40 percent). All the attribute coefficients (except labelling cattle with or without owner's identity) have highly significant standard deviations, implying that there are, indeed, heterogeneous preferences for

[30] The possibility of including socio-demographic variables or their interactions with the DFZ attributes was explored, but this did not improve the model fit.

these attributes. The estimated means and standard deviations of the normally distributed coefficients also provide information on the probability distribution of the population according to the proportion that places a positive value on a particular attribute and the proportion that places a negative value on it (Train, 2003).

Generally, over 90 percent of farmers in the three systems had a positive preference for each of the attributes included in the CE; except 39 percent of agro-pastoralists who expressed a negative preference for labelling of cattle, with identity (Table 15). Somewhat unexpected is a small proportion of farmers (around 9 percent) that have a negative preference for compensation, but this may be an artefact of the normal distribution. A majority of farmers clearly preferred the DFZ attributes included in the CE, suggesting that collectively the attributes used in the CE design fully captured respondents' preference range for DFZs.

Table 15: Positive preferences for DFZ features

Attribute	% of farmers			
	Nomads	Agro-pastoralists	Ranchers	Pooled sample
Training	97.0	98.6	98.2	97.9
Market information only	100.0	92.0	95.0	98.7
Market information and contract	99.4	99.1	98.7	99.1
Compensation	90.2	99.0	98.8	90.7
Label cattle only	100.0	92.9	100.0	100.0
Label cattle with owner's identity	92.3	60.5	100.0	95.7

The WTP results confirm that farmers have heterogeneous preferences for all the DFZ attributes (Table 16). In the pooled sample, farmers are willing to pay between Kshs 733 and Kshs 900 per animal annually for inclusion of training in a DFZ; Kshs 491 to Kshs 638 for provision of market information only; Kshs 580 to Kshs 731 for provision of market information and sales contract guarantee; Kshs 8 to Kshs 11 for compensation per one percent of the value of cattle lost due to a disease occurrence; Kshs 159 to Kshs 279 for labelling of cattle without showing owner's identity; and Kshs 140 to Kshs 229 with owner's identity[31]. On the basis of the WTP values, farmers' ranking of preferences is: training; market information and contract; market information only; labelling cattle only; and labelling cattle with owner's identity[32].

Table 16: Marginal WTP estimates for DFZ attributes (Kshs)

Variable	Marginal WTP (95% confidence interval)			
	Nomads	Agro-pastoralists	Ranchers	Pooled sample
TRAIN	1,273.2	596.6	1,038.4	816.3
	(938.0 – 1,608.0)$^{\xi}$	(532.7 – 660.4)	(768.5 – 1,308.4)	(732.7 – 899.9)
MKI	815.3	391.8	660.6	564.5
	(577.0 – 1,053.5)	(331.9 – 451.7)	(435.7 – 885.5)	(491.2 – 637.8)
MKIC	994.4	450.0	1,072.7	655.3
	(715.0 – 1,273.7)	(395.4 – 504.6)	(773.9 – 1,371.4)	(579.6 – 731.0)
COMPEN	15.0	5.6	12.3	9.1
	(10.3 – 19.7)	(4.4 – 6.8)	(8.6 – 16.0)	(7.7 – 10.5)
LABC	595.0	41.2 $^{\Psi}$	257.2	218.9
	(363.5 – 826.5)	(-5.1 – 87.4)	(73.6 – 440.8)	(159.2 – 278.6)
LABCO	376.4	28.7 $^{\Psi}$	481.9	184.1
	(239.7 – 513.0)	(-15.6 – 73.1)	(316.0 – 647.9)	(139.5 – 228.7)

Notes: $^{\Psi}$ not significant at 5% level.

$^{\xi}$ confidence intervals have been calculated from standard errors estimated using the delta method in LIMDEP version 9.0/NLOGIT version 4.0 (Greene, 2007).

On average, nomads and ranchers are willing to pay relatively more than the agro-pastoralists for *training*, to enable them to implement some of the requirements of the DFZ, such as

[31] The estimated WTP values for all the DFZ attributes seem reasonable, given that the average prices of cattle in the study sites at the time of survey were between Kshs 10,000 and Kshs 30,000. Cattle prices in Kenya generally vary depending on the animal body condition, breed, type of market and purpose of buying, amongst other factors (Randeny *et al*., 2006).

[32] Compensation is not included in the preference ranking because it was entered in the model as a percentage, whereas the other variables were binary.

monitoring and reporting of disease occurrence. This may reflect differences in current access to livestock extension and veterinary advisory services (see Table 12) and, for the nomads, limited opportunities of acquiring cattle production skills in formal livestock-specific training schemes. However, all three farmer types exhibit preference for training in the DFZ, which might suggest that the existing formal education and livestock extension programmes are inadequate. As expected, the inclusion of *contract guarantee* in *market support* raises the WTP across all production systems. The agro-pastoralists' lower WTP for *compensation* may indicate that, in the absence of compensation, they would still be able to achieve reasonable returns from their more diversified enterprises, compared to the nomads and ranchers. This is consistent with the suggestion by Fraser (2003) that, given alternative investment options, farmers would show low preference for compensation programmes that they might consider being less cost-effective in the use of available resources. Thus, they would choose to invest more on enterprises that they perceive to offer high output at lower cost, with a possibility of selling in better markets.

The results also show that agro-pastoralists do *not* prefer *labelling* of cattle with or without the owner's identity. This could be associated with their small farms, hence a preference to continue practising open grazing (while concealing identity to avoid penalties in case of encroachment/trespass). Similarly, the nomads would be willing to pay more for labelling cattle only than for labelling with owner's identity, perhaps implying that they, too, prefer some degree of open grazing and anonymity. In order to prevent infection of cattle in a DFZ and potential collapse of the programme, it would be necessary to ensure that farmers in these two production systems adopt controlled grazing. Ranchers would be willing to pay more for labelling cattle with their identities than without. This reflects the current situation where most ranchers already practice some form of cattle labelling and confined grazing, and suggests that they would fully support traceability of cattle as a key DFZ attribute.

The implementation of a DFZ would be expected to involve a combination of attributes. To illustrate how farmers in different production systems might respond to different combinations, compensating surplus (CS) estimates (see equation 48 in section 5.7 chapter 5) for six possible policy scenarios are derived (Table 17). The CS estimates for all the scenarios considered are positive, suggesting that generally farmers prefer a change from the baseline of no DFZ. However, the CS estimates are significantly different across the three production systems for scenarios 1, 2, 3 and 5, with nomads having the highest CS and agro-pastoralists the lowest. The CS estimates for scenarios 4 and 6 are not statistically different between nomads and ranchers, but higher than for the agro-pastoralists.

Generally, nomads and ranchers have higher and similar CS across all DFZ scenarios, while for agro-pastoralists the estimates are much lower. Given that nomads and ranchers derive most of their income from livestock (see Table 12), it might be expected that they are willing to invest more in DFZs. Also, considering that nomads usually practise open grazing in the wildlife migratory corridor in Kajiado, they might possibly incur more losses from cattle diseases spread by wild animals. Therefore, the nomads would be expected to have relatively higher preference for DFZs. This is consistent with the observation by Bennett and Willis (2007) that households in wildlife-infested areas prefer cattle disease control measures. Scenario 4 is the most preferred by farmers in all three production systems. Scenario 2 is the least preferred by the nomads, and scenario 3 the least preferred by both the agro-pastoralists and ranchers.

Table 17: Attribute levels and compensating surplus for DFZ policy scenarios (in Kshs)

Scenario	Attribute						Compensating surplus in the production systems			
	Training	Market information	Market information and contract	Compensation	Labelling without owner's identity	Labelling with owner's identity	Nomads	Agro-pastoralists	Ranchers	Pooled sample
1	✓	✓		10%	✓		2,833.3[a]	1,085.7[c]	2,079.0[b]	1,691.0
							(737.8)	(111.3)	(562.0)	(175.7)
2		✓		50%		✓	1,941.1[a]	701.5[c]	1,756.6[b]	1,204.9
							(512.9)	(79.1)	(463.0)	(128.1)
3			✓	25%	✓		1,964.1[a]	631.6[c]	1,636.9[b]	1,102.3
							(530.7)	(72.0)	(437.0)	(121.7)
4	✓		✓	25%		✓	3,018.6[a]	1,215.8[b]	2,900.1[a]	1,883.9
							(775.4)	(117.9)	(745.7)	(185.3)
5	✓	✓		10%		✓	2,614.7[a]	1,073.3[c]	2,303.8[b]	1,656.2
							(674.8)	(110.9)	(607.0)	(167.5)
6	✓		✓	10%		✓	2,793.8[a]	1,131.5[b]	2,715.8[a]	1,747.0
							(726.5)	(115.3)	(711.2)	(176.0)

Notes: ✓ indicates the attribute is present in a scenario at the non-zero level.

[a,b,c] Differences in the superscripts denote significant differences, at 5 percent level or better, in CS across the production systems. Standard errors are in parentheses. All CS estimates are significant at 1 percent level.

Across and within all three production systems, the CS estimates are higher where the scenarios have an element of training (scenarios 1, 4, 5 and 6). This is consistent with the low levels of formal education and relatively limited access to livestock extension services noted earlier, and further underlines the importance of incorporating relevant training in a DFZ policy design. In addition, scenarios 4 and 6, with larger CS, include market information and contract, which confirms the high preference noted earlier for this attribute (see Table 16).

Selection of a DFZ scenario for implementation will depend on relative resource availability and the priorities of other key stakeholders (e.g., the government). Assuming the unlikely situation of resource abundance and convergence of stakeholder interests towards a 'one size fits all' policy, scenario 4 would appear a good choice. Alternatively, the CS estimates could be used together with other practical considerations, e.g. existing institutional capacity and regulatory framework, in choosing a scenario to implement. It might also be worthwhile to consider a phased implementation, starting with the most preferred features and/or production systems where the CS is highest.

As noted earlier (see section 5.6.4 in chapter 5), the DFZ implementation in any area would likely be administered through a local management committee comprising farmers' representatives and other stakeholders. Generally, it should be expected that the significant disease-related losses incurred by farmers (see Table 12) would imply considerable uncertainty on their incomes. It is posited that this might enhance the farmers' commitment to comply with DFZ requirements (Fraser, 2002). Following suggestions by Fraser (2004) it is also envisaged that moral hazard would be adequately managed by appropriately targeting the penalties and monitoring aspects, discussed earlier (see section 5.6.2 in chapter 5), on members and non-members of a DFZ.

This study sought to estimate farmers' TE (see chapter 6) and to investigate how the TE influences preferences for DFZ attributes, discussed in this section. Results on the possible influence of TE on farmer preferences for DFZs are presented in the following section.

7.3 Technical efficiency and preferences for disease free zones

In order to investigate the possible influence of TE on preferences for DFZ attributes, the RPL model was re-estimated as follows. First, the TE estimates from the metafrontier were included as an interaction variable in a pooled RPL model. The interaction terms created between TE scores and DFZ attributes, to investigate preference heterogeneity included training and efficiency (TRAIN.TE), market information and efficiency (MKI.TE), market information, contract and efficiency (MKIC.TE), compensation and efficiency (COMPEN.TE), labelling cattle without owners' identity, and efficiency (LABC.TE), labelling cattle with owners' identity, and efficiency (LABCO.TE) and annual membership fee and efficiency (COST.TE) (Table 18).

Further, the sample was divided into two groups; farmers with TE scores below and those above the mean TE score of 0.69. The RPL model was then separately estimated for each TE group to allow comparison of preferences for DFZ attributes between them (Table 19). Estimates of WTP for DFZ attributes were then derived for farmers in each of the TE groups, following the approaches discussed earlier.

Generally, the findings are consistent with earlier observations (see Table 14); all the parameter estimates for the DFZ attributes have expected signs and most are significant (Table 18 and 19). However, it is noticeable that the parameter for labelling cattle, without owner's identity is insignificant for farmers in the pooled sample and in the lower TE group; perhaps these might be mainly agro-pastoralists as shown earlier in Table 14. The pooled sample results show that as the TE increases, there is a significant negative shift in the mean preference parameters for training, market information and labelling cattle with owner's identity (see the middle part of Table 18).

Table 18: Influence of technical efficiency on preferences for DFZ attributes

Variable	Coefficient	t-ratio
TRAIN	7.98***	4.87
MKI	2.83*	1.78
MKIC	7.95***	4.11
COMPEN	0.07**	2.10
LABC	0.42	0.23
LABCO	4.07***	2.96
COST	-0.009**	2.44
Heterogeneity in mean parameters with technical efficiency		
TRAIN.TE	-4.81**	2.38
MKI.TE	0.49	0.22
MKIC.TE	-6.06**	2.43
COMPEN.TE	-0.03	0.63
LABC.TE	1.06	0.44
LABCO.TE	-4.36**	2.29
COST.TE	0.04	0.92
Standard deviations of parameter distributions		
sdTRAIN	2.21***	7.09
sdMKI	1.51***	3.20
sdMKIC	1.46***	3.77
sdCOMPEN	0.04***	3.19
sdLABC	0.13	0.27
sdLABCO	0.63	1.45
Log-likelihood	-570.38	
Adjusted pseudo-R^2	0.36	
n (respondents)	313	
n (choices)	1,252	

Notes: statistical significance levels: ***1%; **5%; *10%. The t-ratios are reported in absolute values.

In addition, most of the attribute coefficients have highly significant standard deviations, confirming that preferences for these attributes are indeed heterogeneous. The estimated models generally have good explanatory power, with pseudo-R^2 of 0.35 - 0.37.

Table 19: Parameter estimates for DFZ attributes in technical efficiency groups

Variable	Coefficient (t-ratio)	
	Below average TE group	Above average TE group
TRAIN	5.03 (5.70)***	4.84 (6.34)***
MKI	2.74 (4.75)***	3.88 (5.12)***
MKIC	4.30 (5.33)***	3.84 (5.49)***
COMPEN	0.05 (4.38)***	0.06 (4.18)***
LABC	0.73 (1.46)	1.50 (2.75)***
LABCO	1.33 (3.43)***	0.68 (1.89)*
COST	-0.006 (4.37)***	-0.006 (5.09)***
Standard deviations of parameter distributions (*t-ratio*)		
sdTRAIN	2.29 (4.71)***	2.81 (4.95)***
sdMKI	1.62 (2.34)**	2.06 (2.55)***
sdMKIC	1.21 (2.56)***	1.97 (4.24)***
sdCOMPEN	0.3 (1.52)	0.05 (3.05)***
sdLABC	0.13 (0.21)	0.70 (0.89)
sdLABCO	0.90 (1.52)	0.15 (0.28)
Log-likelihood	-241.87	-327.09
Adjusted pseudo-R^2	0.37	0.35
n (respondents)	138	175
n (choices)	552	700

Notes: statistical significance levels: ***1%; **5%; *10%. Absolute values of the corresponding t-ratios are shown in parentheses.

A summary of some farmer characteristics based on TE categorisation is shown in Table 20. Generally, in the above average TE group, a higher proportion of farmers had access to livestock extension and market information, sold on contract, and employed a manager. Consistent with an earlier observation (see Figure 15), there is a significantly higher proportion of nomadic pastoralists in the below average TE group and a significantly higher proportion of ranchers in the above average TE group.

Table 20: Farmer characteristics in different technical efficiency groups

Variable	% of farmers in each group	
	Below average TE (n = 138)	Above average TE (n = 175)
Access to livestock extension services in the past year	41.3[b]	55.4[a]
Access to market information in the past year	21.7[b]	40.6[a]
Sale of cattle on contract in the past year	17.4[b]	36.0[a]
Farms with professional manager	11.6[b]	30.3[a]
Production system:		
Nomadic pastoralists	48.6[a]	24.6[b]
Agro-pastoralists	42.8[a]	44.6[a]
Ranchers	8.6[b]	30.8[a]

Notes: [a,b] Differences in these superscripts denote significant differences (at 10 percent level or better) between the two groups of farmers.

The WTP estimates for DFZ attributes by farmers in the different TE groups are shown in Table 21. Farmers with less than average TE have a higher preference for training, and market information and contract, compared to those with above average TE. This may be due to the more efficient farmers having better access to extension services and sales contract opportunities (see Table 20). The relatively more efficient farmers also have a higher preference for labelling cattle without owner's identity, perhaps to conceal some relatively sub-optimal farming methods e.g., uncontrolled cattle grazing by nomads and agro-pastoralists in this TE group.

Farmers with a larger TE show a higher preference for compensation; almost one third of these are ranchers. As noted earlier, the ranchers have larger herds and depend more on cattle for livelihood sustenance, hence they might be expected to seek better compensation. Further, the relatively efficient farmers have a higher preference to receive market information without rather than with contract.

Table 21: WTP estimates for DFZ attributes by different technical efficiency groups

Variable	WTP (t-ratio)	
	Below average TE group (n = 138)	Above average TE group (n = 175)
TRAIN	858.6 (6.9)***	750.5 (7.9)***
MKI	467.9 (5.0)***	601.5 (6.2)***
MKIC	734.6 (6.3)***	595.1 (6.7)***
COMPEN	8.3 (4.7)***	9.1 (5.1)***
LABC	123.9 (1.4)	232.8 (2.9)***
LABCO	227.6 (3.6)***	105.1 (1.8)*

Notes: statistical significance levels: ***1%; **5%; *10%. Absolute values of the corresponding t-ratios are shown in parentheses. All differences between groups are significant at 10 percent level or better.

In order to further explore the possible influence of TE on DFZ implementation, estimates of compensating surplus (CS) measures were derived for the DFZ policy scenarios discussed earlier. The CS estimates are reported in Table 22. Relatively efficient farmers have significantly higher CS estimates for DFZ policy scenarios 1 and 2 that have market information. In contrast, less efficient farmers have significantly higher CS for scenarios 4, 5 and 6, which are characterised with training and market information either with or without contract.

Consistent with earlier findings, regardless of TE level, farmers show the highest preference for scenario 4 which includes both training and market information and contract. However, the second choice DFZ policy alternative differs for the two groups of farmers; scenario 1 for the relatively efficient and scenario 6 for the relatively less efficient. Scenarios 2 and 3, without training, are the least preferred by both groups.

Table 22: Compensating surplus for DFZ policy scenarios by technical efficiency groups

Scenario	Attribute						Compensating surplus	
	Training	Market information	Market information and contract	Compensation	Labelling without owner's identity	Labelling with owner's identity	Below average TE group	Above average TE group
1	✓	✓		10%	✓		1,533.0^{b} (233.6)	1,676.2^{a} (217.2)
2		✓		50%		✓	1,108.3^{b} (170.4)	1,163.2^{a} (152.8)
3			✓	25%	✓		1,064.9^{a} (170.3)	1,056.2^{a} (147.4)
4	✓		✓	25%		✓	2,027.3^{a} (284.6)	1,679.0^{b} (204.6)
5	✓	✓		10%		✓	1,636.7^{a} (238.4)	1,548.4^{b} (193.4)
6	✓		✓	10%		✓	1,903.4^{a} (272.4)	1,542.0^{b} (196.3)
Relative ranking of scenarios							4, 6, 5, 1, 2, 3	4, 1, 5, 6, 2, 3

Notes: ✓ indicates the attribute is present in a scenario at the non-zero level.

[a,b] Differences in the superscripts denote significant differences, at 5 percent level or better, in CS across the efficiency groups. Standard errors are in parentheses. All CS estimates are significant at 1 percent level.

The analytical link between TE and preferences for DFZ attributes provides useful insights on the nature of heterogeneity. This, together with the variations in WTP across production systems (along with other considerations) noted earlier, should inform implementation decisions. Currently, the least efficient farmers generally lack most services required in a DFZ, but have shown a higher WTP to participate in such a programme. Therefore, where it is possible to distinguish farmers according to their efficiency levels, it would appear reasonable to start DFZ implementation among those that are least efficient.

7.4 Summary

In this chapter, the CE results on farmer preferences for DFZs have been presented and discussed. It was noted that most farmers experience disease-related cattle losses, and therefore a DFZ might be beneficial to them. Indeed, the results showed that a majority of farmers preferred the DFZ attributes included in the study. Nomads and ranchers, who typically derive most of their livelihoods from livestock, had relatively higher WTP for the DFZs than agro-pastoralists. In addition, it was noted that generally farmers had a high preference for DFZ policy scenarios that included provision of training and market support. Finally, the results suggest that less efficient farmers have limited access to disease control services; hence they have a higher preference for DFZs compared to the relatively more efficient farmers.

The study provides useful insights to policy, particularly to enhance farmers' compliance with disease control measures. This is important for improving the safety of beef output, in order to promote farmers' access to better markets, both domestic and export. Adherence to DFZ requirements and thereby providing safe beef, are envisaged to minimise meat consumers' exposure to foodborne illnesses. Some key conclusions and suggestions for future research are offered in the final chapter that follows.

Chapter Eight

8. Conclusions and Future Research

The overall objective of this study was to investigate farmers' technical efficiency (TE) and willingness to comply with Disease Free Zones (DFZs) in three main beef cattle production systems in Kenya: nomadic pastoralism, agro-pastoralism and ranches. This has been generally addressed by the findings from the analysis. Important conclusions based on the findings are presented in this chapter. Those relating to farmers' TE are presented in section 8.1 and those on farmers' preferences for DFZs are presented in section 8.2. Overall conclusions are provided in section 8.3, while important contributions made by this study to knowledge are highlighted in section 8.4. Finally, some suggestions for future research are offered in section 8.5.

8.1 Farm technical efficiency

This study has applied the stochastic metafrontier approach to investigate TE and meta-technology ratios (MTRs) in the three main beef cattle production systems in Kenya. Results show that there is significant inefficiency in both the nomadic and agro-pastoralist systems, but less in ranches. Further, in contrast with the ranchers, the two systems were found to have lower MTRs. Considering that nomadic pastoralism and agro-pastoralism contribute two-thirds of total beef production in Kenya, urgent policy measures are necessary in order to reduce inefficiency in these farm types. A majority of farmers were found to have MTR values below 1, implying that they use available technology (crossbreed cattle) sub-optimally. A small proportion of farmers (2 percent) use the available crossbreed cattle optimally; hence there is need to provide them with a relatively better (e.g., more locally-adaptable and affordable) cattle breed and breeding programme in order to enable them achieve further productivity gains. It is also envisaged that promoting skills-sharing by the technology-optimal farmers might contribute to improved use of available technology by most farmers.

The average pooled TE with respect to the metafrontier was estimated to be 0.69, which suggests that there is scope to improve beef output in Kenya by up to 31 percent of the total potential, with the current state of technology and available inputs. Policies that promote efficient utilisation of resources in Kenyan beef production are necessary in order to enhance supply for the domestic and/or export markets. The results show that the main factors that could contribute to improved efficiency include: use of controlled cattle breeding method, access to market contract, presence of professional farm manager, off-farm income and larger herd size. On the contrary, it was found that higher dependence on beef cattle for household income (specialisation), large farm size, peri-urban location, high total household income and possession of formal education do not necessarily have a positive influence on efficiency.

It appears reasonable to enhance farmers' access to effective sales contract arrangements that would enable them to obtain more stable and better incomes. This is particularly urgent, given that generally less than one-third of farmers currently have access to market contracts; nomads and agro-pastoralists have the least access. It is also worthwhile to provide appropriate management skills to support farmers' decision-making on efficient use of resources and co-ordination of farm operations. This could be achieved, for instance, through provision of on-farm livestock extension/training on basic management and record-keeping skills. It is important to build appropriate institutional capacity for provision of these services, particularly considering the differences in the production systems. For instance, a mobile livestock extension approach would appear more suitable for nomads. Use of knowledge transfer approaches such as on-farm demonstration workshops would also encourage older (and relatively experienced) farmers to share their farm knowledge with younger farm operators.

In order to improve resilience to droughts and to enhance livelihood opportunities, farmers should be encouraged to keep optimal herds of cattle and shoats (sheep and goats), and promote synergies between both enterprises (e.g., through balanced re-investments), rather than shifting of resources away from cattle enterprises. Further, long-term investments on water provision and pasture development are essential, as a strategy to promote better use of land, especially by pastoralists. Perhaps this might be achieved by encouraging re-investment of farm- and off-farm earnings into development of livestock services.

In addition, legislative incentives that encourage pasture cultivation (e.g., by providing discounted veterinary services to farmers who are willing to grow pasture) should be explored, especially for nomads. Moreover, it is important to strengthen commercial-orientation among the nomads and enhance their access to better livestock markets in order to improve the TEs. Training nomads on farm business skills would promote their participation in competitive markets for livestock inputs and output, and possibly contribute to optimal production.

8.2 Preferences for Disease Free Zones

This study has also focused on analysis of farmer preferences for DFZs and provides insights into policy and future research on the design of such programmes. Results show that Kenyan farmers prefer the establishment of effective DFZs in order to help them manage disease challenges in cattle production. Compared to the current disease control programmes, farmers would prefer to have a DFZ in which: they are provided with adequate training on pasture development, record keeping and disease monitoring skills; market information is provided and sales contract opportunities are guaranteed; cattle are properly labelled for ease of identification; and some monetary compensation is provided in case cattle die due to severe disease outbreaks. The design of DFZs should therefore include these features to enhance the acceptability of such programmes.

Results also show that there is heterogeneity in farmer preferences for the DFZ attributes, across production systems. Because of their relatively high dependence on cattle for income, nomads and ranchers are willing to pay more in order to have market information and contract included in the DFZ. Farmers in these two production systems also have a higher WTP for compensation. There are also variations across the production systems in WTP for training, perhaps due to differences in access to livestock extension and veterinary advisory services and levels of sedentarisation.

In order to ensure acceptance of cattle traceability among the agro-pastoralists and nomads, it appears important to emphasize that inclusion of cattle owner's identity in the labelling is not meant to penalize farmers for trespass, but rather is a key element in enhancing disease control. Moreover, improving farmers' understanding of the purpose of each attribute is important for a DFZ programme, whose successful implementation requires collective farmer participation.

The study also derived farmers' preferences for various DFZ policy scenarios. Across the production systems, there is a higher preference for scenarios that incorporate training, and market information and contract. The estimates of compensating surplus (along with other factors such as resource availability and stakeholder priorities) should help in choosing the best scenario to implement in a particular system or for the entire cattle sub-sector. Also, appropriate institutional and regulatory frameworks should be established in order to facilitate co-ordination of DFZ services (from public and/or private providers) by the management committee, and to enhance monitoring of implementation. For example, it is envisaged that involvement of private sector meat traders in the inspection of cattle movement across regions as suggested by Matete *et al.* (2010) might enhance compliance with identification and traceability systems in the DFZ.

Moreover, in order to improve compliance with DFZs, policies that encourage sedentarisation of nomads should be explored. These might include development of long-term water resources and encouraging market-oriented livestock production. Further, the implementation of DFZs should be phased, perhaps starting with the least efficient farmers who have limited access to disease control services, but are more willing to participate in the DFZs. Moreover, the implementation of DFZs should be targeted on provision of training and contract opportunities to relatively less efficient farmers, and on market information for the more efficient farmers. Finally, the provision of training and market information should be made more frequent (at least once a month) using locally-popular and relatively accessible channels such as village meetings, mobile phones and informal posters.

8.3 Overall conclusions

The findings from the analysis generally address the main objective of this study, which sought to investigate farmers' TE and willingness to comply with DFZs across three beef cattle production systems in Kenya: nomadic pastoralism, agro-pastoralism and ranches.

Results discussed in chapter 6 provide information that addresses the first and second specific research objectives, which were as follows:

i. to measure farm-specific TE in different production systems;
ii. to investigate factors that influence farmers' TE.

Further, the estimates of TE are less than 1, suggesting that Kenyan beef producers are generally not efficient. In chapter 7, the third and fourth research objectives are investigated. These included:

i. to assess farmers' willingness to comply with requirements in DFZs;
ii. to estimate the possible influence of TE levels on farmers' willingness to comply with requirements in DFZs.

The results show that farmers have a preference for all the DFZ attributes included in the study (see section 7.2). In addition, the level of TE was found to have a significant influence on farmers' preferences for DFZ attributes. Specifically, relatively less efficient farmers had a higher preference for training, and market information and contract (see section 7.3). This is to be expected, considering that the relatively less efficient farmers currently have limited access to requisite services for cattle disease control.

Generally, it can be concluded that enhancing farmers' TE is necessary in order to improve resource utilisation and to possibly enable them to invest in important services for cattle disease management.

8.4 Contributions to knowledge

This study contributes to the existing body of knowledge in various ways. First, it offers insights into the TE of Kenyan beef farmers. Further, the application of the stochastic metafrontier method to estimate TE scores and MTRs, and the use of Tobit model to investigate possible determinants of TE, are useful contributions to the literature, considering that empirical applications of these methods in TE analysis are still relatively limited.

Second, the analysis of farmers' preferences for DFZs is novel; this is the first study on preferences for DFZs. Further, the use of CE in this analysis constitutes a new empirical application of the method. Moreover, the incorporation of farmers' views and estimation of willingness to pay (WTP) and compensating surplus (CS) values for DFZ policy scenarios represent a useful application of the CE method to inform policy design in a developing country.

The third contribution to knowledge involves the use of exploratory surveys to generate prior coefficients for an efficient CE design. In addition, this study used both orthogonal and efficient design criteria in a two-stage approach, thereby enhancing complementarity of both approaches; empirical literature on applications of this nature is relatively limited, more so on developing country issues.

Further, the analytical link between farmers' efficiency and preferences for DFZs was investigated in this study. This is possibly an innovative assessment involving two important economic theories (production and utility measurement) that have previously been applied separately.

8.5 Limitations and suggestions for future research

The present study offers useful information on TE and preferences for DFZs. Nonetheless, it is envisaged that future research could provide further insights by addressing some of the challenges encountered in this study and other issues that are generally relevant, but were outside the scope of the current research.

First, the current analysis of TE is based on cross section data, due to lack of farm records or panel data. As noted by Balcombe *et al*. (2007), results of cross sectional studies are informative, albeit with some caveats. For instance, some farmers may be found to produce low or sub-optimal output during the period of analysis because they might have made recent capital investments (e.g., farm-specific training) that are yet to yield returns, but are expected to generate benefits in the future. There is, therefore, a need to build a comprehensive and reliable panel database in Kenya for agricultural research issues, including TEs. This study recognizes a recent initiative to consolidate agricultural data in Kenya; the agricultural data compendium (see MoA and KIPPRA, 2009). However, the compendium is limited to aggregated district- and national-level statistics, and is incomplete for many years and livestock products. Therefore, it seems reasonable for future researchers in the livestock sector in Kenya to generate long-term farm-level cross-sectional survey data that would enable development of a suitable panel dataset. The availability of such data would facilitate empirical methodological contributions including comparative analysis of efficiency estimates using the stochastic metafrontier and other approaches e.g., the LCM frontier.

Second, this study focused on the analysis of TEs and MTRs across production systems. Essentially, a production system is relatively stable in the short-run; hence it should be a suitable entry point for policy intervention in terms of cost and coherence of policy design and implementation. Further insights could be obtained by investigating the TEs and MTRs using other classifications of beef cattle farms, such as intensive or extensive, which would also contribute to the literature.

Third, the investigation of farmers' preferences for DFZs is the first such analysis in the literature; there is a considerable knowledge gap in this area. Given that livestock diseases lead to enormous losses (Bennett, 2003), and impact the wider society beyond the farm-level, it is important to provide more empirical information on this topical policy issue. Future research could focus on analysing the total costs and benefits of implementing different DFZ policy scenarios, and possible resource contributions from other stakeholders, such as non-farmers in the DFZ neighbourhood, government, private sector enterprises and other development partners. Considering variations in stakeholder contexts and roles in the livestock value chains (Rich and Perry, 2010), it would also be worthwhile for future research to investigate requisite incentives for compliance with DFZs by the various non-farm stakeholders. Future research could also provide more insights by investigating viable market contract options and enforcement mechanisms for DFZs.

Fourth, application of the CE method to investigate a relatively new concept (DFZ) in a developing country context entailed survey challenges such as a low 'learning curve', especially among illiterate respondents. This suggests that, as in this study, future research will continue to find the use of survey tools, such as visual aids to illustrate attributes, enumerator training, appropriate translation and piloting of questionnaires, indispensable.

Fifth, the low 'learning curve' by survey respondents in developing countries and vast geographic area to be covered (coupled with rough terrains and poor road infrastructure as was experienced in the sites visited in Kenya) means a low pace of interviews. This leads to a high cost of surveys in terms of time and money in order to obtain a relatively large sample that is representative. In this study, the survey took six months to complete. Considering that face-to-face interviews are still the dominant and reliable mode of survey in developing countries (Bennett and Birol, 2010), it appears reasonable to enhance the use of efficient or 'efficient and orthogonal' CE designs as one possible option to obtain an optimal sample size at a lower cost. Therefore, complementary application of orthogonality and efficiency criteria deserves further investigation in order to improve the statistical appeal of CE designs.

Sixth, field surveys in developing countries are riddled with numerous expectations from respondents, including perceptions of immediate benefits in the form of a development project from such studies; more so in poor households in very remote localities, as was observed in this study. Generally, it might be difficult for researchers to guarantee respondents that the responses from surveys would be included in national or regional development programmes, given the complexity of policy making process and multiplicity of stakeholders involved. But failure to address respondent expectations might contribute to a high level of resentment and non-response in future surveys. Perhaps researchers should be more involved in policy dialogue or advocacy in order to hasten the incorporation of survey findings into development programmes. This might enhance the urgency of implementing research recommendations, and possibly contribute to faster realisation of tangible outcomes, and also enable development of panel data for future research.

Finally, this study has shown that there is a significant analytical link between TE and preferences for DFZ attributes; this has useful implications to policy as mentioned earlier. Future research could extend this finding by developing a theoretical framework that further links the two important areas of microeconomics in which the present study is grounded; production economics and random utility theories.

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Appendices

Appendix 1: Household survey questionnaire

Cattle Production Survey in Kenya
2009

Respondent

In this survey, only households that have kept cattle for a period of **ONE YEAR** and above are eligible for interview. Only **one person** should be interviewed in the selected household. The interviewee, referred to here as "**respondent" must be an individual who normally makes farm decisions** in the household. In case the main decision maker is not available, his/her deputy should be interviewed.

Objective of the Survey *(the enumerator should explain this part to the respondent)*

The **purpose of this survey** is to obtain information on various aspects of beef cattle production and marketing. Your participation in answering questions on these issues is highly appreciated. Your responses will be analysed together with those from about 300 other households in other parts of Kenya. The results of this survey will be used to inform policy makers on better strategies for improving the beef sector in Kenya. **Confidentiality** will be maintained on all information that you provide. The survey will require about two hours. I would like to request your permission to begin the survey now.

Section A: Identification *(the enumerator should fill this section through observation in consultation with the researcher)*

1) Enumerator's name: ____________________________ 2) Date of interview (dd-mm-yyyy):__________________ 3) Province: __________

4) District: __________________________________ 5) Division: ______________________________________ 6) Location: __________

7) Sub-Location: ________________________________ 8) Village: __________________________________ 9) Household Number: ______

10) Zone/region: ______(a = peri-urban, b = rural) 11) Production system: ____ (a = nomadic pastoralism, b = agro-pastoralism, c = ranch)

Section B: Household Enterprises

12) What livestock types and numbers do you have on your farm?

Livestock type	Is it kept on the farm? **(Tick where applicable)**		Average number kept in the last 12 months
	Yes	No	
Cattle			
Goats			
Sheep			
Pigs			
Poultry			
Camels			
Donkeys			
Other (specify)			

13) Which activities does the household **mainly** depend on for livelihood, e.g., for provision of income, food, fees etc.?

Enterprise	Is it a source of livelihood? **(Tick where applicable)**		If **YES**, please indicate the **proportion of monthly income in an average year, from each enterprise** which is a source of livelihood (*TICK one applicable range for each enterprise*)			
	Yes	No	*Less than quarter (<25%)*	*Between quarter and half (25-50%)*	*Between half and three quarters (50-75%)*	*More than three quarters (>75%)*
Cattle						
Other livestock (*specify the main one*______________________)						
Crops (*specify the main one*______________________)						
Off-farm employment						
Others						

14) For how many years have you practised cattle production? ___________ years.
15) How many days in a month are you normally available on the farm? ______ days.
16) Is there a manager on the farm, besides the household head?__ (1 = Yes, 2 = No).

Section C: Cattle Output

17) Please provide information on beef cattle production in your farm. (*Fill responses in the non-shaded blank areas*)

	Calves		Steers		Heifers		Cows		Bulls	
	Now	**12 months ago**	**Now**	**12 months ago**	**Now**	**12 months ago**	**Now**	**12 months ago**	**Now**	**12 months ago**
How many do you have (did you have)										
What is the average age of the animals in the farm (months)										
		Calves in the last 12 months		**Steers in the last 12 months**		**Heifers in the last 12 months**		**Cows in the last 12 months**		**Bulls in the last 12 months**
How many did you purchase										
What was the average purchase price (Ksh)										
How many did you receive from other sources, e.g., dowry, gifts										
How many did you sell										
What was the average sales price (Ksh)										
How many did you use for other purposes e.g., consumption, gifts, dowry										

Section D: Cattle Losses

18) Have you had cattle die due to any of the following factors during the last 12 months? if **YES**, please indicate the number.

Cause of loss	Did cattle die from this cause? **(Tick where applicable)**		If **YES,** please indicate the number of cattle lost
	Yes	No	
Disease			
Drought			
Floods			
Landslides			
Thunder/lightning			
Disputes over pasture and water			
Attacks by wild animals			
Other factors (please specify)			

Section E: Variable Inputs

19) Please provide information on the inputs used in the beef cattle farm. (*Should refer to periods within the last 12 months*). **Do NOT** fill the shaded areas.

Inputs	**Average quantity used for all cattle per month**	**Total cost (Ksh) per month**
a) Purchased feeds		
Silage e.g., sunflower, rye, corn (Kilograms)		
Fodder e.g., hay, maize stalk/stover, wheat straw, sugarcane straw, rice straw, grass (Kilograms)		
Other feeds e.g., soyabean meal, urea (Kilograms)		
Mineral salt and vitamins (Kilograms)		
Water (litres)		
b) Feeds produced and used in the farm		
Silage e.g., sunflower, rye, corn (Kilograms)		
Fodder e.g., hay, maize stalk/stover, wheat straw, sugarcane straw, rice straw, grass (Kilograms)		
Other feeds e.g., soyabean meal, urea (Kilograms)		
Mineral salt and vitamins (Kilograms)		
Water (litres)		
c) Labour		
How many people are employed?		
How many days do the employed labourers per month?		
How much money is each farm employee paid per month?		
How many family members work?		
How many days do the family members work per month?		
How much money is each family member paid for working per month?		
How many unpaid people work?		
How many days do the unpaid people work per month?		
d) Cost of veterinary drugs and services		
e) Farm mechanization costs		
Fuel (litres)		
Electricity		
Hire of machinery and/or equipment, repairs and maintenance (per month)		
f) Other costs per month, e.g.,market services, ropes, branding, dehorning, etc.		

Section F: Fixed Inputs

20) Does the household own any of the following assets on the farm? if **YES**, please provide the following information. If **NO,** *Go to Question 21*. **Do NOT** fill the shaded areas.

Asset	**Is it owned in the household? (1 = Yes 2 = No)**	**Number owned now**	**How often is it used in cattle farm? (1 = less than quarter of the time; 2 = between quarter and half of the time; 3 = between half and three quarter of the time; 4 = more than three quarter of the time)**	**When was it purchased or constructed? (month and year)**	**Initial purchase price or construction cost (Ksh)**	**Lifespan (years)**	**Insurance costs paid for the asset in the last 12 months (Ksh)**	**Taxes paid on the asset in the last 12 months (Ksh)**
Cattle fence								
Kraal								
Calf pen								
Store for farm inputs								
Dip sprayer								
Chaff cutter								
Wheel barrow								
Truck								
Pick-up								
Tractor								
Other (specify)								

Note: If there are more than one type of any asset (e.g., two farm stores or dip sprayers), the enumerator should fill details of each asset on a separate row *under the other category*.

Section G: Other Inputs and Services

(i) Land

21) What is the approximate size of your farm land (excluding homestead)? ______ acres

22) Which **one** of the following land tenure systems do you have on your farm? (*Tick one option*)

a) Individual owned with title deed/allotment letter ____________

b) Individual owned without title deed/allotment letter __________

c) Communal with title deed/allotment letter __________________

d) Communal without title deed/allotment letter _______________

e) Mixed/other (specify, e.g., part individually-owned and partially communal)___________

(ii) Breed types and breeding method

23) What is the **main** cattle breed kept on your farm? (*Tick one option*)

a) Local breed e.g., Zebu, Boran ______

b) Crossbreed _____________________

c) Exotic e.g., Hereford, Red Angus, Simmental, Aberdeen Angus _________

24) Which cattle breeding method is **normally** used in the farm? (*Tick one option*)

a) Natural breeding (controlled)____

b) Natural breeding (uncontrolled)___

c) Artificial insemination_________

(iii) Extension services

25) Did you get any livestock extension services in the last 12 months? ____ (1 = Yes, 2 = No), if **NO**, *Go to Question 29.*

26) Who was your **main** provider of livestock extension services in the last 12 months? (*Tick one option*)

a) Government officer_______

b) Private provider e.g., Non-Government Organizations, private companies or individuals_________

27) How often does the **main** livestock extension service provider visit your farm? (*Tick only one applicable option*)

a) Weekly ____

b) Every two weeks ___

c) Once a month _____

d) Less than once a month ____

28) How often would you like the main extension service provider to visit your farm? (*Tick one option*)

a) Weekly _____________________

b) Every two weeks ______________

c) Once a month ________________
d) Less than once a month ________
e) Stop coming at all _____________

(iv) Veterinary advisory services

29) Did you receive any veterinary advisory services in the last 12 months? _____ (1 = Yes, 2 = No), if **NO**, *GO to Question 31*.

30) Where do you normally obtain veterinary advisory services from? (*Tick one option*)
a) Government officers______
b) Private providers e.g., Non Government Organizations, private companies or individuals_____

(v) Credit/loan

Cash loan

31) Did any household member try to get cash loan in the last 12 months? ______ (1 = Yes, 2 = No). If **NO, GO to** *Question 35*.
If **YES**, was the loan received? ____ (1 = Yes, 2 = No), if **NO**, **GO to** *Question 35*.

32) What were the sources of cash loan? (*Tick all that apply)*.
a) Bank___
b) Cooperative society____
c) NGO) _____
d) Self help group_______
e) Family________
f) Neighbour______
g) Other (specify)____

33) Was the cash loan **mainly** used in (*Tick one option*):
a) Cattle enterprise? ________
b) Crop enterprise? _________
c) Other purposes, e.g., food, fees, medical bills? ______

34) Has all the cash loan been repaid? ____ (1 = Yes, 2 = No)

In kind loan

35) Did any household member try to get loan in kind (e.g., machinery, equipment, feeds, veterinary drugs and livestock) in the last 12 months? __ (1=Yes, 2= No). If **NO, GO to** *Question 38*. If **YES**, was the loan received? ____ (1 = Yes, 2 = No), if **NO**, **GO to** *Question 38*.

36) Was the in kind loan **mainly** used in (*Tick one option*):

a) Cattle enterprise? ________
b) Crop enterprise? _________
c) Other purposes, e.g., food, fees, medical bills? ______

37) Has all the in kind loan been repaid? ____ (1 = Yes, 2 = No)

Section H: Market Outlets

38) Which one of the following do you normally sell your cattle to? (*Tick one option*)

a) Open market centre _____
b) Slaughterhouses/butcheries ____
c) Kenya Meat Commission (KMC) ____
d) Private exporter e.g., Global Livestock Traders Company _____
e) Other e.g., neighbour, breeder (specify) _______________________________________

39) What is the approximate distance from your farm to where you normally sell cattle? ________ Km

40) What is the type of road from your farm to where you normally sell cattle? (*Tick one option*)

a) Tarmac_____
b) Murram____
c) Other, i.e., no tarmac or murram______

41) How would you describe the condition of the road from your farm to where you normally sell cattle? (*Tick one option*)

a) Good, i.e. easily passable most of the time _________
b) Poor, i.e., pot holed or muddy or rough most of the time _______

42) Do you normally sell cattle through prior arrangement (contract agreement)? ______ (1 = Yes, 2 = No), if **NO**, Go to *Question 44*.

43) Does the contract agreement include the following?

a) Price ___ (1 = Yes, 2 = No)
b) Transportation/delivery ___ (1 = Yes, 2 = No)
c) Other (specify) ____

Section I: Market Information

44) Do you normally receive market information on cattle (e.g., on prices of cattle) before you go the market place? _____ (1 = Yes, 2 = No). If **NO, GO to Section J**.

45) How frequently do you normally receive the market information? (*Tick one option*)

a) Daily ______
b) Once a week ____
c) Every two weeks ______
d) Once a month _____
e) Less than once a month _____

46) How important have the following channels been in enabling you to get market information during the last 12 months. (*Tick the relevant box for each source of information)*

Source of information	**Relative importance**			
	Not Applicable	*1 = Not Important*	*2 = Moderately Important*	*3 = Very Important*
Mobile phone				
Workshops/meetings				
Television				
Radio				
Internet				
Newspapers				
Advertisements/memos on notice boards				
Visiting friends and neighbours				
Others (specify)				

Note: Not Applicable means it was not used at all.

Section J: Choice Experiment

47) Please indicate your opinion on the following statements, on a scale of 1 to 5 (where 1 = strongly disagree, 5 = strongly agree). **Tick one box for each statement.**

Statement	**1 = Strongly Disagree**	**2 = Disagree**	**3 = Neither (undecided)**	**4 = Agree**	**5 = Strongly Agree**
a) I consider cattle diseases as a serious problem to farming					
b) I am satisfied with current disease control programmes					

48) During previous severe outbreaks of cattle diseases, I **mainly** took the following action (*Tick one option*):

a) Sold cattle____________
b) Slaughtered cattle______
c) Moved cattle to safer areas___________
d) None of the above____________

49) Have you heard of Disease Free Zones?______ (1 = Yes, 2 = No).

Introduction to Disease Free Zones

(***Note: The enumerator should explain this section to the respondent before asking question 50 and 51***).

Cattle enterprise supports the livelihood of your household in various ways. However, frequent occurrence of major diseases in cattle (especially Foot and Mouth Disease, and Rift Valley Fever) could result in significant losses in herd size, income and human health. Suppose there is a proposal to establish a Disease Free Zone in this village so as to improve disease control. In the Disease Free Zone, veterinary services, livestock drugs and water would be provided.

In order to participate in the Disease Free Zone, the following regulations would be applied:

A) Compulsory requirements

- Graze cattle within a fenced area only;
- Monitor and report any cattle disease outbreak;
- Slaughter and burn or burry all infected cattle during disease outbreak (to prevent further infection of other cattle).

B) Optional features

The Disease Free Zone would also have a combination of various features, which you may choose. These features would include:

- Training on disease monitoring, record keeping and pasture development
- Identification of cattle through labelling
- Market support (e.g. provision of market information and linking you to buyers)
- Compensation if your cattle die in a disease outbreak
- Annual membership fee

50) If you were to consider being a member of a Disease Free Zone, how important would these features be in your decision?

Attribute	**Relative importance**		
	1 = Not Important	*2 = Moderately Important*	*3 = Very Important*
Training on disease monitoring, record keeping and pasture development			
Identification of cattle through labelling			
Market support			
Compensation (ranging from 10% to 50% of the value of cattle that die from a disease)			

These features could have the following levels:

Attribute	**Attribute levels**
Training	No training
	Training is provided
Labelling	No labelling
	Label cattle only
	Label cattle and indicate owner's identity
Market support	No market support
	Provide market information only
	Provide market information and guarantee for contract sale
Annual membership fee per animal	Ksh 150
	Ksh 300
	Ksh 450
Compensation (when cattle die)	10% of value of the cattle that dies
	25% of the value of the cattle that dies
	50% of the value of the cattle that dies

51) Now I will show you different types of Disease Free Zones that can be made by combining these features. Please compare the various types of Disease Free Zones shown each time and indicate **<u>ONE</u>** which you prefer.

Section K: Respondent's Characteristics and Household Composition

52) Gender: ______ (1 = male, 2 = female)

53) Position in the household (*Tick one option*):
- a) Household head_____
- b) Spouse_______
- c) Son_________
- d) Daughter_____
- e) Other relative____
- f) Farm manager____
- g) Other farm employee____

54) Age: ______ years

55) Highest level of formal education completed (*Tick one option*):
- a) No formal education____
- b) Primary___
- c) Secondary___
- d) Middle level college certificate or diploma____
- e) University degree_____

56) Were you a member of any of the following during the last 12 months? (*Tick all that apply*).
- a) Cooperative society _______
- b) Village committee ________
- c) School committee ________
- d) Church committee ________
- e) Constituency Development Fund (CDF) committee_____________________________
- f) Other development group (specify) __________________________________

57) On average, how many people normally reside in this household during a year?
- a) Total number of children (18 years and under) _________
- b) Total number of adults (over 18 years) ______________

58) Please indicate the approximate average monthly household income from all sources.

Income category	Tick one
Ksh 10,000 or less	
Ksh 10,001 to Ksh 20,000	
Ksh 20,001 to Ksh 30,000	
Ksh 30,001 to Ksh 40,000	
Ksh 40,001 to Ksh 50,000	
Ksh 50,001 to Ksh 100,000	
Above Ksh 100,000	

THANK YOU FOR YOUR PARTICIPATION!

Appendix 2: Stochastic frontier instruction file

Code	*interpretation*
1	1 = Error components model, 2 = TE effects model
pldv-dta.txt	data file name
pldv-cot.txt	output file name
1	1 = production function, 2 = cost function
y	logged dependent variable (y/n)
313	number of cross sections
1	number of time periods
313	number of observations in total
4	number of regressor variables (Xs)
y/n	mu (y/n) [or delta0 (y/n) if using TE effects model]
y/n	eta (y/n) [or number of TE effects regressors (Zs)]
n	starting values specified (y/n)

Source: adapted from Coelli *et al*. (2005).

Appendix 3: Metafrontier and bootstrapping codes

```
* The file sfa#.txt contains n# data observations for group#
* The file parm.txt contains estimated parameters of group stochastic frontiers (by column)
* The file metpa.txt contains estimated parameters of the metafrontier
* The file cow.txt contains observed values of the dependent variable (output)

*1. READ DATA AND ESTIMATED PARAMETERS OF GROUP STOCHASTIC FRONTIERS
sample 1 313
genr one = 1
dim group 313 t 313 y 313 herd 313 feed 313 vet 313 divis 313
read (sfa1.txt) group t y herd feed vet divis / beg=1 end=110 list
read (sfa2.txt) group t y herd feed vet divis / beg=111 end=247 list
read (sfa3.txt) group t y herd feed vet divis / beg=248 end=313 list
sample 1 313
print group t y herd feed vet divis
sample 1 313
matrix x = one|herd|feed|vet|divis
print x
dim x1 110 5 x2 137 5 x3 66 5
copy x x1 / frows = 1;110 trows = 1;110
copy x x2 / frows = 111;247 trows = 1;137
copy x x3 / frows = 248;313 trows = 1;66
dim nomad 5 agrop 5 ranch 5
read (parm.txt) nomad agrop ranch / beg=1 end=5 list
sample 1 5
matrix s = nomad|agrop|ranch
print s
dim s1 5 s2 5 s3 5
copy s s1 / fcols = 1;1 tcols = 1;1
copy s s2 / fcols = 2;2 tcols = 1;1
copy s s3 / fcols = 3;3 tcols = 1;1

*2. CONSTRUCT DATA MATRICES AND ESTIMATE METAFRONTIER
matrix g1 = x1*s1
matrix g2 = x2*s2
matrix g3 = x3*s3
print g1
print g2
print g3
matrix b = -(g1'|g2'|g3')'
print b
stat x / means = xbar
matrix c = (-xbar'|xbar')'
matrix A = (-x|x)
?lp c A b /iter = 5000 primal = bstar
print bstar

*3. USE METAFRONTIER ESTIMATES TO OBTAIN TECHNOLOGY GAP RATIOS
dim meta 5
read (metpa.txt) meta / beg=1 end=5 list
sample 1 5
matrix starb = meta
print starb
matrix g1star = x1*starb
matrix g2star = x2*starb
```

```
matrix g3star = x3*starb
print g1star
print g2star
print g3star
matrix dev1 = g1star-g1
matrix dev2 = g2star-g2
matrix dev3 = g3star-g3
print dev1
print dev2
print dev3
matrix tgr1 = exp(g1)/exp(g1star)
matrix tgr2 = exp(g2)/exp(g2star)
matrix tgr3 = exp(g3)/exp(g3star)
sample 1 110
stat tgr1
sample 1 137
stat tgr2
sample 1 66
stat tgr3
sample 1 110
print tgr1
sample 1 137
print tgr2
sample 1 66
print tgr3
```

*4. COMPUTE STANDARD DEVIATIONS FOR METAFRONTIER PARAMETERS THROUGH BOOTSTRAPPING

```
dim cowva 313
read (cow.txt) cowva / beg=1 end=313 list
sample 1 313
matrix q = cowva
matrix qstar = x*starb
matrix e = q-qstar
dim beta 5 1000
set nodoecho
set nooutput
set ranfix
do #=1, 1000
gen newe = samp(e)*SQRT(N/(N-K))
sample 1 313
stat newe
gen qnew = qstar+newe
OLS qnew herd feed vet divis / COEF=beta:4
endo
matrix bstre = newe'
matrix beta = beta'
set output
sample 1 1000
stat bstre
sample 1 1000
stat beta
stop
```

*5. USE STANDARD DEVIATIONS OBTAINED TO ESTIMATE STANDARD ERRORS FOR METAFRONTIER PARAMETERS (standard error=standard deviation/SQRT(N))

Source: adapted from O'Donnell *et al*. (2008) and Whistler *et al*. (2007).

Appendix 4: Checklist questions used in the focus group discussions

FOCUS GROUP DISCUSSION 2009
KENYA

Respondents

The respondents for this Focus Group Discussion shall be a small group of 6 – 14 farmers who must have at **least two years of experience** in cattle production in one of the districts where the survey is being undertaken.

Objectives

The main aim of the Focus Group Discussion is to obtain some general information on cattle diseases. The information gathered from the Discussion will be kept **confidential** and will only be used for purposes of advising policy making on how to improve disease control. Everyone's opinions are very important and you are all encouraged to participate fully in this discussion. The discussion will require about two hours to complete. I now request your permission to begin the discussion.

District______________________________
Village______________________________
Date________________________________

Questions for Discussion

1) What cattle breeds are kept in this area?
2) Do you consider cattle diseases as a serious problem to farming?
3) What are the main cattle diseases in this area?
4) How frequently do cattle die from diseases in this area/how many in a herd?
5) Are you satisfied with the available disease control measures?
6) Have you heard of Disease Free Zones?
7) Suppose a Disease Free Zone was to be established in this area, what features would you like to be included in it?

Which of the features you have mentioned should be made compulsory (a **MUST**) for every one?

Which ones could be optional?

What about:

- Fencing the grazing area?
- Monitoring and reporting cattle disease outbreaks?
- Slaughtering and burying infected cattle?
- Training on disease monitoring, record keeping and pasture development?
- Identification of cattle through labelling?
- Market support?
- Annual membership fee per animal?
- Compensation when an animal dies?

What are the possible levels for each of these features?

What about the following levels of the features?

Attribute	Attribute levels
Training	No training
	Training is provided
Labelling	No labelling
	Label cattle only
	Label cattle and indicate owner's identity
Market support	No market support
	Provide market information only
	Provide market information and guarantee for contract sale
Annual membership fee per animal	Ksh 50
	Ksh 100
	Ksh 150
Compensation (when cattle die)	5% of value of the cattle that dies
	15% of the value of the cattle that dies
	25% of the value of the cattle that dies

8) Now I will show you different types of Disease Free Zones that can be made by combining these features. Please compare the various types of Disease Free Zones and indicate ONE which you prefer. ***Each member of the group is given four choice situations to consider and make choices individually***.

9) What were your experiences with the choice tasks? Was it difficult to make a choice?

10) How were you making the choices? Were you considering all features or was there a specific feature that you were always looking for before you made a choice in each case?

11) Were you making choices separately or were you trying to remember how you made the previous choices before making the next choice?

Thank you for your participation!

Appendix 5: NGENE choice experiment design syntax

a) Orthogonal design for preliminary survey

```
Design
;alts = alt1, alt2
;rows = 36
;block = 6
;orth = sim
;model:
U(alt1)=b0+b1*x1[0,1]+b2*x2[0,1,2]+b3*x3[0,1,2]+b4*x4[0,1,2]+b5*x5[0,1,2]+b6*x3*x5/
U(alt2)=   b1*x1     +b2*x2       +b3*x3       +b4*x4       +b5*x5        +b6*x3*x5$
```

b) Efficient design for final survey

```
Design
;alts = alt1, alt2
;rows = 24
;block = 6
;eff = (mnl,d)
;model:
U(alt1) =
b1[0.98]*x1[0,1]+b2[1.63]*x2[0,1,2]+b3[0.039]*x3[0,1,2]+b4[0.935]*x4[0,1,2]+b5[-
0.007]*x5[0,1,2]+b6*x3*x5/
U(alt2) = b1      *x1     +b2      *x2       +b3       *x3       +b4       *x4       +b5        *x5
+b6*x3*x5$
```

Appendix 6: List of all choice sets used in the choice experiment survey

a) Block 1

Choice set number 1

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	No training	Training is provided	No training
Market support	Market information	Market information and contract	No market support
Compensation	50%	50%	No compensation
Labelling	Cattle and owner	No labelling	No labelling
Annual membership fee (Kshs)	450	150	No membership fee
Which ONE would you prefer?			

Choice set number 2

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	No training	Training is provided	No training
Market support	No market support	Market information	No market support
Compensation	50%	10%	No compensation
Labelling	Cattle and owner	No labelling	No labelling
Annual membership fee (Kshs)	150	300	No membership fee
Which ONE would you prefer?			

Choice set number 3

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	Training is provided	No training	No training
Market support	Market information	Market information	No market support
Compensation	50%	10%	No compensation
Labelling	No labelling	Cattle and owner	No labelling
Annual membership fee (Kshs)	450	450	No membership fee
Which ONE would you prefer?			

Choice set number 4

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	Training is provided	No training	No training
Market support	Market information and contract	Market information	No market support
Compensation	10%	50%	No compensation
Labelling	No labelling	Cattle and owner	No labelling
Annual membership fee (Kshs)	450	150	No membership fee
Which ONE would you prefer?			

b) Block 2

Choice set number 1

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	No training	Training is provided	No training
Market support	Market information and contract	No market support	No market support
Compensation	25%	25%	No compensation
Labelling	Cattle only	Cattle only	No labelling
Annual membership fee (Kshs)	300	300	No membership fee
Which ONE would you prefer?			

Choice set number 2

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	No training	Training is provided	No training
Market support	Market information and contract	No market support	No market support
Compensation	10%	10%	No compensation
Labelling	No labelling	Cattle and owner	No labelling
Annual membership fee (Kshs)	150	450	No membership fee
Which ONE would you prefer?			

Choice set number 3

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	Training is provided	No training	No training
Market support	No market support	Market information	No market support
Compensation	10%	50%	No compensation
Labelling	Cattle only	No labelling	No labelling
Annual membership fee (Kshs)	150	150	No membership fee
Which ONE would you prefer?			

Choice set number 4

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	No training	Training is provided	No training
Market support	Market information	No market support	No market support
Compensation	10%	50%	No compensation
Labelling	Cattle only	Cattle and owner	No labelling
Annual membership fee (Kshs)	450	450	No membership fee
Which ONE would you prefer?			

b) Block 3

Choice set number 1

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	Training is provided	No training	No training
Market support	Market information	No market support	No market support
Compensation	25%	25%	No compensation
Labelling	Cattle only	Cattle only	No labelling
Annual membership fee (Kshs)	300	300	No membership fee
Which ONE would you prefer?			

Choice set number 2

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	Training is provided	No training	No training
Market support	No market support	Market information and contract	No market support
Compensation	50%	10%	No compensation
Labelling	Cattle and owner	No labelling	No labelling
Annual membership fee (Kshs)	150	150	No membership fee
Which ONE would you prefer?			

Choice set number 3 (Figure 9 illustration)

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	Training is provided	No training	No training
Market support	No market support	Market information and contract	No market support
Compensation	25%	10%	No compensation
Labelling	Cattle and owner	No labelling	No labelling
Annual membership fee (Kshs)	150	450	No membership fee
Which ONE would you prefer?			

Choice set number 4

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	Training is provided	No training	No training
Market support	Market information and contract	Market information and contract	No market support
Compensation	10%	25%	No compensation
Labelling	No labelling	Cattle and owner	No labelling
Annual membership fee (Kshs)	450	150	No membership fee
Which ONE would you prefer?			

b) Block 4

Choice set number 1

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	No training	Training is provided	No training
Market support	Market information and contract	No market support	No market support
Compensation	50%	50%	No compensation
Labelling	No labelling	Cattle and owner	No labelling
Annual membership fee (Kshs)	150	450	No membership fee
Which ONE would you prefer?			

Choice set number 2

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	No training	Training is provided	No training
Market support	Market information	Market information and contract	No market support
Compensation	10%	50%	No compensation
Labelling	Cattle and owner	No labelling	No labelling
Annual membership fee (Kshs)	300	450	No membership fee
Which ONE would you prefer?			

Choice set number 3

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	Training is provided	No training	No training
Market support	No market support	Market information and contract	No market support
Compensation	25%	25%	No compensation
Labelling	Cattle only	Cattle only	No labelling
Annual membership fee (Kshs)	300	300	No membership fee
Which ONE would you prefer?			

Choice set number 4

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	No training	Training is provided	No training
Market support	Market information and contract	No market support	No market support
Compensation	25%	25%	No compensation
Labelling	Cattle only	Cattle only	No labelling
Annual membership fee (Kshs)	300	300	No membership fee
Which ONE would you prefer?			

b) Block 5

Choice set number 1

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	Training is provided	No training	No training
Market support	No market support	Market information and contract	No market support
Compensation	10%	10%	No compensation
Labelling	Cattle and owner	No labelling	No labelling
Annual membership fee (Kshs)	450	150	No membership fee
Which ONE would you prefer?			

Choice set number 2

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	Training is provided	No training	No training
Market support	No market support	Market information and contract	No market support
Compensation	10%	50%	No compensation
Labelling	Cattle and owner	No labelling	No labelling
Annual membership fee (Kshs)	150	450	No membership fee
Which ONE would you prefer?			

Choice set number 3

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	No training	Training is provided	No training
Market support	Market information	Market information	No market support
Compensation	25%	25%	No compensation
Labelling	No labelling	Cattle only	No labelling
Annual membership fee (Kshs)	300	300	No membership fee
Which ONE would you prefer?			

Choice set number 4

DFZ Attribute	**Alternative A**	**Alternative B**	**Alternative C**
Training	No training	Training is provided	No training
Market support	No market support	No market support	No market support
Compensation	50%	25%	No compensation
Labelling	Cattle only	Cattle only	No labelling
Annual membership fee (Kshs)	450	150	No membership fee
Which ONE would you prefer?			

b) Block 6

Choice set number 1

DFZ Attribute	Alternative A	Alternative B	Alternative C
Training	No training	Training is provided	No training
Market support	Market information	No market support	No market support
Compensation	25%	25%	No compensation
Labelling	Cattle and owner	Cattle only	No labelling
Annual membership fee (Kshs)	300	300	No membership fee
Which ONE would you prefer?			

Choice set number 2

DFZ Attribute	Alternative A	Alternative B	Alternative C
Training	Training is provided	No training	No training
Market support	Market information	Market information	No market support
Compensation	50%	50%	No compensation
Labelling	No labelling	Cattle and owner	No labelling
Annual membership fee (Kshs)	150	450	No membership fee
Which ONE would you prefer?			

Choice set number 3

DFZ Attribute	Alternative A	Alternative B	Alternative C
Training	No training	Training	No training
Market support	Market information and contract	Market information	No market support
Compensation	25%	10%	No compensation
Labelling	Cattle only	Cattle only	No labelling
Annual membership fee (Kshs)	450	150	No membership fee
Which ONE would you prefer?			

Choice set number 4

DFZ Attribute	Alternative A	Alternative B	Alternative C
Training	Training is provided	No training	No training
Market support	Market information and contract	Market information	No market support
Compensation	50%	10%	No compensation
Labelling	No labelling	Cattle and owner	No labelling
Annual membership fee (Kshs)	300	300	No membership fee
Which ONE would you prefer?			

Appendix 7: Random parameter logit commands

a) Parameters for DFZ attributes

```
READ; FILE="C:\Documents\CE data.lpj"$
Title; unconditional rpl cost fixed, else normal$
        Sample; all$
        Reject; PRODSY#1$ (Nomads) or #2$ (Agro-pastoral) or #3$ (Ranchers)
        rplogit;Lhs=choice
        ;Choices=a,b,c
        ?;start=b
        ;rhs=TRAINING,MKIF,MKFC,COMPEN,LABC,LABW,COST
        ;rpl
        ;halton
        ;fcn=TRAINING(N),
        MKIF(N),
        MKFC(N),
        COMPEN(N),
        LABC(N),
        LABW(N),
        COST(C)
        ;pds = 4
        ;pts=100 $
```

b) Willingness to pay (WTP) estimates

```
        WALD; Labels=train,
                inform,
                contra,
                compens,
                labelcat,
                owner,
                fee,
                SD_train,
                SD_inform,
                SD_contra,
                SD_compens,
                SD_labelcat,
                SD_owner,
                Fix_fee
                ;start=b
                ;Var=Varb
                ;Fn1=-1*(train/fee)
                ;Fn2=-1*(inform/fee)
                ;Fn3=-1*(contra/fee)
                ;Fn4=-1*(compens/fee)
                ;Fn5=-1*(labelcat/fee)
                ;Fn6=-1*(owner/fee)$
```

c) Compensating surplus for six DFZ policy scenarios

```
        WALD;Labels=b1,
                b2,
                b3,
                b4,
                b5,
                b6,
                b7,
                SD_b1,
```

```
SD_b2,
SD_b3,
SD_b4,
SD_b5,
SD_b6,
Fix_b7
;start=b
;Var=Varb
;Fn1=(-1/b7)*(b1*1+b2*1+b4*10+b5*1)
;Fn2=(-1/b7)*(b2*1+b4*50+b6*1)
;Fn3=(-1/b7)*(b3*1+b4*25+b5*1)
;Fn4=(-1/b7)*(b1*1+b3*1+b4*25+b6*1)
;Fn5=(-1/b7)*(b1*1+b2*1+b4*10+b6*1)
;Fn6=(-1/b7)*(b1*1+b3*1+b4*10+b6*1)$
```

d) Influence of Metafrontier technical efficiency on preferences for DFZ attributes

i) Pooled sample

Parameters

```
Title; Pooled sample rpl conditional on metafrontier technical efficiency$
    Sample; all$
    rplogit;Lhs=choice
    ;Choices=a,b,c
    ?;start=b
    ;rhs=TRAINING,MKIF,MKFC,COMPEN,LABC,LABW,COST
    ;rpl=TEPROP
    ;halton
    ;fcn=TRAINING(N),
    MKIF(N),
    MKFC(N),
    COMPEN(N),
    LABC(N),
    LABW(N),
    COST(C)
    ;pds = 4
    ;pts=100$
```

WTP estimates

```
WALD; Labels=train,
        inform,
        contra,
        compens,
        labelcat,
        owner,
        fee,
        trate,
        infte,
        conte,
        comte,
        labte,
        ownte,
        feete,
        SD_train,
        SD_inform,
```

```
SD_contra,
SD_compens,
SD_labelcat,
SD_owner,
Fix_fee
;start=b
;Var=Varb
;Fn1=-1*(train+trate)/fee
;Fn2=-1*inform/fee
;Fn3=-1*(contra+conte)/fee
;Fn4=-1*compens/fee
;Fn5=-1*labelcat/fee
;Fn6=-1*(owner+ownte)/fee$
```

ii) Below average technical efficiency group

Parameters

```
Title; rpl for farmers with below average efficiency$
    sample;all$
    create;if(TEPROP<0.693)EFGROUP=1$
    Title;rpl for farmers with below average efficiency$
    Sample; all$
    Reject;EFGROUP#1$
    rplogit;Lhs=choice
    ;Choices=a,b,c
    ?;start=b
    ;rhs=TRAINING,MKIF,MKFC,COMPEN,LABC,LABW,COST
    ;halton
    ;fcn=TRAINING(N),
    MKIF(N),
    MKFC(N),
    COMPEN(N),
    LABC(N),
    LABW(N),
    COST(C)
    ;pds = 4
    ;pts=100$
```

WTP estimates

```
WALD; Labels=train,
        inform,
        contra,
        compens,
        labelcat,
        owner,
        fee,
        SD_train,
        SD_inform,
        SD_contra,
        SD_compens,
        SD_labelcat,
        SD_owner,
        Fix_fee
        ;start=b
        ;Var=Varb
```

```
;Fn1=-1*train/fee
;Fn2=-1*inform/fee
;Fn3=-1*contra/fee
;Fn4=-1*compens/fee
;Fn5=-1*labelcat/fee
;Fn6=-1*owner/fee$
```

Compensating surplus

```
WALD;Labels=b1,
        b2,
        b3,
        b4,
        b5,
        b6,
        b7,
        SD_b1,
        SD_b2,
        SD_b3,
        SD_b4,
        SD_b5,
        SD_b6,
        Fix_b7
        ;start=b
        ;Var=Varb
        ;Fn1=(-1/b7)*(b1*1+b2*1+b4*10+b5*1)
        ;Fn2=(-1/b7)*(b2*1+b4*50+b6*1)
        ;Fn3=(-1/b7)*(b3*1+b4*25+b5*1)
        ;Fn4=(-1/b7)*(b1*1+b3*1+b4*25+b6*1)
        ;Fn5=(-1/b7)*(b1*1+b2*1+b4*10+b6*1)
        ;Fn6=(-1/b7)*(b1*1+b3*1+b4*10+b6*1)$
```

iii) Above average technical efficiency group

Parameters

```
Title; rpl for farmers with above average efficiency$
    Sample; all$
    Reject;EFGROUP#0$
    rplogit;Lhs=choice
    ;Choices=a,b,c
    ?;start=b
    ;rhs=TRAINING,MKIF,MKFC,COMPEN,LABC,LABW,COST
    ;halton
    ;fcn=TRAINING(N),
    MKIF(N),
    MKFC(N),
    COMPEN(N),
    LABC(N),
    LABW(N),
    COST(C)
    ;pds = 4
    ;pts=100$
```

WTP estimates

```
WALD; Labels=train,
        inform,
        contra,
        compens,
        labelcat,
        owner,
        fee,
        SD_train,
        SD_inform,
        SD_contra,
        SD_compens,
        SD_labelcat,
        SD_owner,
        Fix_fee
        ;start=b
        ;Var=Varb
        ;Fn1=-1*train/fee
        ;Fn2=-1*inform/fee
        ;Fn3=-1*contra/fee
        ;Fn4=-1*compens/fee
        ;Fn5=-1*labelcat/fee
        ;Fn6=-1*owner/fee$
```

Compensating surplus

```
WALD;Labels=b1,
        b2,
        b3,
        b4,
        b5,
        b6,
        b7,
        SD_b1,
        SD_b2,
        SD_b3,
        SD_b4,
        SD_b5,
        SD_b6,
        Fix_b7
        ;start=b
        ;Var=Varb
        ;Fn1=(-1/b7)*(b1*1+b2*1+b4*10+b5*1)
        ;Fn2=(-1/b7)*(b2*1+b4*50+b6*1)
        ;Fn3=(-1/b7)*(b3*1+b4*25+b5*1)
        ;Fn4=(-1/b7)*(b1*1+b3*1+b4*25+b6*1)
        ;Fn5=(-1/b7)*(b1*1+b2*1+b4*10+b6*1)
        ;Fn6=(-1/b7)*(b1*1+b3*1+b4*10+b6*1)$
```

Source: adapted from Greene (2007).

Appendix 8: Other farm characteristics

Variable	Nomads (n = 110)	Agro-pastoralists (n = 137)	Ranchers (n = 66)	Pooled sample (n = 313)
Experience in cattle production (years)	15.5[a]	13.2[a]	13.7[a]	14.1
Percentage of herd size lost due to drought in the past year	23.9[a]	2.6[b]	5.3[b]	10.7
Percentage of farmers with access to generally good road from farm to main market (tarmac)	53.6[a]	37.2[b]	51.5[a]	46.0
Main provider of extension services is Government as opposed to private agents (% of farmers)	54.5[a]	50.0[a]	31.4[b]	45.5
Current frequency of extension visits (% of farmers):				
Weekly	0.0[b]	0.0[b]	22.0[a]	7.2
Every two weeks	1.8[b]	4.2[b]	14.0[a]	6.5
Once a month	32.7[a]	22.9[a]	24.0[a]	26.8
Less than once a month	65.5[a]	72.9[a]	40.0[b]	59.5
Preferred frequency of extension visits:				
Weekly	30.9[b]	31.3[b]	70.6[a]	44.2
Every two weeks	23.6[a]	25.0[a]	13.7[a]	20.8
Once a month	43.6[a]	29.2[a]	15.7[b]	29.9
Less than once a month	1.8[b]	12.5[a]	0.0[b]	4.5
Stop coming at all	0.0[a]	2.1[a]	0.0[a]	0.6
Main provider of veterinary services is Government as opposed to private agents (% of farmers)	52.6[a]	50.0[a]	27.6[b]	43.9
Current frequency of market information access:				
Daily	10.3[a]	0.0[b]	10.9[a]	7.8
Once a week	17.2[b]	11.1[b]	23.9[a]	18.6
Every two weeks	27.6[a]	3.7[b]	15.2[a]	15.7
Once a month	20.7[a]	37.0[a]	19.6[a]	24.5
Less than once a month	24.1[b]	48.1[a]	30.4[b]	33.3
Relative importance of market information channels (Likert scale: 1= not important, 2=important, 3 = very important):				
Mobile phone	2.6[a]	2.6[a]	2.6[a]	2.6
Workshops/meetings	1.7[b]	1.4[c]	2.0[a]	1.8
Television	1.2[b]	1.3[b]	1.7[a]	1.5
Radio	1.4[b]	1.0[b]	1.7[a]	1.5
Internet	1.0[b]	1.0[b]	2.0[a]	1.7
Print media e.g., newspapers	1.7[b]	1.5[b]	2.0[a]	1.6
Others (e.g., neighbours)	1.6[b]	2.8[a]	2.7[a]	2.8

[a,b,c] Different letters denote significant differences (at 10 percent level or better) in variables across the production systems in a descending order of magnitude.

Appendix 9: Variance inflation factors for farm characteristics in the pooled sample

Variable	R^2	VIF
Beef herd size	0.27	1.37
Farm size	0.22	1.29
Zone/Location	0.19	1.23
Age	0.37	1.59
Gender	0.11	1.13
Experience	0.37	1.58
Off-farm income	0.13	1.15
Household size	0.07	1.08
More than half income from cattle (specialisation)	0.21	1.27
Access to veterinary advisory services	0.22	1.28
Access to extension services	0.32	1.47
Main cattle breed	0.26	1.35
Secondary education and above	0.08	1.09
Distance to market	0.18	1.22
Presence of farm manager	0.46	1.86
Income group	0.45	1.81
Main market outlet	0.20	1.26
Possession of land title deed/allotment letter	0.38	1.62
Group membership	0.19	1.24
Access to prior market information	0.34	1.52
Contract sale	0.31	1.45
Access to credit	0.18	1.22
Use of controlled breeding	0.32	1.46
Land ownership system	0.43	1.75

END*******************************