IMPACT OF CHOICE AND INTEGRATION OF TSETSE FLY AND TRYPANOSOMIASIS CONTROL METHODS ON HOUSEHOLD INCOME IN LAMU COUNTY, KENYA

SETH OOKO ONYANGO

(BSC. AGRIC. ECON., MSC. AGRIC. ECON., EGERTON UNIVERSITY)

DEPARTMENT OF AGRICULTURAL ECONOMICS

FACULTY OF AGRICULTURE

UNIVERSITY OF NAIROBI

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DECLARATION

This thesis is my original work and has not been submitted to any other University for any degree

25/11/2020

____ Date: ______________

Seth O. Onyango (BSc. Agric. Econ., MSc. Agric. Econ., Egerton University)

Candidate

This thesis has been submitted with our approval as Supervisors:

25/11/2020

_______________________________________ Date:_______________

Dr. Sabina Mukoya-Wangia

Department of Agricultural Economics – University of Nairobi

25/11/2020

____________________________________ Date: _______________

Dr. Josiah M. Kinama

Plant Science and Crop Protection Department – University of Nairobi

25/11/2020

_____________________________________ Date: ________________

Dr. Pamela A. Olet

Kenya Tsetse and Trypanosomiasis Eradication Council

DEDICATION

To my dear wife Esther A. Ooko and my children Leslie B. A. Ooko, Marvin R. O. Ooko, Tedric O. Ooko and Natalie A. Ooko.

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ABSTRACT

The farm households in Lamu County had participated in the control of tsetse flies and trypanosomiasis using insecticide treated livestock, insecticide treated targets and trypanocidal drugs. However, the methods that households chose, the factors influencing the choices made as well as the level of integration of different methods were not known. The impact of the control of tsetse flies and the disease on household income had not been estimated which made it necessary to carry out this study. The specific objectives of the study were: (1) To assess the factors that influence choice and integration of tsetse fly and trypanosomiasis control methods among livestock farmers in Lamu County; (2) To determine the effect of integration level of tsetse fly and trypanosomiasis control methods on livestock herd structure in Lamu County and (3) To determine the impact of multiple application of tsetse fly and trypanosomiasis control methods on household income among livestock farmers in Lamu County. The study applied quasi-experimental research design with treatment and control groups of household constructed from a sample size of 536 livestock rearing households from Lamu East and Lamu West sub-Counties. A total of 328 households were users of tsetse fly and trypanosomiasis control methods and 208 were non-users. A multivariate probit model was used in objective one and results showed that household social and economic factors including age, sex, education, occupation, off-farm income, land and livestock ownership had significant influence on choice of tsetse fly and trypanosomiasis control methods. Technological attributes including availability, cost and effectiveness of technology also had significant influence on choice of insecticide treated targets and trypanocidal drugs. A multivariate tobit regression model was used in objective two and results showed that the level of integration of tsetse fly and trypanosomiasis control methods positively affected the herd structures for cattle and donkeys but negatively affected the herd structures for sheep and goats. Lastly, endogenous switching regression model was used in objective three and the results showed that users of insecticide treated livestock had an annual earning of KES 10,200 more than non-users but would have earned KES 21,400 had they not used the method. Users of insecticide treated targets earned KES 31,300 more than non-users and KES 46,600 less had they not used the method. The trypanocidal drug users earned KES 50,900 more than non-users. The users would have earned KES 27,300 more had they not used trypanocidal drugs. Households which combined insecticide treated livestock and trypanocidal drugs earned KES 20,900 more than non-users but users would have earned KES 22,700 had they not decided to use. Users who integrated the three methods earned KES 121,200 more than non-users, but would have earned KES 58,300 less had they not used. In conclusion, the study has shown that household socio-economic characteristics and technological attributes were the major factors that influenced the choice of tsetse and trypanosomiasis control methods. The level of integration of the three methods of control improved the herd composition and structure of cattle and donkeys as a pathway to possible increase in household income. This study has demonstrated that the control of tsetse fly and trypanosomiasis in Lamu County had a positive impact on household income and that the effects of the control varied depending on the method or combination of methods used. The study recommends that the national institutions and devolved units of government designs farmer outreach programs that take into consideration key household social and economic characteristics as well as technological attributes which may stimulate adoption of appropriate tsetse fly and trypanosomiasis control technologies for increased household income.

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AAT	-	African Animal Trypanosomiasis
AfDB	-	African Development Bank
AI	-	Artificial Insemination
ANOVA	-	Analysis of Variance
ATE	-	Average Treatment Effect
ATT	-	Average Treatment Effect on the Treated
ATU	-	Average Treatment Effect on the Untreated
AU	-	African Union
BCR	-	Benefit Cost Ratio
BCT	-	Buffy Coat Technique
CEM	-	Coarsened Exact Matching
CIA	-	Conditional Independence Assumption
CV	-	Contingent Valuation
DID	-	Difference in Difference
ESR	-	Endogenous Switching Regression
ESRI	-	Environmental Systems Research Institute
ETTSSA	-	Eradication of Tsetse and Trypanosomiasis in Sub-Saharan Africa
FAO	-	Food and Agriculture Organization
FIML	-	Full Information Maximum Likelihood
FTD	-	Flies per Trap per Day
GIS	-	Global Information System
GM	-	Gross Margin

GoK	-	Government of Kenya
GPS	-	Geographical Positioning System
HAT	-	Human African Trypanosomiasis
ICM-FFS	-	Integrated Crop Management Farmer Field School
IIA	-	Independence from Irrelevant Alternatives
IM	-	Integrated Methods
IRM	-	Imazapyr-Resistant Maize
ITC	-	Insecticide Treated Cattle
ITL	-	Insecticide Treated Livestock
ITT	-	Insecticide Treated Targets
KENTTEC	-	Kenya Tsetse and Trypanosomiasis Eradication Council
KES	-	Kenya Shillings
KNBS	-	Kenya National Bureau of Statistics
KCSE	-	Kenya Certificate of Secondary Education
MDAs	-	Ministries Departments and Agencies
MDM	-	Mahalanobis Distance Matching
MNL	-	Multinomial Logit
MNP	-	Multinomial Probit
MVP	-	Multivariate Probit
NGOs	-	Non-Governmental Organizations
NTD	-	Neglected Tropical Disease
OLS	-	Ordinary Least Squares
PATTEC	-	Pan African Tsetse and Trypanosomiasis Eradication Campaign

PCA	-	Principal Component Analysis
PSM	-	Propensity Score Matching
QALYs	-	Quality Adjusted Life Years
RUM	-	Random Utility Model
SB	-	Standardized Bias
SPSS	-	Statistical Package for Social Scientists
STEP	-	Southern Tsetse Eradication Project
TRYRAC	-	Trypanosomiasis Rational Chemotherapy
TTD	-	Treatment with Trypanocidal Drugs
T&T	-	Tsetse and Trypanosomiasis
TLU	-	Tropical Livestock Units
TOC	-	Theory of Change
USD	-	United States Dollars
VIF	-	Variance Inflating Factor
WHO	-	World Health Organization
WI	-	Wealth Index
YLDs	-	Years Lived with Disability

CHAPTER 1 : INTRODUCTION

1.1 Background

Tsetse flies (*Glossina spp*) transmit a fatal zoonotic disease called trypanosomiasis. The disease is known as sleeping sickness in humans and *nagana* in livestock. Tsetse flies infest 37 sub-Saharan African countries covering approximately 9 million km^2 and threaten about 60 million people and 48 million cattle (WHO, 2001). It is one of the greatest constraints to agricultural development in the sub-humid and humid zones of Africa. According to Meyer *et.al 2020*, tsetse fly and typanosomiasis infestation negatively affects health of livestock and thus, leading to economic losses to farmer. Sleeping sickness was under control in Africa during the 1960s and 1970s. However, the last two decades have seen the disease spread to epidemic proportions due to the breakdown of control programmes causing a public health crisis in many affected areas (Smith *et al.,* 1998). If the goal of poverty reduction and food security has to be achieved, this major constraint that hampers profitable livestock production especially for rural farmers has to be removed.

To address the problem, African Heads of States and Governments collectively launched the Pan African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC) project in 2000 with a view of guiding the process of eradicating tsetse flies and trypanosomiasis (T&T). As part of this initiative, the African Union PATTEC (AU-PATTEC), the African Development Bank (AfDB) and the governments of affected countries prepared a proposal for a Pan-African programme, the Eradication of Tsetse flies and Trypanosomiasis in Sub-Saharan Africa (ETTSSA), as well a proposal for the first phase of the eradication campaign (AfDB, 2004). Six countries participated in the Phase I Project, three countries in West Africa (Burkina Faso, Mali and Ghana) and three others in East Africa (Ethiopia, Kenya and Uganda). In Kenya, the area infested by tsetse flies is estimated to be 138,000 km^2 covering 38 out of 47 counties (KENTTEC, 2011). The disease impoverishes livestock farmers and threatens food security and livelihoods. The risk of human sleeping sickness outbreak is high in the Lakes Victoria basin and the Mara Serengeti tsetse belt all with a total human population of about 11 million people at risk of infection (KENTTEC, 2011; KNBS, 2010). The first phase of PATTEC-Kenya project was implemented from 2005 to 2011 covering a total area of 24,000 square kilometres in three tsetse belts namely Lake Victoria basin, Lake Bogoria and Meru/Mwea.

The control of tsetse flies and trypanosomiasis in Pate Island served as a pilot project in the Coastal tsetse belt in an area of approximately 62 square kilometres with control starting in 2010. An integrated approach was adopted to carry out interventions for the eradication of tsetse fly and trypanosomiasis in Pate Island of Lamu County. With community involvement, the PATTEC project used three techniques, namely deployment of Insecticide Treated Targets (ITT) in the farmlands and in conservation areas, use of Insecticide Treated Livestock (ITL) which entailed applying insecticides on livestock, and use of trypanocidal drugs (TTD) for prophylaxis or curative purposes against the disease (KENTTEC, 2010).

According to periodic entomological and parasitological surveillances conducted by the PATTEC project in collaboration with area communities and stakeholders (KENTTEC 2011, 2012, 2013, 2014, 2015), the interventions reduced tsetse fly population from 46 to 0 Flies per Trap per Day (FTD) and disease prevalence from 20 to below 5%, making it possible for the communities to keep livestock profitably. Thus, it was expected that profits earned by livestock farmers could have a positive effect on household income which could translate to improved livelihoods. The direct achievements of tsetse and trypanosomiasis eradication interventions under the PATTEC-Kenya programme include reduction of tsetse fly populations and reduced disease prevalence in cattle and in humans (KENTTEC, 2011; 2012; 2013; 2014; AfDB, 2011).

Choice and application of one or several integrated methods of tsetse fly and trypanosomiasis control methods by livestock farmers must be emphasized as a way of cementing the successes that have so far been achieved. Farmers decide to use one method or a combination of several methods and therefore there are trade-offs when making such decisions. Moreover, choice and integration of tsetse fly and trypanosomiasis control methods is influenced by several factors that include socioeconomic, institutional and technological factors. Thus, the discussion going forward must focus on what drives choice and integration of control methods as well as quantifying the impact of tsetse fly and trypanosomiasis control on farmer incomes and the general wellbeing of the households.

1.2 Statement of the problem

Tsetse fly infestation remains one of the major problems hampering livestock production enterprises in Kenya. Approximately 23 percent of the country, covering 38 out of the 47 counties, Lamu County included, are infested by the flies (KENTTEC, 2011). The economic losses in livestock enterprises are experienced through increased cost of treatment, mortality of infected animals, abortion in animals, reduced milk production and loss of animal draught power. Sub-Saharan African countries continue to promote measures to control tsetse flies and trypanosomiasis. The Government of Kenya in collaboration with area communities promoted the application of different methods to control tsetse flies and trypanosomiasis (*nagana*) in selected parts of Lamu County from 2009. The available options for the control of the vector and the disease included Insecticide Treated Livestock (ITL), Insecticide Treated Targets (ITT) and Treatment with Trypanocidal Drugs (TTD). Livestock rearing households had options of choosing either to use a single method of control or a combination of two or more methods. However, full uptake of the control methods had not been realized possibly due to how household characteristics, technological and institutional factors affect farmers' decisions to adopt the control technologies hence the limited successes. The understanding of the interactions between these factors and farmers' decisions to adopt will feed into the on-going review of tsetse fly and trypanosomiasis eradication policies and strategies to incentivize the control of the vector and the disease. Further to this, periodic surveillance reports of the Kenya Tsetse and Trypanosomiasis Eradication Council (KENTTEC) over the ten-year implementation period of PATTEC indicated a steady decline in tsetse fly populations as well as a reduction in the prevalence of trypanosomiasis in animals in many parts of the study area. The reduction in tsetse fly populations and the decline in trypanosomiasis prevalence in the study area suggests that livestock health had improved, the morbidity and mortality rates in livestock had gone down and hence possible increase in the productivity of livestock and livestock products. The reduced burden of trypanosomiasis in the study area may have therefore resulted to an improved herd structure for cattle, donkeys, sheep and goats kept in the households. As an indicator of herd health and a pathway towards increasing household income, the potential changes in the livestock herd structure needed to be well understood to guide the development of sustainable land management guidelines in tsetse controlled areas. Lastly, it can also be argued that the resultant increase in livestock productivity has in turn had impact on household income yet empirical evidence of impact is lacking. The empirical evidence that tsetse fly and trypanosomiasis control pays off is needed in order for governments and development partners to invest more resources for the eradication of the flies and the disease in the vast areas of Africa which are still tsetse infested and household livelihoods compromised. Documentation of the impact of tsetse fly and trypanosomiasis control on household income will be the basis for developing bankable proposals for the control of tsetse fly and trypanosomiasis in the affected areas hence contributing to poverty reduction.

1.3 Objectives of the study

1.3.1 Overall objective

The overall objective of the study was to assess the impact of tsetse and trypanosomiasis control on household income in Lamu County, Kenya.

1.3.2 Specific objectives

The specific objectives were:

i. To assess the factors that influence choice and integration of tsetse fly and trypanosomiasis control methods among livestock farmers in Lamu County.

ii. To determine the effect of level of integration of tsetse and trypanosomiasis control methods on household livestock herd structure in Lamu County.

iii. To determine the impact of multiple application of tsetse and trypanosomiasis control methods on household income among livestock farmers in Lamu County.

1.4 Hypotheses

The following were the hypotheses for testing:

i. Household socio-economic, institutional as well as technological factors have no effect on choice and integration of tsetse fly and trypanosomiasis control methods among livestock farmers in Lamu County.

ii. Level of integration of tsetse fly and trypanosomiasis control methods has no effect on the herd structure of livestock owned by households in Lamu County.

iii. Multiple applications of tsetse fly and trypanosomiasis control methods has no impact on the income of livestock keeping households of Lamu County.

1.5 Justification of the study

In Kenya, the control of tsetse flies under the PATTEC initiative started in 2005 and was implemented in selected parts of three tsetse fly belts of the country namely Lake Victoria, Lake Bogoria and Meru/Mwea. In 2009 the interventions were rolled out to the Coastal region on a pilot basis. Periodic entomological and parasitological studies were carried out and results showed zero tsetse fly catches and lowered disease prevalence to levels where livestock rearing could be profitable. On the other hand results of socio-economic studies remained qualitative and impacts of the interventions not measured (KENTTEC, 2011, 2012, 2013, 2014). The findings of this study have policy recommendations for the improvement of service delivery as well as bridge the existing knowledge gap on impacts of tsetse control and avail data on impacts to aid resource mobilization for the control of tsetse flies. Firstly the County Governments as implementers of some devolved functions of Government for example will take into consideration key household characteristics as well as technological attributes which may stimulate adoption of appropriate tsetse fly and trypanosomiasis control technologies. More over both County and National Government will consider offering concessionary fees, rates and licenses for the establishment of farm input shops making farm inputs affordable and accessible. The Kenya Tsetse and Trypanosomiasis Eradication Council together with relevant Ministries, Departments and Agencies (MDAs) on the other hand will use the study to develop guidelines on tsetse and trypanosomiasis eradication technologies and their application to ensure effectiveness and efficacy. The findings on livestock herd structure changes will contribute to the development of sustainable land management guidelines for use in tsetse controlled areas where herd sizes may have increased and structure improved. The evidence of impacts from this study will inform the development of resource mobilization proposals and strategies contributing to the improvement of livelihood outcomes in tsetse infested areas by governments, public agencies and non-governmental organizations (NGO).

The study also contributes to the existing stock of scientific knowledge through publication of findings in scientific journals and presentations in seminars and scientific conferences. This will therefore add to the scanty literature on impacts of tsetse fly and trypanosomiasis control. The study provides lessons learnt from implementation of the PATTEC programme to improve future tsetse control programmes rolled out among livestock farmers.

CHAPTER 2 : LITERATURE REVIEW

2.1 The agricultural challenges and solutions

2.1.1 Challenges in sub-Saharan Africa

The world population has quadrupled over the last one century. Recent estimates indicate that the global population increased from 1.8 billion people in 1915 to approximately 7.7 billion people in 2019 (Elferink & Schierhorn, 2016; United Nations, 2019). Furthermore, it is projected that the world's population will increase further to 8.5 billion and 9.7 billion people in 2030 and 2050, respectively. But population growth is disproportionate, with high growth rates in developing countries than developed nations. For instance, population in Sub-Saharan Africa will almost double by 2050 and Northern Africa will grow by almost 46 percent (United Nations, 2019). The largest population growth in Sub-Saharan Africa will occur in Tanzania, Democratic Republic of Congo, Nigeria, and Ethiopia.

The projected increases in population are expected to further raise global demand for food. Recent estimates show that global food demand will increase by between 59 percent and 98percent by 2050 (Valin *et al*., 2014). Much of the food demand will be concentrated in developing countries, where rapid population growth will be accompanied by a rise in per capita income (Fukase & Martin, 2017). However, the United Nations (2019) notes that rapid population growth presents challenges for sustainable development in poor countries. For instance, population growth rate challenges national, regional, and global efforts towards eradicating poverty and achieving greater equality. Aggregate food demand is also affected by income distribution, meaning that between-country income inequality may reduce aggregate changes in food demand (Cirera & Masset, 2010). Additionally, the United Nations (2019) posits that rapid population growth may jeopardize alleviation of hunger and malnutrition in developing countries.

Agriculture is an important sector for meeting the growing food demand. The agricultural sector succeeded in matching the rising global demand for food due to population growth (FAO, 2017; Valin et al., 2013; Keating et al., 2014). According to FAO (2017), global food supply tripled across the world between 1960s and the twenty-first century. One of the impacts of the increase in total food supply was a reduction of the number of undernourished people in the developing world. The proportion of the undernourished population reduced to 14.9 percent between 2010 and 2012 down from 23.2 percent between 1990 and 1992 (United Nations, 2012, 2013). The projected population growth is also expected to continue shaping global agriculture and food systems. Nevertheless, agricultural sector capacity to meet the growing demand for food in the developing countries is threatened by adverse effects of climate change and degradation of natural resources. The challenges are largely attributed to consequences of rapid population increase and slowdown in agricultural expansion.

Sub-Saharan Africa is severely affected by the consequences of population growth and adverse effect of climate variability and change. Extreme weather variability and climate change cause low agricultural productivity and food production which impact on food systems and rural livelihood (FAO, 2019). The slowdown in agricultural production has resulted in a reversal of the gains made in reducing food insecurity and poverty. For instance, the prevalence of undernourished people increased from 22 percent in 2016 to 22.7 percent in 2017 and 22.8 percent, up from 21.7 percent in 2010 and 20.9 percent in 2015 (FAO, 2019). Furthermore, approximately 40 percent of the African population is poor, that is, over 416 million people

(World Bank, 2019a). For instance, approximately 34 percent and 33percent of the Kenya people lived below the international poverty line in 2018 and 2017, respectively (World Bank, 2019b). Besides the impact of climate change on livelihoods of millions of people in the region, significant efforts towards creating economic opportunities for the poor population are missing.

Leveraging of food systems in Kenya and Sub-Saharan Africa is required for alleviation of poverty and improvement in food and nutritional security. Economies need to grow and transform by harnessing new opportunities in the agricultural sector. FAO (2019) identifies increased access to agricultural technology as crucial to opening up new opportunities for the sector. As a result, medium-and long-term policies that revitalize agricultural productivity and food production are paramount. Since agricultural expansion is not sustainable in meeting food requirements in the region and reducing environmental footprint, the increasing demand for food can be achieved by enhancing agricultural productivity. Adoption, integration and intensification of low cost and sustainable productivity enhancing technologies like irrigation, improved crop varieties and livestock breeds, and pest and disease control methods are necessary (Elferink & Schierhorn, 2016). Technological adoption and intensification should be supported by public and private agricultural research and extension activities, and subsidies (FAO, 2017). Supportive government policies need to be well-designed and implemented to avoid market distortions.

Technology is identified as crucial to modernization of traditional agricultural systems in the region by increasing efficiency in agricultural production. Schultz (1964) argued that smallholder farmers in Sub-Saharan Africa are not inefficient, instead, they are constrained by access to improved and modern technologies in both crop and livestock production. This underscores a common argument in literature that improved access to modern and improved technology would unlock the potential of the agricultural sector to alleviation of poverty and food insecurity.

Technology inspires changeovers in agricultural production systems from low productivity peasant, traditional, and subsistence to market-oriented farming. The second pathway via which technology contributes to productivity improvements is that it deepens the market share of the agricultural sector by encouraging efficiency in resource use as well as output diversification (Awotide *et al*., 2016). Technology adoption promotes growth of specialized commercial farming enterprises, boosts competitiveness of the agricultural sector, lower production and agro-processing costs, which, in turn decreases real food prices (Jayne *et al*. 2005). Fuglie *et al*. (2019) argue that increased agricultural productivity allows farmers to raise yields, use inputs efficiently, improve quality of their products, adapt and build resilience to climate challenges, and reduce environmental deterioration. The productivity effects translate into improved livelihoods, incomes, and reduced poverty and vulnerability.

2.1.2 The solution: Livestock production technology adoption

The livestock sub-sector is important to the alleviation of food and nutritional security and poverty. The projected 33 percent increase in world population is expected to increase demand for animal products. Therefore, the livestock sub-sector is a crucial strategy for sustaining agricultural productivity. It is projected that the demand for animal proteins would rise by 70 percent by 2050 (Rojas-Downing *et al*., 2017). Specifically, increasing urbanization, incomes, and population especially in the developing countries has had unprecedented effect on demand for animal products such as meat and milk. Beef and dairy farming and promising options that would improve food and nutritional security and incomes for farmers in Sub-Saharan Africa

(Kibebe, 2015). Tapping present and future opportunities in the livestock sub-sector requires stimulation of uptake of improved livestock production technologies such improved breeds, veterinary supplies, feeding, vector pest control methods, equipment and value addition (Kibebe, 2019).

The potential contribution of livestock to the livelihoods of the poorest households in the world is likely to be constrained by uncertainties in climate variability. Besides the obvious impacts on availability of quality fodder, climate change may affect water availability, livestock productivity, diseases, reproduction and breeds, and biodiversity (Nardone *et al*., 2010; Reynolds *et al*., 2010; Henry *et al*., 2013; Polley *et al*., 2013). For instance, rising temperatures are expected to increase the emergence and increased prevalence of livestock diseases and vectors. The prevalence and spread of climate-induced livestock diseases varies geographically, by disease type, as well as by animal susceptibility and land use practices. Rising temperatures may increase animal morbidity and death from diseases caused by pathogens and parasites spreading vectors (Tubiello *et al*., 2008; Nardone *et al*., 2010). Thornton *et al*. (2009) explain that climate change may cause shifts in disease spreading or trigger occurrence of severe diseases. Additionally, climate change may result in emergence of new livestock diseases and changes in spread and occurrence of ticks, flies, and other vector-borne pests.

The solution to controlling disease vector and pests and preventing the spread of diseases is technology adoption. Technology uptake and diversification of livestock is part of adaptation measures that improve resilience of livestock production systems to extreme effect of climate change (Rojas-Downing *et al*., 2017). Additionally, integration of livestock systems has been cited as an important adaptation measure. Diversification of livestock is crucial to improving the tolerance of livestock and technology improves and sustains production and productivity when the animals are exposed to climate-related diseases as well as outbreak of vector-borne diseases (Rojas-Downing *et al*., 2017). Some of the important livestock technologies and practices that reduce production risks and improve the resilience of livestock system to adverse consequences of climate change include improved feeding practices (Havlík *et al*., 2013), breeding strategies (Henry *et al*., 2012), spraying and shifting grazing (Rojas-Downing *et al*. 2017).

2.2 Tsetse and trypanosomiasis situation in Kenya

Tsetse flies (Diptera: *Glossinidae*) are vectors of Human African Trypanosomosis (HAT) and African Animal Trypanosomosis (AAT). The former is a major neglected human tropical disease and the latter is considered as one of the greatest constraints to improved livestock production in sub-Saharan Africa (Bouyer *et al*., 2014). Available literature recognizes tsetse fly and trypanosomiasis as a problem of Sub-Saharan Africa, affecting 37 countries. The area affected by tsetse fly and trypanosomiasis is approximately 11 million square kilometers (WHO, 2001; Smith *et al*., 1998; AfDB, 2004; KENTTEC, 2011).

In Kenya, there are eight species of tsetse flies, namely *Glossina brevipalpis, G. fuscipleuris, G. longipennis, G. pallidipes, G. austeni, G. swynnertoni, G. fuscipes fuscipes, G. morsitans submorsitans* distributed in seven tsetse belts. The tsetse belt in Kenya covers a total area of 138,000 square kilometers (KENTTEC, 2011). This is approximately 23 percent of the country, that is, 38 out of the 47 counties (KENTTEC, 2011).

The disease affects both humans and animals with economic losses experienced through cost of treatment for humans and livestock, and mortality of infected animals and human lives. It leads to sick and unproductive people, abortion in animals, loss of milk and animal draught power.

Tsetse infestation also makes it impossible to graze in certain areas, leads to lower prices for trypanosomiasis affected animals and poor livestock body conditions. Poor animal conditions make animals unsuitable for slaughter. There is loss of foreign exchange through imports of drugs and loss of opportunity to export livestock and livestock products (KENTTEC, 2011; WHO, 2013).

2.2.1 African Animal Trypanosomiasis

African Animal Trypanosomiasis (AAT) is a parasitic disease that causes serious economic losses. Affected animals become anemic and emaciated. Many untreated cases are fatal. The AAT is found mainly in those regions of Africa where its biological vector, the tsetse fly, exists (KENTTEC, 2011).

The major trypanosomes transmitted by tsetse flies that cause disease in Kenya are *Trypanosoma congolense*, *Trypanasoma vivax*, *Trypanasoma simiae* and *Trypanasoma brucei brucei*. Studies have shown that trypanosomes particularly *Trypanasoma evansi and Trypanasoma vivax* are mechanically transmitted by other biting insects, mainly in camels. Domestic animals are more affected by trypanosomes infection while wildlife animals are reservoirs. The disease has a devastating effect on livestock due to increased mortality, reduced milk yield, low live weight gain, abortions, infertility and increased susceptibility to other diseases (KENTTEC, 2011).

2.2.2 Human African Trypanosomiasis

Human African Trypanosomiasis (HAT) is a disease caused by infection with *T. brucei gambiense* or *T. b. rhodesiense* parasites. The disease is transmitted to humans through the tsetse fly. Approximately 7,216 of HAT cases were reported in 2012 and it is estimated that 20,000 people across Africa are infected (WHO, 2013). According to the Global Burden of Disease, recent estimates of Years Lived with Disability (YLDs)[1] for HAT annually range from 2,000 to 25,000 which is way above the global average burden of disease (Vos *et al.*, 2012). There are approximately 30 African countries affected by this disease, and it has been identified by the WHO as a Neglected Tropical Disease (NTD) (WHO, 2013). In Kenya, HAT is known to be endemic only in the Lake Victoria basin mainly Lambwe Valley in Homa Bay County, Teso area in Busia County and in Siaya County.

2.2.3 Economic losses from livestock diseases and vectors

Vectors and pests infesting livestock are grouped into fleas, ticks, mites, and lice. Narladkar (2018) reported that biting and non-biting ticks and flies are the most important vectors for many viral, protozoan, and bacterial diseases. Narladkar (2018) also added that vector-borne livestock pest possess economic significance on three perspectives; (1) direct losses from their bite and worries, annoyance, and psychological damage produced during the act of feeding and biting, (2) diseases they transmit, as well as (3) expenditure incurred for their control. Mersha *et al.* (2013) posited that tsetse fly and ticks play an important role in transmitting diseases in addition to their direct effects. The importance of ticks, tsetse and diseases are highly related to the economic impact that they impose on the regions where they occur (Rodrigues and Leite, 2013).

Various studies have estimated economic losses associated with vector-borne pests and diseases like trypanosomiasis in livestock production. These economic losses are associated with effects on livestock products such as reduced milk and meat off-take, increasing calf mortality and calving rate, and cost of livestock management. Other losses include decrease in traction power,

[1] Years lived with disability (YLDs) are a measurement of the burden of disease. It is calculated by multiplying the prevalence of a disorder by the short- or long-term loss of health associated with that disability.

reduced work efficiency, and decreased crop production. In Ethiopia, the occurrence of tsetse fly related disease, trypanosomiasis, subjected the community to additional expenditure estimated at about US$ 28.23 and US$ 18.2 per household for purchase of preventive and curative drugs, respectively (Mersha *et al.* 2013). Tick-borne diseases result in substantial losses to the livestock sub-sector throughout the world since they cause serious economic impacts such as lowered working efficiency, death, decreased productivity, and increased cost for control measures (Makala *et al.,* 2003; Ananda *et al.,* 2009). Kivaria (2006) found that ticks resulted in significant economic loss as a result of costs associated with tick control and animal treatment. Rodríguez-Vivasa *et al.* (2017) reported a potential economic impact due to ticks in terms of productivity losses associated with infestation.

Kristjanson *et al*. (1999) conducted a cost-benefit analysis and found that African animal trypanosomosis (AAT) disease caused economy-wide losses to both producers and consumers. Bukachi *et al.* (2017) assessed the socio-economic burden of human African trypanosomiasis (HAT) in Kenya and found that HAT disrupted household food security and incomes through death and cost of medication. Huge economic losses in livestock production resulted from vector-borne pests (ticks and tsetse fly) and diseases like trypanosomiasis.

2.3 Tsetse and trypanosomiasis interventions in Lamu County

There are several methods outlined by KENTTEC reports and past studies applied in the control of tsetse and trypanosomiasis. They include use of insecticide treated livestock, insecticide treated targets, use typanocidal drugs as well as other traditional methods for example bush clearing, avoiding vector infested areas and ethno-veterinary practices. The other methods outlined by Shaw *et. al* (2018) include sequential aerosol treatment which entails either ground spraying or aerial spraying depending on the ability of the farmer. In the study area, three methods of control of tsetse fly and trypanosomiasis that are widely applied are discussed as follows:

2.3.1 Use of insecticide treated livestock

The Insecticide Treated Livestock (ITL) also referred to as moving targets, involves using livestock treated with insecticide as live baits to attract and kill tsetse flies on contact. This technique involves using insecticides to spray, dip or apply pour-on to livestock then using the animal as bait in the grazing field, which kills the flies when they bite.

According to Vale and Torr (2004) and Van den and De Deken (2004), the use of this technique as mobile baits simultaneously controls ticks, other vectors and nuisance insects and tsetse flies, and can be integrated into farmers' existing tick control regimes. The PATTEC project promoted the use of the technique in Pate Island where members of the community constructed crush pens for spraying livestock, applied pour-ons or dipped the animals to serve as live baits for killing tsetse flies while grazing out in the fields (KENTTEC, 2010). Figures 2.1 and 2.2 show pictures of how cattle are sprayed or dipped as a measure to control tsetse flies. According to KENTTEC report, this method is generally laborious when compared to other methods. However, the spraying or dipping interval of two weeks allows livestock farmers to do other activities without having to closely monitor the animals. In the project area, the first chemicals used for spraying and dipping was provided by government as seed capital so that the little fee charged from the farmers could sustain the programme.

Figure 2.1: Application of insecticides by spraying of livestock.

Figure 2.2: Application of insecticides by dipping of livestock

2.3.2 Use of insecticide treated targets

The Insecticide Treated Targets (ITT) method also referred to as stationery targets, involves use of insecticide treated clothes fitted with metal frames that attract and kill tsetse flies on contact. The net or trap is treated with an insecticide and deployed in tsetse fly prone areas. The use of this technique, to protect individual cattle compounds or Zero Grazing Units has been documented to have an impact on overall tsetse populations (Bauer *et al*., 2006, Maia *et al.*, 2010).

This technique is considered to confer public benefit to livestock in the entire area of interventions as opposed to protection of individual farms (Swallow *et al*., 1995). Bauer *et al.* (2006) and Maia *et al*. (2010) report that targets can have an impact on overall tsetse populations, implying that the approach can be used on a significant scale to suppress tsetse flies. In Kenya, insecticide treated target screens were used in Pate Island in farm lands and thickets according to technical specifications. The targets serve as stationery baits killing tsetse flies within a given area. In Uganda, *G. fuscipes* has been controlled by use of traps (Okoth *et al*., 1991). In some locations infested by flies of the *palpalis* group, much higher trap densities have been used (Vale and Torr, 2004). The picture of insecticide treated tsetse target and a trap is shown in Figures 2.3 and 2.4 respectively.

Figure 2.3: Insecticide treated tsetse target screen used for the control of tsetse flies.

Figure 2.4: A tsetse trap used for monitoring tsetse fly populations

2.3.3 Treatment with trypanocidal drugs

Treatment with Trypanocides Drugs (TTD) is a method often used for prophylaxis and curative purposes (Holmes *et al*., 2004). The baseline surveys conducted in Pate Island indicated that trypanocidal drugs were used either for treatment or prophylactic purposes (KENTTEC, 2010). Laker (1998) estimated that, on average, 1.9 doses of trypanocides are given in dairy herds per head per annum. However, the dosage to other cattle populations is likely to be between 1 and 2 doses.

2.4 Theories underpinning impact evaluation

2.4.1 Utility theory

Utility as a concept in economics is seen as an abstract measurement of the degree of goal-attainment or want-satisfaction provided by a product or service. One cannot measure directly how much utility a person may gain from a product or a service. However, inferences can be made about utility based on individual's behaviour, presuming that people act rationally. Thus, it follows that a rational person acts to increase utility (Train, 2003). Essentially, this means that consumer preferences can be revealed by their choice habits.

Utility theory is sometimes referred to as theory of consumer behaviour. It explains the consumers' decision making process and the resulting consequences (Shi and Wang, 2019). This theory was put forward by Daniel Bernoulli in the 18th century and has been improved overtime in the application of various choice making situations. A consumer faced with a set of choices will choose a combination that maximizes utility assuming that the assumption of rationality is upheld. Utility is subjective and therefore only choices made by the consumers are observed.

Choices are usually based on the benefits derived or losses to be accrued. The final outcome is that consumers present subjective values of utility in a linearized form. The expected utility will thus, depend on probability of possible outcomes (Stigler, 1950).

The current study assesses farmers' choices of tsetse fly and trypanomiasis control methods and thus such decisions can be explained by utility theory. However, farmers make decisions to apply one method at a time or a combination of two or three methods depending with how effective the methods are. Moreover, farmers were free to switch from one method to the other and this depended with other factors other than utility aspects for example availability of the technology. Therefore, this study could not be anchored directly on utility theory.

2.4.2 Random utility theory

Random utility theory posits that a choice decision is made by an individual *i* from a set of alternatives *j* (McFadden, 1978). Consumers choose from an array of alternatives that are fundamentally different based on specific product attributes and their trade-offs. Individuals have a set of available consumption choices and whichever alternative that is chosen maximizes their utility

For the i^{th} individual faced with *j* choices, suppose that the utility of choice *j* is

$$U_{ij} = z_{ij}^{'}\theta + \varepsilon_{ij} \qquad 2.1$$

Where

U_{ij} is utility of choice *j* for individual *i*

Z_{ij} includes aspects specific to individual *i* as well as the choice *j* that the individual makes.

If the individual makes choice *j*, then it is assumed that U_{ij} is the maximum among the *j* utilities. Hence, according to Greene (2012), the statistical model is driven by the probability that choice *j* is made, which is:

Prob ($U_{ij} > U_{ik}$) for all other $k \neq j$. ……………………...…………………………………….2.2

If Y_i is a random variable that indicates the choice made by individual *i* and where x_{ij} are called the attributes of the choices while the w_i contains the characteristics of the individual the probability of choice decision is presented as follows:

$$\text{Prob}(Y_i = j \mid w_i) = P_{ij} = \frac{\exp(w'_i \alpha_j)}{1+\sum_{k=1}^{J}\exp(w'_i \alpha_k)}, \; j = 0,1,\ldots\ldots\ldots, J \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.3$$

Where

Y_i is a random variable that indicates the choice made by individual *i*

P_{ij} is a set of probabilities for the J+1 choices for an individual making the decision

j is the choice made by individual *i* from among *J* choices

J is the number of choices facing individual *i*

w_i is a set of characteristics of individual *i* (the decision maker)

Equation 2.3 simply captures the probability that individual *i* makes choice *j* given a set of characteristics, *w*, of that individual.

According to Hanemann (1984), is the latent utility derived by an individual household from choosing to buy fertilizer form source, is the observable systematic component of utility, and is the stochastic error term unobservable to the researcher and treated as a random component. This study applied the unordered multiple choices set model as opposed to ordered choices where an individual reveals their preferences for the choices they make. In this study, the choices to be made were from a set of tsetse fly control methods which the farmer had to adopt to reduce or eliminate the problem of tsetse flies and the disease. According to Greene (2012), unordered choice models can be motivated by a random utility model. The current study was thus anchored on random utility theory.

2.4.3 Means-end chain theory

Means-End Chain (MEC) theory, has recently been applied in consumer decision making process although it applies principles of economics psychology and departs from neoclassical economic theory. This theory was developed by Gutman (1982) and later improved by Reynolds (2010). Several, recent studies focusing on factors that influence choice decisions by consumers have applied this theory (Santosa and Guinard, 2011).

The MEC theory posits that product attributes are linked to consequences in consumers' mind. These consequences are driven by personal goals that individuals yearn to fulfill in life. Attributes are recognizable product features such as smell, colour, taste and texture of bread for example. According to Arsil *et al.* (2014) and Okello *et al.* (2014), consequences refer to outcomes individuals get after consuming a given product. Personal values are goals, cognitive representations or desires that determine decisions by individuals to consume a given product. They are the end states and can either be individual or societal expectations.

Consumers' choice of a product is influenced by goals which act as stimulus to action (Aarts *et al.,* 2008). The linkage between attributes-consequences-values (A-C-V) form connections in a hierarchical manner. This is referred to as MEC hierarchy that comprise of attributes at the base then consequences and personal values or goals at the top. Goals exist in individual minds and require special methods for example the laddering technique to retrieve them. This study did not deploy this method when collecting data and thus MEC theory was not applied.

2.4.4 Theory of change

A theory of change (TOC) describes the causal assumptions behind the links in the results chain; what has to happen for the causal linkages to be realized (Blamey and Mackenzie, 2007; Leeuw, 2012; Rogers, 2008; Weiss, 1995). Theories of change lead to the understanding of how and why the activities of the intervention are expected to lead to the desired results. The use of ToC in development evaluations has been reviewed by James (2011); Stein and Valters (2012) and Vogel (2012) and all point out that TOC uses intuitive notions of reaching some target group, changing their motivation and behavior. This results in direct benefit to them and subsequent improvements in their wellbeing as opposed to the more traditional model using outputs, immediate outcomes, intermediate outcomes and final outcomes or impact (Douthwaite *et al*., 2007).

Measurement of these impacts presents a large variety of econometric complications. The ultimate objective of an analysis of a treatment or intervention would be the effect of treatment on the treated. In literature it is documented that measuring this effect econometrically encounters at least two compelling computations namely endogeneity and missing counterfactuals (Greene, 2012; Roy, 1951; Rubin, 1974). In the endogeneity of the treatment problem, the analyst risks attributing to the treatment causal effects that should be attributed to factors that motivates both the treatment and the outcome. Drawing an example from tsetse control, an individual farmer who participates in tsetse control might well have succeeded more in life than their counterpart who did not participate even if they themselves did not participate in tsetse control.

On the other hand, with the missing counterfactual problem, in order to measure the impact of tsetse control on individual farmer's income, we would have to run an individual’s lifetime twice, once with participation in tsetse control and once without. But any individual is observed in only one of the two states, so the pure measurement is impossible leading to the missing counterfactual problem. Greene (2012) points out that accommodating these two problems, the endogeneity of treatment and the missing counterfactual, forms the focal point of this enormous and still growing literature on program evaluation and Rubin’s causal model (1974, 1978) provides a useful framework for the analysis.

Measurement of the impact of tsetse fly control on individual farmer's income would involve estimating the impact of ‘with’ and ‘without’ intervention outcomes. However, absence of the without situation is a major challenge because an individual is observed in only one of the two states. Therefore, the pure measurement is impossible, which leads to missing counterfactual problem. Greene (2012) points out that accommodating endogeneity and the missing counterfactual problem forms the focal point of the enormous task of measuring impact.

The current study finds theory of change appropriate since it focusses on application of tsetse fly and trypanosomiasis control methods by farmers either singular or when combined and expected changes on household income.

2.4.5 Program theory

Funnel and Rogers (2011) and Sedani and Sechrest (1999) explain that the program theory consists of a set of statements that describe a particular program, explain why, how, and under what conditions the program effects occur, predict the outcomes of the program, and specify the requirements necessary to bring about the desired program effects. Program theory modeling uses three components to describe the program: program activities or inputs, the intended outcomes or outputs, and the mechanisms through which the intended outcomes are achieved (Reynolds, 1998; Rogers, 2000; Rogers *et al.*, 2000; Lipsey, 1993; Sedani & Sechrest, 1999).

A program theory is graphically captured in a logic model which describes logical linkages among program resources, activities, outputs and short, intermediate, and long-term outcomes related to a specific problem or situation (Funnell & Rogers, 2011). The most basic logic model uses words and graphics to describe the sequence of activities thought to bring about change and how these activities are linked to the results the program is expected to achieve. The components of Basic Logic Model are shown in Figure 2.5.

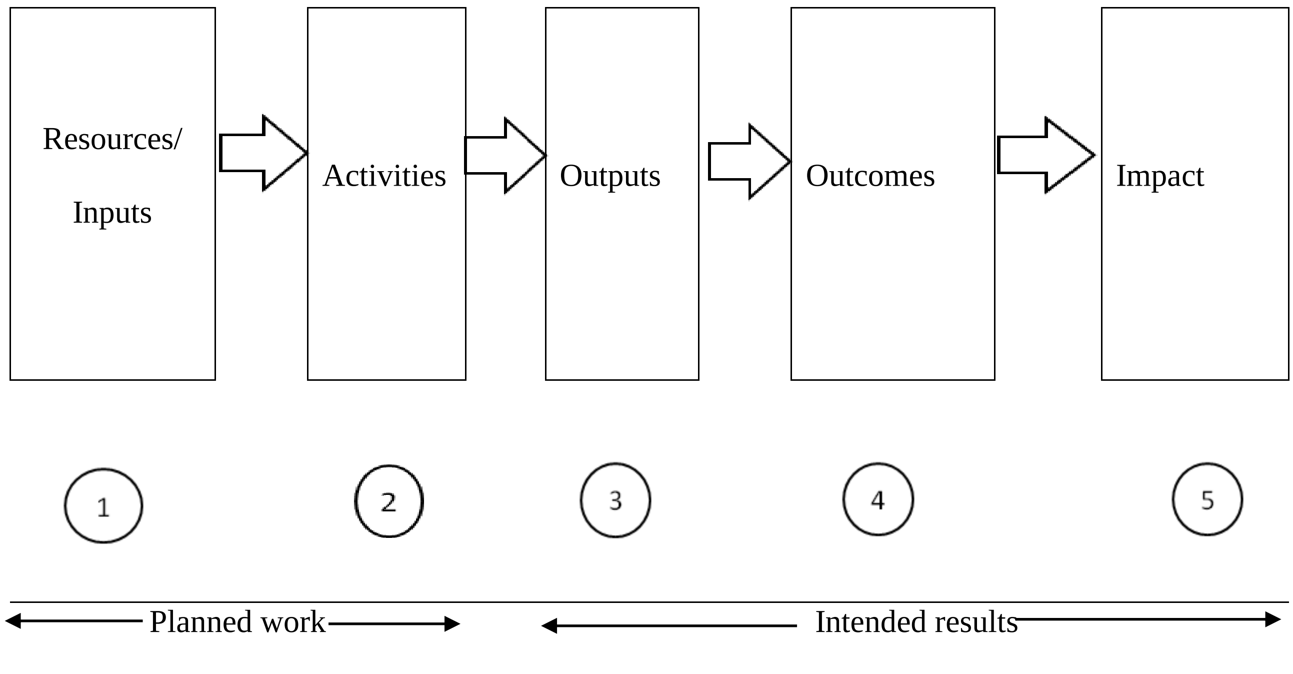

Figure 2.5: The basic logic model

In the basic logic model, planned work describes the resources and activities needed to implement the program and activities to be carried out. Resources include the human, financial, organizational, and community resources that a program has to direct toward doing the work. Program activities are what the program does with the resources. Activities are the processes, tools, events, technology, and actions that are an intentional part of the program implementation. These interventions are used to bring about the intended program changes or results. Intended results include all of the program's desired results (outputs, outcomes, and impact). Outputs are the direct products of program activities and may include types, levels and targets of services to be delivered by the program. Outcomes are the specific changes in program participants' behavior, knowledge, skills, status and level of functioning. Impact is the fundamental intended or unintended change occurring in organizations, communities or systems as a result of program activities. Unlike the theory of change, the program theory does not lead to the understanding of how and why the activities of the intervention are expected to lead to the desired results.

2.5 Empirical literature on choice of tsetse fly and trypanosomiasis control methods

Adoption literature highlight a number of factors that encourage or constraint technology adoption. A number of studies are in agreement that the adoption of agricultural technologies depends on a range of personal, social, cultural and economic factors, as well as on the characteristics of the innovation itself (Pannell et al., 2006; Loevinsohn et al. 2012). However, literature on technology adoption in livestock production is scanty compared to crop production as noted by Elliott *et al*. (2013). Additionally, Rosenstock *et al*. (2019) observes that literature on livestock technology adoption is skewed towards improved livestock and gives less attention to other livestock management practices and technologies such as vector-borne pests and disease control, pasture management, and improved breeds. Therefore, the study provides a brief literature review of the determinants of livestock technology use.

Lima *et al*. (2018) investigated the determinants of adoption of precision livestock technologies in Wales and England. The study applied multivariable logistic regression to estimate the determinants of adoption and intention to adopt electronic identification technology. Lima *et al*. (2018) found technology attributes were significantly associated with farmers' decisions to adopt. The convenience of the technology, time and ease of use were significantly associated with electronic identification technology adoption. Additionally, farmers who strongly believed that the technology was useful had higher odds of adoption. The usefulness was rated in terms of health, productivity, and breeding benefits of electronic identification technology.

Michels *et al*. (2019) went beyond the economic reasoning of technology adoption by investigating drivers of adoption and use of herd management smartphone applications. The study was anchored on technology acceptance model and applied the partial least squares model in estimating the frequency of technology use in herd management. The results supported Lima *et al*. (2018) finding by indicating that ease of use and usefulness of the smartphone application drove the adoption. Michels *et al*. (2019) found a positive association of the two technology attributes with farmer intentions to use and the actual usage behaviour. They argued that ease of use enhanced dairy farmers' decision-making process which, in turn influenced actual adoption. Farmers’ perception that the technology would fit well in farm routine operations and be useful in herd management encouraged adoption.

Livestock technological products and innovations may substitute or complement each other. Therefore, Campbell *et al*. (2019) examined drivers of Tanzanian farmers' preferences of Newcastle vaccines. The study used household surveys, focus group discussion, and key informant interviews to elicit determinants of the use of vaccines. Logistic regression analysis was used to analyze farmers' choices of vaccines. Logistic regression estimates indicated that price predicted the choice of Newcastle vaccines. Campbell *et al*. (2019) observed relative changes in vaccine prices impacted on the variable cost of acquisition of the vaccines across village, which was identified by focus group discussions as well as key informants. The price discrepancies made households to incur additional costs, which, in turn, determined the choice of vaccine. Households indicated the vaccines were effective, although their availability varied by village. The interchangeable use of the vaccines was, therefore, attributed more to availability than effectiveness.

Technology adoption allows producers to improve productivity and quality on farm. Therefore, farmer and farm level characteristics may be important determinants of adoption. Elliot *et al.* (2013) studied producer and farm level characteristics on the adoption of reproductive technology (artificial insemination) among beef farmers in Missouri. Farm level or operational characteristics that were the focus of the study were farm size and herd size. Farmer characteristic included experience in livestock farming, age, education, as well as knowledge and information. Results from univariate probit model indicated that farm level characteristics had the largest marginal impact on adoption of reproductive technologies while farmer characteristic had the lowest marginal effects (Elliot *et al*., 2013). Farm size, herd size, and the age of the farmers significantly affected adoption of artificial insemination.

Muddassir *et al*. (2016) established that the age of the farmers was a significant determinant of adoption of fish farming practices in Pakistan. Younger farmers were more likely to adopt fish farming practices compared to older farmers. Agustine *et al*. (2019) used multinomial logistic regression to analyze the determinants of adoption of frozen bull semen in Indonesia. The study found that households' size, land ownership, and farmer knowledge were significant determinants of adoption. Muddassir *et al*. (2016) established that farmer characteristics were associated with adoption of recommended fish farming practices in Pakistan.

Campbell *et al*. (2018) identified determinants of Newcastle vaccine uptake among smallholder farmers in Tanzania and found that large flock size was an important predictor of adoption. Farmers' knowledge of fellow farmers vaccinating their poultry increased the odds of adoption. In another study, Gargiulo *et al*. (2018) found that large herd sizes were positively and significantly associated with farmer decisions to adopt technologies such as automated milk systems and cup removers. Gargiulo *et al*. (2018) explains that large farms in terms of herd size enjoy economies of scale, making it easier for them to adopt. The study corroborated earlier results by studies by Edwards *et al*. (2015) in New Zealand and Dharma *et al*. (2012) in Australia. Edwards *et al*. (2015) and Dharma *et al*. (2012) found that large herd sizes and farms improved adoption of milking practices and feed technologies, respectively.

Farmer attitude and perceptions also drive adoption decisions. Bruijnis *et al*. (2013) reported that farmers' positive attitude towards good health of livestock foot was positively correlated with intentions to use farm management practices that improve foot health. In another study, Ritter *et al*. (2015) found that farmer participation in voluntary Johne’s disease control intervention was driven by farmers' knowledge and attitude towards the disease. Attitude also played a major role in farmer use of either blanket dry treatment or selective dry cow treatment. Besides farmers’ knowledge and livestock production experience, Toma *et al*. (2015) found that attitude moderated farmer willingness to adopt control measures against Escherichia coli infections. In a similar study, Velde *et al*. (2015) also found that positive attitude towards anthelmintic drugs influenced farmers' intention and decision to use diagnostic methods before administration of the drug. Negative attitudes reduced the probability of farmers' uptake of diagnostics and anthelmintic drugs.

Social and institutional support is important in encouraging technology adoption and continued usage. Examples of social and institutions innovations include social capital, farmer groups, extension services, credit and insurance. Amare *et al*. (2019) examined factors that determine farmers’ access to index-based livestock insurance among pastoral communities in Ethiopia. Applying binary logistic model, the study found that better education, participation in off-farm activities, membership to social organizations, access to credit, awareness of livestock insurance influenced farmers' uptake of livestock insurance schemes as an adaptive strategy to the adverse effects of climate change on livestock. The study did not only underscore the role of institutions on awareness, education, and off-farm activities in the uptake process, but also pathways to adoption of other farm-level livestock management practices. Furthermore, Amare *et al*. (2019) found evidence that distance to the weather stations, which provide weather and climate-related information, reduced the likelihood of uptake of index-based livestock insurance.

Knowledge transfer activities are important in technology adoption process. Consequently, Heffernan *et al*. (2011) explored factors that influence diffusion and adoption of vaccination among poor farming households in India. The study found that social systems drove the adoption of vaccination at macro-level. Knowledge frames drove micro-level adoption of vaccination. Mutua *et al*. (2019) examined drivers of uptake of vaccines for the control of rift valley fever in Kenya and Uganda. Results from content analysis revealed that besides the direct and indirect costs of vaccines, farmers' decisions to adopt the vaccines were negatively influenced by accessibility to crushes and distance to vaccination point and lack of adequate information about the technology.

Ritter *et al*. (2017) investigated the determinants of infectious diseases control in Canada and found that extension services were important influencers of adoption. The authors propounded that extensionists act as social referents in the provision of technical information on control methods of infectious diseases. Extension advisors provide personalized approaches to information delivery such as individual communication and participatory group learning. Personalized delivery of information usually tailors technological recommendations that are specific to farmers' situations (Ritter *et al*., 2017). The approach elicits positive and desired behaviour which positively influences adoption. However, Olorunfemi *et al*. (2019) argues that the effectiveness of extension services in delivery of the climate-smart technology information depends on educational qualification, years of experience of extensionist and area of coverage by the extension officers.

Social networks are a source of information and also facilitate multifaceted interactions among agents in the agricultural value chains. Vishnu *et al*. (2019) used social networks analysis to map social networks that are crucial to overcoming low level of vital livestock technology uptake in Kerala region of India. The study focused on dairy-farmers' uptake of calcium supplements that are important for enhancing milk productivity. The study focused on three categories of information; local interpersonal, cosmopolite interpersonal, and cosmopolite impersonal (Vishnu *et al*., 2019). Local interpersonal information was sourced from fellow farmers, elite farmers, and relatives and family members. Cosmopolite interpersonal were sourced from veterinary doctors, extension officers (private and public), milk cooperatives and producer groups, and input dealers. On the other hand, cosmopolite impersonal sources were mass media sources like newspapers, magazines, and television. Social network analysis showed that the social networks enabled farmers to access information. In particular, Vishnu *et al*. (2019) found social networks were more important in technology adoption than mass media. Veterinary officers provided the most crucial information that led to the adoption of calcium supplements. The study also established that irrespective of the gender and location of the farmer, small-sized homogenous peer groups supported technology use among dairy farmers. The authors attributed the findings to meaningful interactions and information sharing among peer group farmers.

2.6 Empirical literature on impacts of tsetse and trypanosomiasis control

There is dearth of literature on the effect of integration of livestock technologies on herd size and structure. Studies that have attempted to draw the relationships between adoption and herd size and structure miss the link to livestock structure. Kramer *et al*. (2019) focused on the short-term and mid-term implication of dairy barn on herd size in Switzerland. Results indicated that dairy barn had a direct effect on herd size in the mid-term. Brotzman *et al*. (2018) investigated the impact of dairy management practices such as freestall housing and parlor milking on improvement of the overall herd performance. Result indicated that variations in application of the management practices explained the differences in herd performance. Gaddis *et al*. (2016) using stepwise logistic regression found that herd turnover, parity and weather conditions were important predictors of healthier herds. None of these studies investigated herd structure which is the focus of the current study.

Gwaza *et al*. (2018) assessed the herd structure in Nigeria and established that herd structures were poor. The authors attributed the problem to inbreeding and lack of efforts to retain heifers as replacement stock. In particular, the number of heifers and bulls in the herd was low. Additionally, there were disproportionately higher numbers of cows than heifer. The low number of heifers and bulls against cows was attributed to the selection of the former for sale in the local market. Another attribution to the poor herd structure was the decreased pregnancy rates resulting from longer intervals between parturition. The Gwaza *et al*. (2018) recommended adoption of livestock reproductive technologies such as improved breeds and artificial insemination as solution to the poor herd structure.

Lubungu (2017) examined drivers of herd size growth in Zambia in terms of inflows and outflows. The study revealed net positive herd inflows which were attributed to reduced mortality rates. The decline in mortality rate was attributed to government intervention that implemented nationwide vaccination of animals against outbreaks of bovine pleuro- pneumonia. Additionally, improvements in herd structure was influenced by livestock restocking program that was supported by international agricultural development partners. Thereafter, the government commenced another vaccination program against east coast fever and foot and mouth disease. Furthermore, Lubungu (2017) attributed the improvement in herd structures to provision of preventive health care and other animal health programs to smallholder livestock producers. The services helped to build herd size through increased live births.

2.6.1 Socio-economic impacts of tsetse and trypanosomiasis control

The economic analysis of African Trypanosomosis can be traced back to estimates of the costs of control, progressing to studies on the impact on livestock productivity and to project-based benefit–cost studies for specific areas where disease control operations were undertaken (Shaw, 2004). In Eastern Africa for example, Shaw *et al*. (2014) calculated the potential benefits from the removal of bovine trypanosomosis. They used demographic herd parameters including birth, death and off-take rates to project cattle populations in a series of spatially defined production systems over a 20-year study period using ‘with trypanosomosis’ production parameters. The output from the herd, in terms of milk, meat, animal traction and off-take was calculated and prices applied to estimate income year by year. The same procedure used to calculate income was then repeated using the ‘without trypanosomosis’ production parameters. The difference between the two income streams gave the potential benefits from the disease’s absence. These figures were estimated per bovine and applied to cattle population density maps that were projected using herd growth and spread models to provide a monetary value for the benefits of disease removal per square kilometer.

Bouyer *et al.* (2014) assessed the impact of farming systems on cattle productivity parameters including herd size and milk production and on economic variables including animal sales price, and annual sales using an analysis of variance. Binomial generalized linear models were used to compare cattle mortality and birth rates within the farming systems. The main indicator used to calculate benefits in this study was ‘‘cattle sales’’ corresponding to the total cash income for livestock producers coming from animal products (milk and meat). The 2 percent cattle replacement rates found in the Zanzibar case was applied in the Niayes areas of Senegal to estimate the potential benefits of tsetse elimination resulting in Benefit-Cost ratios ranging from 0.98 to 4.26 depending on the discounting rates and scenarios analyzed.

A study implemented two and five years after the completion of the eradication operations in Zanzibar (Feldmann *et al*., 2005) found that the average monthly income of farm households increased by 30 percent in the period of 1999 to 2002. Additionally, the proportion of households with a monthly income of over 25 USD and over 50 USD increased from 69 percent to 86 percent and from 22 percent to 36 percent, respectively. The increase in income resulted from increases in the proportion of small-scale farmers holding indigenous cattle, proportion selling milk from indigenous cattle, proportion using oxen for ploughing and proportion holding improved cattle breeds.

Vreysen *et al*. (2014) reviewed the ex-post socio-economic surveys conducted in Zanzibar Island after the elimination of a *Glossina austeni* population and showed an estimated initial replacement rate of 2 percent per year of traditional to improved livestock breeds. The surveys concluded that the proportion of small-scale farmers keeping indigenous cattle increased from 31 percent to 94 percent between 1985 and 2002, while the proportion selling milk from indigenous cattle increased from 11 percent to 62 percent between 1985 and 1999. The proportion using oxen for ploughing increased to 5 percent in 2002 and the percentage of farmers keeping improved cattle breeds increased from 2 percent to 24 percent in the period of 1985 to 2002.

Technology adoption affects livestock productivity and household economic status. Shaw *et al*. (2014) mapped the economic benefits of controlling bovine trypanosomiasis based on the ‘with’ or ‘without’ tsetse fly scenarios. Shaw *et al*. (2014) demonstrate remarkable benefits from implementation of tsetse fly and trypanosomiasis control methods in Kenya, Ethiopia, Southern Sudan, and Somalia. However, the benefits were uneven. Using the basic cattle herd model, the study hypothesized that reduction of livestock mortality associated with bovine trypanosomiasis would impact on livestock offtake and calving rates, milk yield, and improved draught power. Results indicate that the actual implementation of the tsetse fly and bovine trypanosomiasis control methods would be important pathways to economic benefits. The pathways are increased income through improved productivity and income increases.

Bouyer *et al*. (2014) found that elimination of tsetse fly in infested areas increased the productivity and potential of cattle sales in Senegal. The effect of the tsetse fly control methods differed by type of cattle production system. Vreysen *et al*. (2014) measured the socioeconomic impact of the pour-on tsetse fly eradication in Unguja Island, Zanzibar. The survey was conducted two and five years after project implementation. Results indicated that the number of smallholder farmers keeping indigenous livestock increase by approximately threefold. Milk marketing increased by almost six times in a span of 14 years as a result of productivity gain. Milk production almost tripled within the same period. In the mid-term, pour-on technology increased the usage of oxen draught power. However, utilization of the oxen draught power reduced in the long-run. Furthermore, Vreysen *et al*. (2014) established an increase in the demand for improved livestock breed as a result of tsetse fly eradication program. Increased demand for improved livestock breed and the accompanying productivity gains translated into increased household incomes. The average monthly incomes increased by between 22% and 86%. Vreysen *et al*. (2014) associated the changes to eradication of tsetse fly and trypanosomiasis. Furthermore, tsetse fly eradication encouraged livestock and crop integration.

Meyer *et al*. (2018) calculated the benefits and cost associated with the control of Animal African trypanosomiasis (AAT) in Cameroon and Zambia. The evaluated practices were insecticide-treated targets (ITT), insecticide treatment of cattle (ITC), sequential aerial spraying (SAT) and trypanocidal drugs. The findings revealed that SAT had higher benefit-costs ratio compared to targets. The authors explain, however, that integration of the control methods resulted in higher benefit. The benefits are attributed to the productivity gains resulting from increases in herd sizes rather than productivity in terms of livestock products. Sutherland *et al*. (2017) reports that the benefits of integration of emerging and contemporary tsetse fly control methods were effective in reducing the flies and AAT compared to contemporary drugs. The economic benefits associated with adoption of new tsetse fly and AAT control methods were significantly higher.

In other livestock technology adoption studies, Kibebe *et al*. (2017) applied matching methods to estimate the effect of adoption of improved forages and cross-breed dairy cows on household nutritional status and income in Ethiopia. The study found that adoption has positive and significant effect on nutrition and incomes. In another study, Hussain *et al*. (2019) found evidence that vaccination reduced the spread of foot and mouth disease in Pakistan. Reduced disease prevalence reduced economic costs associated with treatment and death of livestock.

2.6.2 Indicators of household welfare

There are various indicators of welfare that may be used as outcomes to gauge impacts of a program. Baker (1960) considers poverty measures including head count index, poverty gap index, squared poverty gap and Watts's index. The head count index measures the proportion of the population living in households with income per person below the poverty line while the poverty gap for each household is the difference between the poverty line and the household income (Ravallion, 1994). The two methods are however not distribution sensitive. Some distribution sensitive measures include Watts index which is the mean of log of the ratio of the poverty line to income (Atkinson, 1987).

According to Deaton (1997), expenditure-based economic status indicators have been found to be more reliable than other indices. Moreover, wealth levels estimated using asset indicators can also be used as measures of welfare. Filmer and Pritchett (2001) popularized the use of Principal Component Analysis (PCA) for estimating wealth levels. PCA provides plausible and defensible weights for an index of assets to serve as proxy for wealth. Asset-based measures depict an individual or a household's long-run economic status and therefore do not necessarily account for short-term fluctuations in economic well-being or economic shocks. This study however focused on household income so as to take into account the direct changes in livestock incomes due to tsetse fly and trypanosomiasis control. Moreover, although wealth indexes may tap a long term dimension of economic well-being of the households (Cordova, 2008), it was more preferable to capture the change that could have occurred due to program interventions in the study area.

2.6.3 General methods used in evaluating program impacts

In program evaluation, an individual who has participated in the program is paired with an "otherwise comparable" individual or set of individuals who have not participated. It also involves establishing what would have happened to the outcomes of non-participants if they had participated. A number of econometric and statistical methods are available for measuring differences between persons receiving treatment and potential matching partners.

2.6.3.1 Simple before-after estimator

The before-after estimator is a comparison strategy based on panel, longitudinal or repeated cross-section data. It exploits the idea that persons can be in both states at different times, and that outcomes measured in one state at one time are good proxies for outcomes in the same state at other times at least for the no-treatment state (Heckman, 1999). This gives rise to the motivation for the simple "before-after" estimation, which is still widely used. The before-after estimator assumes that there is access to either longitudinal data on outcomes measured before and after a program for participating persons or to repeated cross-section data from the same population where at least one cross-section is from a period prior to the program. Assuming that $E(Y_{0t} - Y_{0t'} \mid D = 1) = 0$, Heckman (1999) points out that the "before-after" estimator in the scenario where longitudinal data are available is given by:

$$(\bar{Y}_{1t} - \bar{Y}_{0t'}) \qquad 2.4$$

where

Y_{1t} = outcome of a person who participates in the program at time t (after the program).

$Y_{0t'}$ = outcome of the person if he does not participate in the program at time t' (before the program).

Subscript "$_1$" = conditioning on program participation, D (D = 1 if the person participates and D=0 if otherwise).

"$\bar{Y}$" = Sample means

Heckman and Robb (1985) note that the before-after estimator has the advantage that it only requires information on the participants and their pre-participation histories to evaluate the program. The major drawback to this estimator is its reliance on the assumption that the approximation errors average out. This assumption requires that among participants, the mean outcome in the no-treatment state is the same in t and t'. Changes in the overall state of the economy between t and t', or changes in the life cycle position of a cohort of participants, can violate this assumption.

2.6.3.2 Cross-section estimator or simple treatment versus control estimator

The cross-section estimator compares mean outcomes of participants and non-participants at time t. It does not compare the same persons because by hypothesis, a person cannot be in both states at the same time (Heckman, 1999). Because of this fact, cross-section estimators cannot estimate the distribution of gains unless additional assumptions are invoked beyond those required to estimate mean impacts. According to Heckman (1999), the key identifying assumption for the cross-section estimator of the mean is that $E(Y_{0t} \mid D=1) = E(Y_{0t} \mid D=0)$;

i.e., that on average, persons who do not participate in the program have the same non-treatment outcome as those who do participate. If this assumption is valid, then the cross-section estimator is given by:

$$(\bar{Y}_{1t})_1 - (\bar{Y}_{0t})_0 \qquad 2.5$$

The advantage of this estimator over the before-and-after estimator is that as long as the macro economy and aging process operate identically on participants and non-participants, the cross-section estimator is not vulnerable to the problems that plague the before-after estimator. The weakness of the cross section estimator method is that one person cannot be in two different places at the same time and so one compares two different persons who may have different management regimes.

2.6.3.3 Difference-in-Difference (DID) estimator

A more widely used approach to the evaluation problem assumes access to either longitudinal data or to repeated cross-section data on participants and non-participants in periods t and t'. If the mean change in the no-program outcome measures are the same for participants and non-participants, that is, if the assumption that $E(Y_{0t} - Y_{0t'} \mid D=1) = E(Y_{0t} - Y_{0t'} \mid D=0)$ is valid, then the difference-in-differences estimator given by:

$$(\bar{Y}_{1t} - \bar{Y}_{0t'})_1 - (\bar{Y}_{0t} - \bar{Y}_{0t'})_0 \qquad 2.6$$

is valid for $E(\Delta_t \mid D=1) = E(Y_{1t} - Y_{0t} \mid D=1)$ where $\Delta_t = T_{1t} - Y_{0t}$ because

$$E[(\bar{Y}_{1t} - \bar{Y}_{0t'})_1 - (\bar{Y}_{0t} - \bar{Y}_{0t'})_0] = E(\Delta_t \mid D=1) \qquad 2.7$$

The three estimators namely before-after, cross-section and difference-in-difference estimators exploit three different principles but all are based on making some comparison. They extend the simple mean differences discussed above by making a variety of adjustments to the means.

The strength of the DID estimator over the cross section and the before-after estimators is that it makes use of panel data that combines time series and cross section observations. This gives rise to more variability, less collinearity among variables, more degrees of freedom and more efficiency (Gujarati & Porter, 2009).

2.6.3.4 Matching methods

Inference about the impact of a treatment on the outcome of an individual involves speculation about how this individual would have performed had he not received the treatment. The standard framework in evaluation analysis to formalize this problem is the "potential outcome approach" or the Roy–Rubin model (Roy, 1951; Rubin, 1974). The main pillars of this model are individuals, treatment, and potential outcomes. In the case of a binary treatment, the treatment indicator Di equals one if individual i receives treatment and zero otherwise. The potential outcomes are then defined as Yi (Di) for each individual i, where $i = 1 \ldots N$ and N denotes the total population. The treatment effect for an individual i can be written as:

$$\tau_i = Y_i(1) - Y_i(0) \qquad 2.8$$

The fundamental evaluation problem arises because only one of the potential outcomes is observed for individual i (Stuart & Rubin, 2007). The unobserved outcome or the "counterfactual" outcome gives what would have happened if a treated individual would not have been treated. Hence, estimating individual's treatment effect, $\tau_{i,}$ is not possible and one has to concentrate on the population to get average treatment effects (Austin, 2009).

The first effect is the Population Average Treatment Effect (ATE), which is the difference of the expected outcomes with treatment and without:

$$\tau_{ATE} = E(\tau) = E[Y(1) - Y(0)] \qquad 2.9$$

This parameter gives the expected effect on the outcome if individuals in the population were randomly assigned to treatment. Heckman (1997a) notes that this estimate includes the effect on persons for whom the programme was never intended and which might not be useful to policy makers. This, therefore, leads to the most prominent evaluation parameter called the Average Treatment Effect on the Treated (ATT), which focuses explicitly on effects of the program on beneficiaries of the program (Heckman, 1997a; Iacus *et al.*, 2011). It is given by:

$$\tau_{ATT} = E(\tau \mid D=1) = E[Y(1) \mid D=1] - E[Y(0) \mid D=1] \qquad 2.10$$

The expected value of ATT is defined as the difference between expected outcome values with and without treatment for those who actually participated in treatment (Heckman, 1997b). In the sense that this parameter focuses directly on actual treatment participants, it determines the realized gross gain from the programme and can be compared with its costs, helping to decide whether the programme was successful or not (Heckman *et al.*, 1999).

The focus of most evaluation studies lies on ATT. This study will focus on this parameter, too. As the counterfactual mean for those being treated, $E[Y(0) \mid D = 1]$ is not observed, one has to choose a proper substitute for it in order to estimate ATT (Stuart, 2010; King *et al.*, 2011). The outcomes of individuals in the treatment and comparison groups would differ even in the absence of treatment leading to a ‘selection bias’. In experimental studies where assignment to treatment is random, this is controlled for and the treatment effect is identified (King *et al.* (2011). In non-experimental studies one has to invoke some identifying assumptions to solve the problem of selection bias (Stuart, 2010). The treatment group and the control group are matched conditional on a vector of covariates, X.

It is clear that conditioning on all relevant covariates is limited in case of a high number of covariate variables contained in vector X. To deal with this problem, Rosenbaum and Rubin (1983) suggested the use of balancing scores for matching of treatment and control groups. Matching is a technique used to select control subjects who are matched with treated subjects on background covariates that the investigator believes need to be controlled (Ralph, 1998).
A number of matching methods have been used, for example Coarsened [2]Exact Matching (CEM) (Stuart, 2010), multivariate matching based on Mahalanobis distance (Cochran & Rubin 1973; Rubin 1979, 1980) and propensity score matching (Rosenbaum & Rubin 1983).

2.6.3.5 Coarsened exact matching

In Coarsened Exact Matching (CEM), each variable is first temporarily and reasonably coarsened. Units with the same values for all the coarsened variables are placed in a single stratum and finally control units within each stratum are weighted to equal the number of treated units in that stratum. Strata without at least one treated and one control unit are thereby weighted at zero, and thus dropped from the data set (Iacus *et al*. 2011). The weights for each control unit equals the number of treated units in its stratum divided by the number of control units in the same stratum. The weights are normalized so that the sum of the weights equals the total matched sample size. Units with the original un-coarsened values of their variables are included

[2] Coarsening is the recoding of variables so that substantively indistinguishable values are grouped and assigned the same numerical value, then exact matching algorithm is applied to the coarsened data to determine the matches and prune the unmatched units.

in the analysis stage. Unreasonably bad matches are dropped as an integral part of CEM procedure in the second step (Iacus *et al*. 2011, 2012).

2.6.3.6 Mahalanobis distance matching

Mahalanobis distance matching (MDM) and propensity score matching (PSM) are built on specific notions of distance between observations of pre-treatment covariates. Taking the example of King *et al*. (2011) and Ralph (1998), MDM measures the distance between observations X_i and X_j with the Mahalanobis distance $M(X_i, X_j)$ given as:

$$M(X_i, X_j) = \sqrt{(X_i - X_j)' S^{-1} (X_i - X_j)} \quad \ldots\ldots 2.11$$

Where S is the sample covariance matrix of X, X_i is the value of the matching variables for treated subject i, and X_j is the value of the matching variable for control subject j.

One of the drawbacks of this technique is that it is difficult to find close matches when there are many covariates included in the model. As the number of dimensions on which the Mahalanobis distance is calculated increases, the average distance between observations increases as well.

2.6.3.7 Propensity score matching

In Propensity Score Matching (PSM), the vectors are first collapsed to a scalar “propensity score,” which is the probability that an observation receives treatment given the covariates. The probabilities of treatment are usually estimated by a probit or logistic regression. The most common implementation of each approach is the application of the one-to-one nearest neighbor matching without replacement algorithm (Austin, 2009). This procedure matches each treated unit to the nearest control unit. The same procedure is then applied to remove treated units that are unreasonably distant from the control units to which they were matched. The most common such procedure is calipers, which are chosen cut-offs for the maximum distance allowed (Stuart and Rubin, 2007; Rosenbaum & Rubin, 1985).

Although the idea of finding matches seems straightforward, it is often difficult to find subjects who are similar and that can be matched on all important covariates. Assuming that CIA holds and that there is overlap or common support between both groups, the PSM estimator gives an unbiased estimator for the impact of tsetse fly and trypanosomiasis control. The advantage of PSM is that it solves this problem by allowing an investigator to control for many background covariates simultaneously by matching on a single scalar variable (Imbens, 2004). The drawback of PSM is that the more balanced the data becomes by dropping of some observations through matching, the more likely PSM will degrade inferences. This problem is referred to as PSM paradox (King & Nielsen, 2016). The method also does not account for unobserved heterogeneity.

2.6.3.8 Endogenous switching regression method

Although PSM is a solution to selection bias and lack of a valid control group in the absence of randomization (Baker 2000, Imbens 2015), the unconfoundedness assumption holds that heterogeneity accounts for the self-selection bias. Thus, PSM is more sensitive to bias that arise when either selection or outcomes of the intervention are affected by unobservable confounders (Imbens, 2015). On the other hand, Endogenous Switching Regression (ESR) provides consistent estimates even when the independence of irrelevant alternatives assumption (IIA) is violated. Additionally, ESR has the capability of handling individual and combined use of interventions. The ESR framework is a two-step procedure in which the first stage involves using probit model to model farmers' choices of individual and combined tsetse and trypanosomiasis control methods. Ordinary least squares (OLS) is used in the second stage to evaluate the impact of individual and combined tsetse control methods on household incomes.

2.7 Summary of knowledge gaps

The review of literature has indicated the following gaps that need to be filled:

1. The studies on the impact of tsetse fly and trypanosomiasis control mainly concentrated on the impacts on animal health and productivity indicators with limited economic analyses.
2. The attempts made to date on the social and economic impacts of tsetse fly and trypanosomiasis control applied approaches that showed varied drawbacks. The methods applied by the studies did not account for endogeneity and selection biases which weakens the plausibility of the findings.
3. The pre versus post estimators used in most of the studies had greater heterogeneity which may have biased the impact. Same weakness applied to longitudinal studies which are known for high level of accuracy but costly since a large number of households would require to be monitored every month for a number of years.

To minimize possible self-selection bias or endogeneity, this study applied ESR model. The advantage of this method is that comparison of the treatment group and a control group is by generating a counterfactual of what would have happened if the programme was not there. While the PSM was an equally powerful tool for analysis, it was not implemented because of possibility of violation of unconfoundedness assumption. Furthermore, the PSM method was not applied because of its sensitivity to bias that arises due to self-selection of respondents into the program. The DID was not applicable in this study because of unavailability of baseline data. The study applied the ESR which accounted for endogeneity and self-selection bias that may affect the treatment effects.

CHAPTER 3 : RESEARCH METHODOLOGY

3.1 The study area

Lamu County is located along the Northern Coast of Kenya lying between latitude 1°40, 20° 30 S and longitude 40° 15 and 40° 38 East (GoK, 2018). It borders Tana River County in the South West, Garissa County to the North, Republic of Somalia to the North East and the Indian Ocean to the South. The study was carried out in Pate Island in Lamu East sub-county and Amu/Manda Islands in Lamu West sub-county which are the largest Islands in the Lamu Archipelago (GoK, 2018). The total land area of Lamu County is 6,273.1 km^2 out of which the area sampled for the study was 1,346.9 km^2. The study area experiences two rainy seasons and temperatures ranging between 23^0 and 32^0 C throughout the year. The long rainy season comes in April and May and ends by June while the shorter rainy season from November and December.

The main economic activities in the study area include crop agriculture which entail growing of coconuts, cashew nuts, maize farming, bananas and horticultural crops. Livestock keeping entail rearing of cattle, sheep, goats, donkeys and poultry. The marine activities in the study area include fishing and boating. The area residents are predominantly Muslim.

Lamu County was selected for the study because the Government of Kenya was implementing tsetse and trypanosomiasis control programme on pilot basis before rolling the programme out to the rest of the Counties in the Coastal region and the natural Isolation of the Islands provided an environment where the risk of re-infestation was minimized once tsetse eradication is achieved. Figure 3.1 presents the map of the study area.

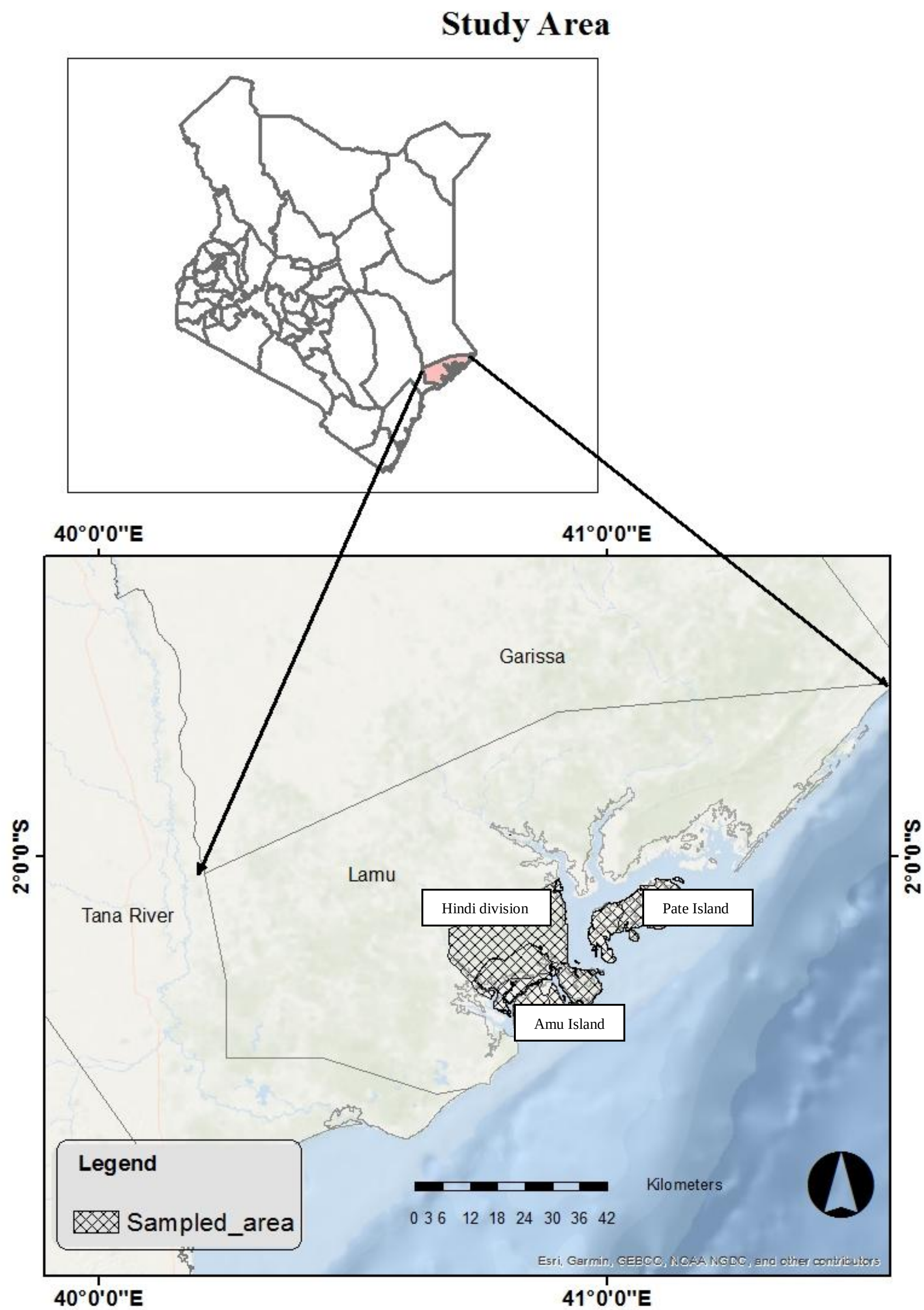

Figure 3.1: The study areas of Pate Island, Amu Island and Hindi division of Lamu County, Kenya

3.2 Conceptual framework

The study conceptualized that at the inception of the PATTEC project, livestock farmers were sensitized and trained on tsetse and trypanosomiasis control using different control methods. The extension staff was also given technical training on tsetse flies and trypanosomiasis control. The trainings and the support given in terms of initial insecticides issued to farmers, insecticide treated tsetse target screens, tsetse traps and provision of other project operational costs served as project inputs which in the project results chain culminated into project outputs.

The outputs conceptualized in this study include the increase in farmers' capacity in terms of knowledge, attitudes and skills to control tsetse and trypanosomiasis and extension officers able to deploy the insecticide treated tsetse targets in the tsetse infested thickets and farmlands.

The immediate and intermediate outcomes of the interventions include farmers applying the enhanced capacity to spray livestock against tsetse flies, farmers graze their livestock in areas protected with insecticide treated tsetse targets, extension staff and farmers carrying out the maintenance of insecticide treated tsetse targets in the fields. The uptake of the technologies was also conceptualized as depending on factors such as age of household head, gender of the household head, household size, education level of household head, farming as the main occupation of household head, Tropical Livestock Units, total land acreage, institutional factors, distance to market, extension services, group membership and technology attributes. It was assumed that the skills acquired by implementers were used and the technologies were applied correctly. The conceptual framework is presented in Figure 3.2.

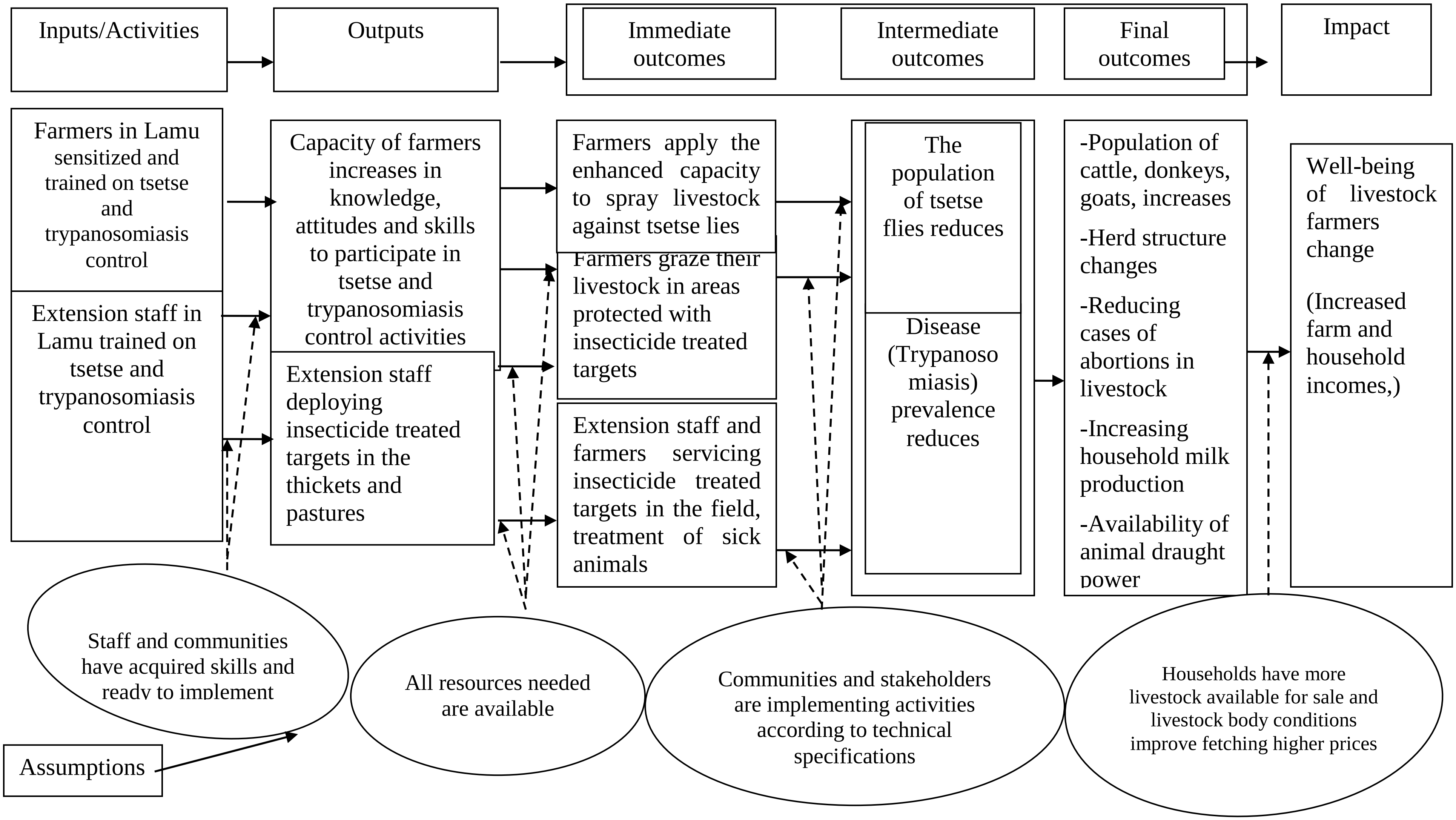

Figure 3.2: Conceptual framework

The population of tsetse flies was therefore expected to reduce and disease (trypanosomiasis) prevalence in the intervention areas to decline. The final expected outcome of this was that the herd sizes and structure for cattle, donkeys, goats and sheep were expected to increase, cases of trypanosomiasis related abortions in livestock to reduce and household milk production increased. The livestock parameters were envisaged as the pathways through which household livelihood outcomes would improve upon tsetse and trypanosomiasis control. The farmers in turn get more income from the sale of milk, sale of cattle, sheep, goats and donkeys. In the conceptual framework, the solid arrows represent the causal links between results; what has to happen for the causal linkages to happen. The doted arrows represent the underlying assumptions in the causal linkages for the planned change to occur.

3.3 Empirical framework

This study was anchored on two theories; Random Utility Model (RUM) and Theory of Change (ToC). Objective one of the study was anchored on the random utility model while objectives two and three were anchored on the theory of change.

3.3.1 Analysis of factors influencing choice and integration level of tsetse and trypanosomiasis control methods in the study area

Tsetse and trypanosomiasis control methods that were widely used in Lamu County include Insecticide Treated Livestock (ITL), Use of Insecticide Treated Targets (ITT) and Treatment with Trypanocidal Drugs (TTD). ITL involved using insecticide to spray, dip or apply pour-on to livestock then using the animal as bait in the grazing field which kills the flies when they bite. ITT involved using insecticide treated clothes fitted with metal frames attracting and killing tsetse flies on contact. TTD involved using trypanocides which are drugs used for prophylaxis and curative purposes. Apart from the indigenous methods, farmers applied one or a combination of these technologies to control Tsetse and Trypanosomiasis.

The first objective was assessed in two parts. First, to assess factors that influence choice of Tsetse and Trypanosomiasis control methods, a Multivariate Probit (MVP) model was used. In the second part, this study assessed factors that influence integration level of Tsetse fly and Trypanosomiasis control methods and truncated regression model was used.

A Multivariate Probit Model was chosen instead of Multinomial Logit (MNL) and Multinomial Probit regression models. Although all the three methods are used in analyses where the decision variable has more than two choice options, MNL and MNP are restrictive in nature, and do not allow simultaneous choices. On the other hand MVP is flexible and allows simultaneous uptake of Tsetse and Trypanosomiasis disease control methods, thus, potential correlation in adoption decisions (Mulwa *et al*., 2017). Since farmers in the study area applied one or more methods simultaneously for effective control of Tsetse and Trypanosomiasis disease, MVP model was more appropriate for the analysis. The MVP is an extension of the bivariate probit and uses Monte Carlo simulation techniques to jointly estimate the multiple probit equation system (Geweke, 1989). A bivariate probit model is restricted to two equations only.

The MVP model depicting farmer choices and combinations from the three control technologies was specified as follows:

$$y_i = 1 \text{ if } X_i\beta + \varepsilon_i \quad > 0; \qquad \text{...3.1}$$

$$y_i = 0 \text{ if } X_i\beta + \varepsilon_i \quad \leq 0; \qquad i = 1, 2, 3, ..., k \qquad \text{...3.2}$$

Where:

$\boldsymbol{y_i}$ = represents unobservable latent variable choice of Tsetse and Trypanosomiasis disease control method by a farmer.

$\boldsymbol{x^i}$ = a vector of observed variables that affect the choice decision of Tsetse and Trypanosomiasis disease control method for farmer $\boldsymbol{i}$.

$\boldsymbol{\beta_i}$ = a vector of unknown parameters to be estimated.

$\boldsymbol{\varepsilon_i}$ = a vector of random error terms distributed as multivariate normal distribution with zero mean and a covariance matrix with diagonal elements equal to one (Cappellari & Jenkins, 2003)

The implicit functional form of the model was specified as follows:

$$\begin{aligned}
&\text{Control Methods}_{1,2,3} = \beta_0 + \beta_1 GenderHHH + \beta_2 SizeHH + \beta_3 Age + \\
&\beta_5 OccupationHHH + \beta_6 TLU + \beta_7 Landacreage + \beta_8 AccessCredit + \\
&\beta_{10} Extension + \beta_{11} GrouPMembership + \beta_{12} TechAvail + \beta_{13} TechUse + \beta_{14} TechCost + \\
&\beta_{15} TechEffectiveness + \beta_{16} Offfar\min come + \beta_{17} Location + \varepsilon \text{......................................} 3.3
\end{aligned}$$

Each household could choose from a set of Tsetse and trypanosomiasis control methods categorized as follows:

1 = Insecticide Treated Livestock (ITL) – using insecticide to spray, dip or apply pour-on to livestock

2 = Insecticide Treated Targets (ITT) – using insecticide treated clothes fitted with metal frames attracting and killing tsetse flies on contact

3 = Treatment with Trypanocidal Drugs (TTD) – using Trypanocides which are drugs used as prophylaxis and curative purposes.

A truncated regression was used for the second part of objective one because of estimating the effect of various factors on integration level of Tsetse and Trypanosomiasis control methods by farmers. It was thus important to truncate farmers with zero application levels. Truncated regression only allowed including farmers at least one application and therefore had fewer observations (Cragg, 1971). This is referred to as truncating from below. The dependent variable (y) was index of integrated control technologies applied by a given farmer. This variable is the incompletely observed value of the latent dependent variable denoted by y*. The actual value of the dependent variable was observed if it was greater than the lower limit in this case zero.

$y = y^{*}$ if $y^{*} > 0$ …………………………………………………………………………3.4

Where y is actual observed dependent variable while y* is latent unobserved value of the dependent variable.

The marginal effects for a dependent latent variable when the sample is truncated show the highest effect of the independent variables on the dependent variable less the impact of truncated sample (Safriandi *et. al*., 2016). According to *Su et al.* (2015), we specify the marginal regression structure as follows:

$\Pr(Z_{ij} = 1) = x_{ij}\beta$ ……………………………………………………………………......3.5

Where Z_{ij} = distribution of the occurrence variable

x_{ij} = Vector of covariates

β = Marginal covariate effects

The marginal covariate effects are proportional to the subject-specific conditional covariate effects

$\tilde{\beta}$ with $\beta = \phi\tilde{\beta}$. Therefore we could rewrite as follows:

$$\Pr(Z_{ij} = 1 | \theta_i) = x_{ij}\beta / \Phi + \theta_i \quad \ldots\ldots 3.6$$

Where θ_i is subject level random intercept.

The vector of household characteristics, land and livestock characteristics, technological attributes and institutional factors determining choice and integration of tsetse fly control methods and their expected signs are given in Table 3.1.

Table 3.1: Description of variables in Multivariate Probit model and their hypothesized signs

Variable		Description	Measurement	Sign
Household characteristics	Gender	Gender of Household Head	Dummy (1=Male 0=female)	-/+
	Size of Household	Number of persons in Household	Count (Assigned 1=One Person…)	+
	Age	Age of Household Head	Continuous	+
	Occupation	Main occupation of Household Head	Dummy (1=Farming 0=Otherwise)	+
Livestock and Land characteristics	Tropical Livestock Unit	Total number of cattle, sheep, goats, donkeys	Continuous	+
	Land Acreage	Total Land in Acres owned by a household	Continuous	+
Institutional Factors	Access Credit	Access to credit facilities	Dummy (1=Accessible, 0=otherwise)	+
	Extension Services	Availability of extension services	Dummy (1=Available, 0=otherwise	+
	Group Membership	Membership to a group	Dummy (1=Member, 0=otherwise)	+
Technological factors	Availability	Availability of technology	Dummy (1= Available, 0=otherwise)	+
	Ease of Use	Ease of use of technology	Dummy (1= Easy to use, 0=otherwise)	+
	Cost	Cost of technology	Dummy (1=High, 0=otherwise)	-
	Effectiveness	Perception about effectiveness of technology	Dummy (1=Effective, 0=otherwise	+

3.4 Justification for inclusion of various variables in the empirical model

A number of studies are in agreement that the adoption of agricultural technologies depends on a range of personal, social, cultural and economic factors, as well as on the characteristics of the innovation itself (Pannell et al., 2006; Loevinsohn et al. 2012). According to Diederen et al., (2003); Sambodo and Nuthall, (2010); Morris and Doss, (1999) and Rogers, (1995), factors influencing adoption of a technology are such as the recipient factors of innovation (farmers' characteristics), the nature of innovation, social influence and communication resources available.

3.4.1 Age of household head

Age of the household head was hypothesized to have either a positive or a negative effect on adoption of technologies. Results from some studies (Mignouna *et al*, 2011; Kariyasa and Dewi 2011) have shown that age has a significant positive influence on technology uptake. Older farmers are assumed to have gained knowledge and experience over time and are better able to evaluate technology information than younger farmers. On the contrary, Adesina & Zinnah (1993), Mauceri *et al*. (2005) and Howley *et al.* (2012), found age to have a negative relationship with adoption of technology. These studies argued that as farmers grow older, there is an increase in risk aversion and a decreased interest in long-term investment in the farm. Moreover, they are conservative, less flexible and more skeptical about the benefits of new technologies. Sometimes, they simply lack the energy to adopt technologies. Younger farmers on the other hand, are better educated and therefore more aware of the benefits of reproductive technologies.

3.4.2 Gender of the household head

The roles played by men and women in society are different and particularly those related to livestock ownership and management. Moreover differences also exist in terms of access to resources and information. In rural areas, women are still disadvantaged in accessing and controlling productive resources (Gallina, 2016). Insecure rights over livestock ownership, limited access to land, credit and technical support are some of disadvantages that can easily be observed. Truong and Ryuichi (2002) found that men were applying technologies for rice, fruit and fish production while women used technology for pig and chicken production in Mekong Delta of Vietnam. A study by Obisesan (2014) on adoption of technology found that gender had a significant and positive influence on adoption of improved cassava production in Nigeria. This study thus hypothesized that being male or female household head would have either positive or a negative significant effect on choice of the method or a combination of them to control Tsetse and Trypanosomiasis disease.

3.4.3 Household size

This study hypothesized that household size may have positive effect on uptake as well as the intensity of application of Tsetse and Trypanosomiasis control methods. A study by Anley *et al*. (2007), showed that household size has a positive effect on adoption of new technology. Mignouna *et al*, (2011) and Bonabana-Wabbi (2002) noted that household size was a simple measure of labor availability which determines adoption process in that, a larger household has the capacity to relax the labor constraints required during introduction of new technology. Most farmers in rural areas are not able to hire labour and they largely depend on family labour.

3.4.4 Education level of household head

Prokopy *et al.* (2008) found that education level was positively associated with the adoption of best agricultural management practices. Education level of a farmer increases his ability to obtain; process and use information relevant to adoption of a new technology (Mignouna *et al*., 2011; Lavison 2013). A study by Okunlola *et al*. (2011) on adoption of new technologies by fish farmers found that the level of education had a positive and significant influence on adoption of the technology. This study expected that the level of education of household head is positively related with choice of control technology.

3.4.5 Main occupation of household head

Employment is a proxy for better access to economic resources. Therefore, farmers who are employed can easily buy required inputs necessary for uptake of a new technology. This study thus, hypothesized that farmers with better access to economic resources have a priori positive sign to technology uptake. Asfaw *et al*. (2014) also showed that the higher the income of a farmer the higher the likelihood of using new technologies.

3.4.6 Tropical Livestock Unit

The number of livestock owned by the household leads to farmers making a choice of technology to apply. In Uganda, Kaaya *et al*. (2005) found that herd size affected the adoption of Artificial Insemination (AI). Abdulla *et al*. (2014) found that ownership of livestock and availability of extension services directly affected adoption of the technology to enhance the capacity of farmers to process waste from rice straw and droppings from cattle in Indonesia.

3.4.7 Total land acreage

Livestock farmers require land for grazing or fodder production. Large sizes of land is thus an impetus for rearing large numbers of livestock. Moreover farmers may also diversify to rear several categories of livestock on their farms. This study hypothesized that large farm sizes will have a positive influence on uptake and the level of application of Tsetse and Trypanosomiasis control technologies. Elliot *et al.* (2013) found that farm size influenced adoption of livestock reproductive technology (artificial insemination) among beef farmers in Missouri.

3.4.8 Access to Credit

Access to credit has been reported to stimulate technology adoption (Mohamed & Temu, 2008). It is believed that access to credit promotes the adoption of risky technologies through relaxation of the liquidity constraint as well as through the boosting of household's-risk bearing ability (Simtowe & Zeller, 2006). This is because with an option of borrowing, a household can do away with risk reducing but inefficient income diversification strategies and concentrate on more risky but efficient investments (Simtowe & Zeller, 2006).

3.4.9 Distance to market

A study by Mano *et al*. (2003), indicated that markets play important role in providing support services which include farm inputs, credit organizations, agricultural information as well as transaction cost indicator. Distance to input market and tarmac road were found to influence adoption of technologies (Nyangena, 2007). Households that are closer to the market are assumed to have better access to inputs and information on new technologies and thus have better uptake. On the contrary, households farther away from the market are likely to have limited access to inputs necessary to implement a technology, and this might negatively affect uptake. The role of distance in the adoption of agricultural technologies has been emphasized by Rogers (2003). In this case, any significant travel costs involved in the initial learning about a technology and subsequently establishing it might reduce the likelihood of adopting that technology. According to Kariyasa and Dewi (2010) in their study of factors affecting adoption of integrated crop management farmer field school (ICM-FFS) in swampy areas of Indonesia, distance to production input source did not significantly affect the adoption at 10% probability level but was more influenced by the accessibility to farmers' inputs.. It is expected that households located near livestock input markets for spraying or dipping or where targets have been deployed will benefit more than those far away.

3.4.10 Extension services

Abdulla *et al*. (2014) in the integrated farming systems of rice and beef in Indonesia found that availability of extension services directly affected adoption of the technology to enhance the capacity of farmers to process wastes from rice straw and droppings from cattle. According to Bonabana-Wabbi (2002), acquisition of information about a new technology determines adoption of technology as it enables farmers to learn the existence as well as the effective use of technology. This is because farmers will only adopt the technology they are aware of or have heard about. Other authors who have reported a positive relationship between availability of extension services and technology adoption include Mignouna *et al.* (2011) in the case of adoption of Imazapyr-Resistant Maize Technologies (IRM), Uaiene *et al*. (2009) in factors determining technology adoption; Sserunkuuma (2005) in the adoption of improved maize and land management in Uganda and Akudugu *et al.* (2012) in adoption of modern agricultural technologies in Ghana. Thus, this study expected that livestock farmers who received extension services would apply the tsetse and trypanosomiasis technologies promoted by the PATTEC project.

3.4.11 Group membership

Mignouna *et al*. (2011) found that belonging to a social group enhances social capital allowing trust, idea and information exchange and therefore adoption of Imazapyr-Resistant Maize technology by farmers in Western Kenya. Farmers within a social group learn from each other the benefits and usage of a new technology. Uaiene *et al.* (2009) in their study of determinants of agricultural technology adoption in Mozambique found that social network effects are important for individual decisions and that farmers share information and learn from each other. Studying the effect of community based organization in adoption of corm-paired banana technology in Uganda, Katungi and Akankwasa (2010) found that farmers who participated more in community-based organizations were likely to engage in social learning about the technology hence raising their likelihood to adopt the technologies. This study hypothesized that livestock farmers belonging to social groups would most likely engage in tsetse and trypanosomiasis control activities.

3.4.12 Technology availability

Wekesa *et al.* (2003) when analyzing determinants of adoption of improved maize variety in coastal lowlands of Kenya found unavailability of seeds as one of the factors responsible for low rate of adoption. The study done by Makokha *et al.* (2001) on determinants of fertilizer and manure use in maize production in Kiambu County, Kenya reported unavailability of demanded packages as one of the main constraints to fertilizer adoption. According to Kariyasa and Dewi (2010) adoption of production input by farmers could be explained by the input availability as found in their study of factors affecting adoption of integrated crop management farmer field school (ICM-FFS) in swampy areas of Indonesia.

3.4.13 Ease of use of a technology

This study hypothesized that technologies that are perceived as easy to use are likely to be applied by farmers compared to those that are perceived as otherwise. Lima *et al*. (2018) and Michels *et al*. (2019) found that ease of use of smart phones enhanced dairy farmers' decision-making process which influenced actual adoption. Therefore, how farmers ranked Tsetse and Trypanosomiasis control technologies in terms of ease of use, would have either a positive or negative influence on their uptake.

3.4.14 Cost of a technology

The cost of adopting agricultural technology has been found to be a constraint to technology adoption. For instance, the elimination of subsidies on prices of seed and fertilizers since the 1990s due to the World Bank-sponsored structural adjustment programs in sub-Saharan Africa has widened this constraint (Muzari *et al*., 2013). Previous studies on determinants of technology adoption have also reported high cost of technology as a hindrance to adoption. The study done by Makokha *et al*. (2001) on determinants of fertilizer and manure use in maize production in Kiambu county of Kenya reported high cost of labor and other inputs as one of the main constraints to fertilizer adoption. Cost of hired labor was also reported by Ouma *et al*. (2002) as one among other factors constraining adoption of fertilizer and hybrid seed in Embu County Kenya.

3.4.15 Effectiveness of a technology

Farmers' perception about the effectiveness or performance of the technologies significantly influences their decision to adopt them. A study by Adesina and Zinnah (1993) showed that farmers' perception of characteristic of modern rice variety significantly influenced their decision to adopt it. In studying determinants of adopting Imazapyr-Resistant Maize (IRM) technology in Western Kenya, Mignouna *et al.* (2011) stated that, the characteristic of the technology plays a critical role in adoption decision process. They argued that farmers who perceive the technology as being consistent with their needs and compatible to their environment are likely to adopt since they find it as a positive investment. Farmers' perception about the effectiveness of the technologies significantly influences their decision to adopt them.

3.5 Determining the effect of integrating tsetse and trypanosomiasis control methods on herd structure in Lamu County

3.5.1 Estimating the Herd Structure Index

The derivation of herd structure was based on the number of animal types for each livestock type. Cattle had a maximum of 8 possible categories of animals with different sexes and ages. That is, bulls, castrates, cows, in-calf cows, heifers, young bulls, male calves, and female calves. Donkey animal types were female donkey, young female donkey, young male donkey, and male donkey. The goat animal types were female goat, male goat, male kid, and female kid and sheep animal types were female lamb, male lamb, male sheep, and female sheep. Since farmers adopt integrated tsetse fly and trypanosomiasis control methods ex-ante, the practices are expected to influence the herd structure. Thus, the herd structure index was calculated by considering minimum and maximum animal types for each livestock type. A simple summation of affirmation of ownership of each animal type for each livestock type was then calculated to obtain herd structure as follows:

$$HSI = \sum_{i=1}^{S} h \text{ ………………………………………………………………………………}3.7$$

where HSI is the index for herd structure for i^{th} livestock type, S is sum of animal types owned by a household, and N is the maximum number for animal types that a household can own. The herd structure index had values ranging from 0 to 1 to allow for direct comparison of results. The normalization of the index, according to Naumann *et al*. (2014), avoids possible bias in interpretation of the result by assigning equal weights to each livestock type and animal type.

3.5.2 Estimating integration index of application of tsetse and trypanosomiasis control methods

The integration index for tsetse and trypanosomiasis control methods was generated using a simple count of the control methods used by the farmer out of the possible 3 practices. The index was bound between 1 and 0 to allow direct comparison of integration levels. A household that used all the control methods was termed as being fully integrated.

According to Wooldridge (2015), a truncated regression model for continuous dependent variable can be specified as follows:

$$E(y \mid y > 0) = x'\beta + \sigma\lambda(\frac{x'\beta}{\sigma}) \text{ ………………………………………………………….....}3.8$$

$$y^{*} = x'\beta + \varepsilon \text{ ………………………………………………………………………………}3.9$$

Where: y* is the latent dependent variable – Tsetse fly control methods index.

x' is a vector of factors that affect intensity of application of tsetse fly control methods

β is a vector of unknown parameters to be estimated

ε is a vector of random error terms

3.5.3 Estimating multivariate tobit model

A multivariate tobit model was chosen instead of univariate tobit model because the latter does not take into account simultaneity in terms of livestock types owned by farmers (Deng & Xue, 2014). This study observed that farmers simultaneously owned several livestock types within which variations in terms of age and sex existed. Thus, a multivariate tobit model which relaxes the restrictive assumptions of the univariate tobit model was appropriate.

According to Wooldridge (2015), a univariate tobit regression model for bounded dependent variable between zero and one and censored from below, can be specified as follows:

$$y_i = \begin{cases} y_i^* & \text{if } y_i^* > 0 \\ 0 & \text{if } y_i^* < 0 \end{cases} \quad \text{.....3.10}$$

$$y_i^* = x_i'\beta_i + \varepsilon_i, \qquad \textit{where } \varepsilon_i \sim N(0,\sigma^2) \quad \text{.....3.11}$$

Where: y_i = Observed dependent variable – herd structure

y* = Latent (unobserved) dependent variable

x_i = A Vector of factors that affect herd structure

β_i = A vector of unknown parameters to be estimated

ε_i = A vector of random error terms which are normally distributed

The herd structure captures diversity within livestock types. Following Wagner *et. al*. (2001), the dependent variable for the current study, simultaneously captured the four latent dependent variables for the four types of livestock.

The model can thus be specified as follows:

$$y_{ik}^{*} = x_i'\beta_i + \varepsilon_i, \quad \text{...}3.12$$

Where k denotes the number of livestock types

The implicit functional form of the model was specified as follows:

$$Herdstructure_{(Cattle,Goats,Sheep,Donkey)} = \beta_0 + \beta_1 ControlMethodInt. + \beta_2 GenderHHH + \beta_3 SizeHH + \beta_4 Age + \beta_5 Education + \beta_6 OccupationHHH + \beta_7 AccessCredit + \beta_8 Offfar\min come + \beta_9 LandAcreage + \beta_{10} DistMarket + \beta_{11} Extension + \beta_{12} GrouPMembership + \varepsilon \quad \text{.....................}\ 3.13$$

3.6 Determining the impact of multiple application of tsetse and trypanosomiasis control methods on household income among livestock farmers in Lamu County

Impact evaluation are either conducted after commencement or end of a program. This implies that ex-post changes in outcomes of interest are used to measure the impact, which is the case in this study. However, there are difficulties involved in using ex-post measures because of changes in observable and non-observable characteristics over time. The changes alter outcomes of the beneficiaries of the program. The implication of this argument is the difficulty experienced in attributing the changes in outcomes to the intervention due to lack of data on 'without' situations. Thus, the impact may be under or over-attributed to the intervention and, therefore, biased. The attribution problem is overcome by creating counterfactual scenarios based on control group characteristics. The control group are non-user households that have almost similar observable characteristics as user households. The treated and control group are assumed to differ only in terms of their participation in the tsetse control program. This ensures the validity of outcome variable. The outcome variable of interest to this study was household incomes.

The study recognizes that non-user household information may be insufficient in attributing the differences in household incomes to the interventions. This is because households may have self-selected themselves into the program. That is, use and non-use of the interventions were likely to have been influenced systematically by observed and unobserved characteristics. Therefore, it is possible that differences in household incomes may be biased due to self-selection. That is, self-selection biases estimates of the impact of the intervention. To overcome self-selection bias, comparison households (non-user households) must, besides having similar socio-economic and farm level characteristics, have had almost equal chances of using the interventions.

One of the farm level characteristics that was comparable across the user and non-user households was use of indigenous methods for tsetse fly and trypanosomiasis control. The user households made their selection from a choice set of three tsetse fly and trypanosomiasis control methods. The control methods included insecticide treated livestock, insecticide treated targets, and treatment with trypanocidal drugs. The use of these control methods was not isolated, that is, households used different combinations of the methods to achieve the desired results. The possible combinations adopted by this study were presented using the following notations:

$L_0T_0D_0$ – Non users

$L_1T_0D_0$ – Users of insecticide treated livestock (ITL) only

$L_0T_1D_0$ – Users of insecticide treated targets (ITT) only

$L_0T_0D_1$ – Users of trypanocidal drugs (TTD) only

$L_1T_0D_1$ – Users of insecticide treated livestock (ITL) and trypanocidal drugs (TTD)

$L_1T_1D_1$ – Users of all the three methods

Thus, to be able to disentangle the impact of the use of either isolated or combinations of the tsetse and trypanosomiasis control methods, the study used endogenous switching regression (ESR) model which accounts for endogeneity and selection bias.

The study would have used Propensity score matching (PSM) as an alternative model. PSM is a commonly used estimator of treatment effects. According to Baker (2000) and Imbens (2015), the PSM method is a solution to selection bias and absence of a valid and random control group. However, PSM is based on unconfoundedness assumption. This assumption holds that observed heterogeneity accounts for the self-selection bias. The unconfoundedness assumption makes PSM sensitive to bias that arises when either selection or outcomes of an intervention are affected by unobservable confounders (Imbens, 2015). This implies that PSM ignores unobserved heterogeneity arising from self-selection into the program. The ESR overcomes PSM limitations by accounting for endogeneity that arises from unobserved heterogeneity. The method provides consistent and efficient estimates of the selection process, accounts for possible correlation between unobserved heterogeneity and outcomes.

The ESR framework is a two-step procedure. The first step involves modeling of farmers' choices of individual and combined tsetse fly and trypanosomiasis control methods using probit model. Ordinary least squares (OLS) is used in the second stage to evaluate the impact of individual and combined tsetse control methods on farm and household incomes.

Following Di Falco (2015), farmers use a combination of tsetse fly and trypanosomiasis control methods that have a potential of maximizing utility. Therefore, let I_{ji}^{*} to describe household i^{th} behaviour in using a single or a combination of tsetse fly and trypanosomiasis control methods $j(j=1,...,8)$ rather than using an alternative combination m, the first stage probit model is specified as follows:

$$I_{ji}^{*}=\beta_j X_{ji}+\varepsilon_{ji} \text{ ....} 3.14$$

where X is a vector of exogenous predictor variables (household characteristics and farm level and institutional factors), β are parameters associated with predictor variables, and ε are stochastic error terms (unobservable characteristics).

The choice of a single or a combination of tsetse fly and trypanosomiasis control methods can be explained by the random utility theory. A household uses a single or a combination of tsetse fly and trypanosomiasis control methods that yields higher utility than the utility derived from alternatives *m.* The utility function of selecting a single method or a combination of methods is observable. Therefore, a household uses j^{th} tsetse fly and trypanosomiasis control methods from m alternatives if:

$$I=\begin{cases} 1 \text{ if } I_{ji}^{*}>\max_{m\neq 1}(I_{mi}^{*}) \text{ or } \eta_{1i}<0 \\ \quad\quad\quad\quad . \\ \quad\quad\quad\quad . \\ \quad\quad\quad\quad . \\ 1 \text{ if } I_{ji}^{*}>\max_{m\neq J}(I_{mi}^{*}) \text{ or } \eta_{1i}<0 \end{cases} \quad \text{for all } m\neq j \text{ ....} 3.15$$

where, according to Bourguignon *et al*. (2007), $\eta_{ij}=\max_{m\neq j}(I_{mi}^{*}-I_{ji}^{*})$. The implication of equation 3.15 is that household i uses j^{th} control method or a combination of tsetse fly and trypanosomiasis control methods to maximize the effectiveness of the individual methods if its expected utility exceeds utility derived from alternative combination $m\neq j$, that is, $\eta_{ij}=\max_{m\neq j}(I_{mi}^{*}-I_{ji}^{*})$. That is, it suggests that choice of a single method or combination of control methods occurs when $I_{mi}^* > I_{ji}^*$. Letting P be a dummy variable that equals 1 for household using either single or a combination of tsetse fly and trypanosomiasis control methods, and 0 otherwise, then equation 3.15 becomes the selection equation.

The association between household income and set of predictor variables is estimated for each single method or a combination of control methods. It is also important to outline how the second stage equations are modeled conditional on household decision to use either individual or a combination of tsetse and trypanosomiasis control methods. There are two outcome equations capturing the effects when P = 1 and P = 0. According to Khonje *et al*. (2015), regime 1 and regime 2 outcome equations are conditional on households having used j^{th} combination and having not, respectively.

$$\text{Regime 1 (Users)}: Y_{1i} = X_{1i}\beta_1 + \varepsilon_{1i} \text{ if } P = 1 \ldots\ldots 3.16$$

$$\text{Regime 2 (Non-users)}: Y_{0i} = X_{0i}\beta_0 + \varepsilon_{0i} \text{ if } P = 0 \ldots\ldots 3.17$$

Here, X_{1i} and X_{0i} are the observed characteristics of users and non-users of individual or a combination of tsetse fly and trypanosomiasis control methods, respectively, β_1 and β_0 are the parameters to be estimated, and ε_1 and ε_0 are the associated error terms that are assumed to be normally distributed with a mean of zero. In ESR framework, the outcome error terms are non-zero because they are assumed to be correlated with the error term of the select equation (Di Falcao *et al*., 2011).

Household income comprises of income from farm enterprises (livestock and crop) and off-farm sources such as salaries and wages, self-employment, pension, social support, and other sources.

Farm income was taken as the gross margins of crop and livestock production, that is, difference between crop and livestock revenues and variable costs. Revenues from sale of livestock and livestock products, and opportunity cost of livestock sales were calculated. The opportunity cost was the amount of money that the household would have received were they to sell the livestock at the prevailing market prices of stock. Use of the opportunity cost was necessary because only 30% of the households sold their livestock within the reference period. Variable costs were calculated as the summation of all costs associated with pest and disease control and cost of livestock feeding.

Regime 1 and regime 2 equations estimate impact of tsetse fly and trypanosomiasis control methods on household income. The conditional expectation of regime 1 error term is given as:

$$E[\varepsilon_{1i} \mid P_i = 1] = \sigma_{\varepsilon 1} \frac{\phi(X_i \beta)}{\Phi(X_i \beta)} = \sigma_{\varepsilon 1} \lambda_{1i} \quad \text{......3.18}$$

and the conditional expectation of regime 2 error term is given as:

$$E[\varepsilon_{1i} \mid P_i = 0] = \sigma_{\varepsilon 1} \frac{\phi(X_i \beta)}{1 - \Phi(X_i \beta)} = \sigma_{\varepsilon 1} \lambda_{1i} \quad \text{......3.19}$$

where ϕ and Φ denote the standard normal distribution and cumulative density functions, respectively, and λ_{1i} and λ_{0i} are the inverse mills ratio that are obtained from regime 1 and regime 2 equations , respectively. If regime $\sigma_{\varepsilon 1}$ and $\sigma_{\varepsilon 0}$ are statistically significant, then decision to use either single or a combination of tsetse fly and trypanosomiasis control methods and the incomes are endogenous (El-Shater *et al*., 2016).

The inverse mills ratios are included in the OLS outcome equations to correct for selection bias. The outcome equations 3.16 and 3.17 are simultaneously estimated with the select equation using full information maximum likelihood (FIML) ESR (Lokshin & Sajaia, 2004). ESR conditional expectations were estimated following Di Falcao *et al*. (2011) and Khonje *et al*. (2015).

The actual incomes of users of tsetse fly and trypanosomiasis control methods is given as follows:

$$E(Y_{1i} \mid P=1; X) = X_{1i}\beta_1 + \sigma_{\varepsilon 1}\lambda_{1i} \quad \ldots\ldots 3.20$$

The counterfactual: Incomes of users of individual or a combination of tsetse fly and trypanosomiasis control methods had they not used the control methods is given as follows:

$$E(Y_{0i} \mid P=1; X) = X_{1i}\beta_0 + \sigma_{\varepsilon 0}\lambda_{1i} \quad \ldots\ldots 3.21$$

The actual incomes of non-users of tsetse fly and trypanosomiasis control methods is given as follows:

$$E(Y_{0i} \mid P=0; X) = X_{0i}\beta_0 + \sigma_{\varepsilon 0}\lambda_{0i} \quad \ldots\ldots 3.22$$

The counterfactual: Incomes of non-users had they used the control methods is given as follows:

$$E(Y_{1i} \mid P=0; X) = X_{0i}\beta_1 + \sigma_{\varepsilon 1}\lambda_{0i} \quad \ldots\ldots 3.23$$

The difference between equations 3.20 and 3.21 is the average treatment effect on the treated (ATT). The ATT is the effect of single or a combination of tsetse fly and trypanosomiasis control methods on household income of households that used them (use effect). The ATT is given as:

$$ATT = E(Y_{1i} \mid P=1; X) - E(Y_{0i} \mid P=1; X) = X_{1i}(\beta_1 - \beta_0) + \lambda_{1i}(\sigma_{\varepsilon 1} - \sigma_{\varepsilon 0}) \quad \ldots\ldots 3.24$$

The difference between equations 3.22 and 3.23 is the treatment effect on the untreated (ATU), which is the non-use effect. The ATU is calculated as:

$$ATU = E(Y_{1i} \mid P = 0; X) - E(Y_{0i} \mid P = 0; X) = X_{0i}(\beta_1 - \beta_0) + \lambda_{0i}(\sigma_{\varepsilon 1} - \sigma_{\varepsilon 0}) \quad \text{.....................3.25}$$

3.7 Research design

The study applied quasi-experimental research design with treatment and control groups of household constructed from the study area which covered Lamu East and Lamu West. The households in the study area that used the various tsetse fly and trypanosomiasis control methods formed the treatment group. On the other hand, the households that did not use the tsetse fly and trypanosomiasis control methods formed the control group. Cross section data was collected from the two groups of household. The data was used to construct a counterfactual outcome for every household to enable comparison of the outcomes in the use and non-use scenarios.

3.8 Data types and sources

3.8.1 Data types

The study collected both primary and secondary data.

3.8.1.1 Primary data

A semi-structured questionnaire (Appendix 1) was used to collect socio-economic data from Faza and Kizingitini divisions of Lamu East sub-county and Amu and Hindi divisions of Lamu West sub-county. The questionnaire captured data on household characteristics, social and economic activities in the study area. Household characteristics including household composition, gender of the household head, education level of the household head, distance of household from the nearest market, GPS coordinates of the household, age of household head and household membership to community groups. Livestock production data that were collected include number of livestock in the household by types (cattle, goats, sheep, and donkeys), livestock products and production inputs. The livestock production data was collected for the year 2016.

3.8.1.2 Secondary data

The secondary data collected include household population, livestock types and population and economic activities in the study area.

3.8.2 Data sources

The primary data used in the study was collected from the farm households by administering a semi-structured questionnaire. The data was collected six years after the commencement of the pilot tsetse and trypanosomiasis control project in Lamu County. Secondary data was obtained from the existing records in both national government and Lamu county government offices.

3.8.3 Sampling

3.8.3.1 Sample size determination

The number of households which participated in the study was determined as suggested by Kothari and Gaurav (2014). The population of livestock rearing farm households in the selected divisions of Lamu West and Lamu East sub-counties was obtained from the extension reports of the County Government of Lamu. According to Kothari and Gaurav (2014) the sample size determination formula applicable in the case of a finite population is given as:

$$n = \frac{z_{\alpha/2}^{2} N \sigma^{2}}{(N-1)e^{2} + z_{\alpha/2}^{2}\sigma^{2}} \quad \text{.....3.26}$$

Where:

n is the size of the sample

N is the size of population

e is the acceptable estimation error given by $e = z_{\alpha/2}\frac{\sigma}{\sqrt{n}}$

σ is the standard deviation of the population

$z_{\alpha/2}$ is the critical value using the N(0,1) distribution for confidence level α

In this study, the sample size was computed using the above stated formula at a Confidence level of 95% and a margin of error of 5%. The population of livestock rearing households in Amu and Hindi divisions of Lamu West sub-county was 734 and that of livestock rearing households in Faza and Kizingitini divisions of Lamu East was 959. With the critical value $z_{\alpha/2}$ = 1.96 and σ = 0.5, the sample size for the Lamu East households was determined as follows:

$$n = \frac{1.96^2 * 734 * 0.5^2}{(734-1)0.05^2 + 1.96^2 * 0.5^2} = 252.4 \simeq 253$$

and the sample size for the Lamu West households was determined as:

$$n = \frac{1.96^2 * 959 * 0.5^2}{(959-1)0.05^2 + 1.96^2 * 0.5^2} = 274.5 \simeq 275$$

3.8.3.2 Sample selection

Firstly, Lamu County was purposively selected because government had piloted the implementation of tsetse and trypanosomiasis eradication programme in the County and the population of households in the targeted administrative divisions in Lamu West and East sub-counties was homogenous.

The area was then stratified into Lamu East and Lamu West sub-Counties each of which had administrative locations namely Kwatini, Kwatongani, Pate, Siyu, Shanga, Tchundwa, Kizingitini and Myabogi in Lamu East and Hindi, Bargoni, Mokowe, Kilimani, Matondoni, Kipungani, and Manda in Lamu West Sub-County all with varying number of livestock rearing households. Since the number of households with livestock varied by the administrative units, a systematic proportional random sampling method was applied to draw a total of 536 households; 254 households from Lamu East and 282 from Lamu West. The village roads were used as transects along which proportional samples were systematically drawn until the desired sample size was obtained. The first livestock rearing household along each transect was randomly selected. There after every 5th household with livestock was selected for interviewing. Tables 3.2 and 3.3 show how systematic proportional random sampling of the households was carried out in in the study area.

Table 3.2: Systematic proportional random sampling of households in Lamu East Sub-County

Location (A)	Sub-location (B)	HH Population with livestock (C)	Proportion of HH (D)	Sample size (D*253)
Faza	Kwatini	46	0.06	16
	Kwatongani	54	0.07	19
Pate	Pate	121	0.16	42
Siyu	Siyu	53	0.07	18
	Shanga	38	0.05	13
Tchundwa	Tchundwa	154	0.21	53
Kizingitini	Kizingitini	185	0.25	64
Mbwajumwali	Myabogi	83	0.11	29
	TOTAL	**734**	**1**	**253**

Table 3.3: Systematic proportional random sampling of Households in Lamu West Sub-County

Location (A)	Sub-location (B)	Population of HH with livestock (C)	Proportion	Sample size (D*275)
Hindi/Magogoni	Hindi	188	0.20	54
	Bargoni	217	0.23	62
Mokowe	Mokowe	245	0.26	70
	Kilimani	80	0.08	23
Shella/Manda	Manda	107	0.11	31
Matondoni	Matondoni	26	0.03	7
	Kipungani	96	0.10	28
	TOTAL	**959**	**1**	**275**

The household sample obtained from the two sub-counties was further categorized into users and non-users of specific tsetse fly and trypanosomiasis control methods which enabled the study's analysis of factors affecting choice of different tsetse fly and trypanosomiasis control methods, the resultant changes in herd structure for different types of livestock and the impact of using different tsetse fly and trypanosomiasis control methods on household income.

3.8.4 Data collection

The data was collected by a team of enumerators led by four supervisors. The supervisors were first recruited from county and national government frontline extension staff in the study area. The supervisors were then trained on the data collection tools before engaging them in the recruitment and training of enumerators for the data collection exercise.

Twenty enumerators were recruited, ten to collect data from Lamu East sub-County and ten to collect data from Lamu West sub-county. The minimum qualification considered for the enumerators was Kenya Certificate of Secondary Education (KCSE) Certificate and a good command of Kiswahili language, which was the main language of the study area inhabitants. The researcher and the supervisors conducted a two-day training for the enumerators on the data collection tools. The questionnaires were pre-tested and adjusted appropriately. This was followed by actual data collection.

3.8.5 Data capture and analysis

The data was entered using Statistical Package for Social Sciences (SPSS) version 22 while STATA version 14 was used for the analysis. Descriptive statistics were used to determine means, frequency distributions and percentages to compare the different categories of respondents by age, gender, education levels, family size, total land acreage, number of different livestock types owned as well as their respective tropical livestock units. Access to credit, extension services and group membership levels within the two groups were compared using percentage proportions. Further, average household income for the users and non-users of the control methods was calculated.

Uptake of technologies by farmers either singular or an integration of them, were compared using percentage proportions. In addition, the differences in the levels of perceptions towards the technologies were also estimated.

Multivariate Probit (MVP) model was used to assess factors that influence choice of Tsetse and Trypanosomiasis control methods while a truncated regression model assessed factors that influence integration level of control methods. Similarly, the second objective was achieved using a multivariate tobit model. The model was used to determine the effect of different levels of integration of Tsetse fly and Trypanosomiasis control methods on herd structure of livestock kept by farmers respectively. An endogenous switching regression was used to analyze the third objective, which focused on determining the impact of use of tsetse fly and trypanosomiasis control methods on household income among livestock farmers.

3.8.6 Diagnostic tests

The following diagnostic tests were carried out for the regression models used in the study:

3.8.6.1 Multicollinearity tests

The problem of multicollinearity occurs when the explanatory variables are highly correlated and it becomes difficult to disentangle the separate effects of each of the explanatory variables on the explained variable (Maddala, 2005). The study used the correlation matrix method as suggested by Maddala (2005) and Gujarati *et al.* (2009) to detect if there was multicollinearity between any of the explanatory variables. The explanatory variables include age of household head, Tropical Livestock Units (TLU) owned by household, gender of the household head, size of household, distance of household from the nearest market, years of education of household head, availability of the technology, cost of the technology, effectiveness of the technology, access to credit, availability of extension services and household membership to community group. This study used Variance Inflation Factor (VIF) and Pearson's pair-wise correlation matrix to test for multicollinearity. A VIF value of less than 5 indicates absence of multicollinearity among the explanatory variables. On the other hand, a statistically significant Pearson correlation coefficient between any two regressors that is greater or equal to 0.8 indicates presence of multicollinearity (Gujarati, 2009). The results for VIF test and Pearson's pair-wise correlation matrix are shown in Appendix 2 and 3 respectively.

3.8.6.2 Testing for heteroscedasticity

The variance of the error term must be consistent for efficient and valid test of hypothesis. When the variance of the error terms is inconsistent, the data has heteroscedasticity problem (Wooldridge, 2015). This study used White test (Appendix 4) to test for heteroscedasticity under the null hypothesis of constant variance (homoscedasticity). A significant p-value of the White test test leads to rejection of the null hypothesis, implying that the data set has heteroscedasticity problem (Coenders & Saez, 2000).

3.8.6.3 Testing for goodness-of-fit

According to Maddalla, (2005) and Greene, (2012), goodness–of–fit measure is a summary statistic showing the accuracy with which a model approximates the observed data. This study used the Likelihood Ratio (LR) and Wald Test to determine model fitness. A significant LR statistic indicates goodness of fit of the model in predicting the dependent variable.

CHAPTER 4 : RESULTS

4.1 Descriptive statistics

Descriptive statistics for both users and non-users of the tsetse fly and trypanosomiasis control methods are presented in four categories. First, household characteristics which include socio-economic, land and institutional factors. Second, livestock characteristics which focused on number of different livestock types owned by farmers and their respective Tropical Livestock Units (TLUs). Third, the use of Tsetse and Trypanosomiasis control methods by farmers as well as various combinations of these methods. Lastly, perceptions of farmers in both areas on availability, ease of use, cost and effectiveness of the control methods.

4.1.1 Household characteristics

The summary statistics for household characteristics are presented in Table 4.1. The sample average age of household heads was 38 years implying that most of livestock farmers in both project and non-project area were middle aged. The average ages for users (43) and non-users (31) were significantly different at 1 percent level. This finding suggests that older farmers tend to use modern tsetse fly and trypanosomiasis control methods compared to younger farmers. An explanation for this is that perhaps older farmers tend to be experienced over time and therefore could understand the benefits of using modern tsetse and trypanosomiasis control technologies as compared to traditional methods.

The average size of household was 7 for the overall sample and sub-samples for both users and non-users. This was higher when compared with the national average of five persons per household (KNBS, 2019).

Table 4.1: Household Characteristics

	Overall (n=536)	Users (n=328)	Non-Users (n=208)	Test statistic (t-test)
Variable	Mean	Mean	Mean	
Age of the Household Head	38.319	43.067	30.832	13.731***
	(11.683)	(9.358)	(11.063)	
Size of the Household	6.321	6.104	6.666	1.863*
	(3.398)	(3.007)	(3.921)	
Education of Household Head (Years)	5.388	5.284	5.553	0.693
	(4.382)	(4.430)	(4.313)	
Total Land Acreage	4.353	4.395	4.288	0.087
	(13.896)	(17.201)	(5.626)	
Off-farm income	72,250.53	91,881.00	41,294.80	7.856***
	(78,669.01)	(94,865.18)	(14,328.20)	
Household Income	94,754.80	120,499.70	54,157.11	7.633***
	(103172.50)	(124413.30)	(18791.09)	
	Proportion (%)	*Proportion (%)*	*Proportion (%)*	(chi^2)
Sex of Household Head (Male)	60.45	54.57	69.71	12.201***
Primary Occupation (Farming)	62.13	58.23	68.27	5.450**
Access to Credit (Yes)	23.32	21.65	25.96	1.325
Access to Extension Services	68.28	70.43	64.90	1.793
Group Membership (Yes)	55.41	56.40	53.85	0.337
Distance to Market (<5km)	44.96	49.09	38.46	5.805**

***, **, * = significant at 1%, 5%, and 10%, respectively

Numbers in parentheses are standard deviations

This could attributed to the fact the cultural lifestyle of residents of Lamu County especially in Kiunga, Faza, parts of Hindi, Manda Island, Witu and Bahari allows extended families that hold together for social support.

A comparison of the household sizes for both samples showed that they were significantly different at 10 percent level of significance implying that differences in household socioeconomic characteristics could exist.

The average level of education of the head of household was 5.4 years when the samples are pooled together. This implies that most of the household heads dropped out of school before completing primary education. This is in tandem with the KNBS report that 58.4 percent of the Lamu county population did not complete primary education. The results further indicate a slight difference in the average number of years of education for users (5.3 years) and non-users (5.5 years). Although a comparison of the two showed that they were not significantly different, a direct indication is that most of the users dropped out slightly earlier compared to non-users. Generally the prevailing level of education for most of livestock farmers in Lamu County could an impediment to the uptake of tsetse fly and trypanosomiasis control methods particularly in they require technical understanding. This means that for improved uptake of technologies, extension services especially in terms of on-farm trainings and demonstrations may be required.

The average land acreage was 4.4 acres for pooled households, 4.4 for user households and 4.3 for non-user households. The difference in land acreage between the user and non-user households was however not significant. According to Lamu County Integrated Development Plan 2018-2022, the average land acreage per small scale farmer is 10.28 acres meaning the farmers in the study area hold smaller parcels of land owing to the fact that most people have settled on the islands with fixed land masses. Land ownership is largely communal and small parcels left for private ownership. Perhaps, this is a constraint to individual expansion of livestock enterprises and extensive grazing system and calls for intensive production systems for example introduction of improved dairy breeds in tsetse fly and trypanosomiasis controlled areas.

The average annual household income for all households put together was KES 94,754.80, that of user households was KES 120,499.70 and that of non-user households was KES 54,157.11. A test for the two average incomes for the two groups showed that they were significantly different. Generally, the average household incomes show that most of the households in the study area are classified as poor. However, the difference in average income levels of the two groups suggests that the application of tsetse and trypanosomiasis control methods may have led to improved household incomes for the user households.

On the other hand, the average off-farm income for user households (KES 91,881.00) was statistically different from that of non-user households (KES 41,294.80) at a significance level of 1 percent. The non-user households seemed to be getting their income from other sources to compensate for the income they would have earned from livestock enterprises had they used the tsetse and trypanosomiasis control methods. However, their off-farm incomes were still lower compared to their user counterparts contrary to the expectation of this study.

The other household characteristics examined were gender and primary occupation of the household head, household access to credit facilities, access to extension services and distance to the nearest market. First, the percentage of male headed households was higher (60.45%) compared to their female counterparts. This is in tandem with KNBS (2019) census report that showed the population of males (53%) was higher than females (47%) in Lamu County. Although the percentage of male headed households was higher, the proportion of the female headed households (39.55) is large enough to be overlooked. It implies that the role of women in livestock enterprises in the study area is increasing. This is a good indicator in terms of mainstreaming of gender in agricultural production owing to the fact that customarily women were not fully involved in decision making on agricultural enterprises. A further comparison indicated that the percentage of male headed households was higher for non-users (69.7 percent) than users (54.7 percent) at 1 percent significance level. This implies that more female headed households were using the interventions in the project area compared to non-project area.

Secondly, although more than half (62.13 percent) of the households interviewed had farming as their primary occupation when taken together, the number was higher among the non-users (68.27 percent) compared to the users (58.23 percent). This is contrary to the expectations of this study. The users of tsetse fly and trypanosomiasis control technologies would be expected to concentrate on their enterprises and thus, making farming their primary occupation. However, perhaps these group of farmers diversify into other non-farm enterprises serving as a source of income to purchase the control technologies. Moreover, this explains the earlier observation that users had higher off-farm income when compared to non-users,

Thirdly, the results show that 23.32 percent of all the households had access to credit. This implies that a small proportion (less than half) of the households accessed credit. This depicts a low level of participation by Lamu livestock farmers in the credit market probably due to cost of credit or lack of collateral for credit. Farm households mostly use land as collateral for credit, however in Lamu County, land is largely unregistered hence most households have no title deeds for the parcels they hold. According to Lamu County Integrated Development Plan (CIDP) 2019-2022, only 42 percent of all households in the county have titles for their lands. A different picture is observed when looking at access to extension services. More than half of the respondents accessed extension services, 70.43 percent of users and 59.6 percent of non-users. The difference between the users and non-users was however not significant. This shows that technical information on tsetse and trypanosomiasis control reached the targeted farmers albeit for the insecticide treated targets which were mainly provided as a public good. The lower access realized by the non-users could be attributed to the fact that the current policy of Kenya government is that extension services is demand driven and hence many farmers may not have come up to request for services especially in the non-project areas. The promotion of cost sharing in service delivery may also have lowered farmers' demand for these services.

Fourthly, the study found that 55.41 percent of all the households were members of a group while the rest were not. The users had 56.40 percent of the households as members of community groups compared to 53.85 percent of the non-user households who were members of community groups. The finding is an indication that membership to groups had benefits attributed to it this could have offered more support to the farmers to apply tsetse fly and trypanosomiasis control methods. In the Lamu county especially the project areas, farmers came together in tsetse control groups which constructed crush pens for spraying livestock at lower charges per head of livestock. This may have encouraged use of tsetse fly control techniques.

Lastly, the results showed that more than half of households were close to the market, that is, within a radius of 5km to the nearest market. Forty nine (49) percent of the user households were within the 5km radius to the nearest market while 38.46 percent of non-user households were within the same radius. More households living in the proximity of markets were users of tsetse and trypanosomiasis control technologies probably because of nearness to agricultural input sources such as agro-vet shops thus reducing transport costs.

4.1.2 Livestock characteristics

The findings on the number of livestock in the household from the pooled data showed that the mean number of cattle, goats, sheep, donkeys and poultry was 8, 9, 1, 1 and 7 respectively. This shows that households owned very few sheep and donkeys compared to other livestock types. Perhaps, households kept more cattle and goats due to milk value aspect of the two livestock types. The variations in the total numbers of livestock owned were bigger in all the types of animals indicating that some farmers had very large herds while others had very few animals. Descriptive statistics for livestock characteristics are presented in Table 4.2.

The mean tropical livestock units was found to be 7.9 when all households are taken together, 6.8 for user households and 9.6 for non-user households. The higher TLU for the non-users was an unexpected finding; however this can be attributed to the fact that the non-users mainly found in non-project areas where tsetse flies was still a big challenge prompting widespread rearing of trypanotolerant species of cattle. This explains the higher figures of TLU in an area of higher tsetse fly and trypanosomiasis challenge. The mean TLU for the two groups of household were significantly different.

Table 4.2: Livestock characteristics

Variable	Overall (n=536) Mean	Users (n=328) Mean	Non-Users (n=208) Mean	Test statistic (T-test)
Number of Cattle owned	8.119	6.067	11.356	5.249***
	(11.646)	(8.747)	(14.576)	
Number of Goats owned	8.759	7.128	11.332	03.090***
	(15.473)	(14.608)	(16.46)	
Number of Sheep owned	0.625	0.588	0.683	0.322
	(3.299)	(3.437)	(3.075)	
Number of donkeys owned	0.832	0.936	0.668	-1.573
	(1.923)	(1.886)	(1.973)	
Number of Poultry owned	6.957	6.296	8.000	1.446
	(13.308)	(13.228)	(13.400)	
Tropical Livestock Units	7.884	6.818	9.595	3.504***
	(8.937)	(8.142)	(9.854)	

***, **, * = significant at 1%, 5%, and 20%, respectively

The numbers in parentheses are standard deviations

4.1.3 Tsetse fly and trypanosomiasis control methods and their combinations

The combinations of tsetse fly and trypanosomiasis control methods applied by the Lamu households include insecticide treated livestock (ITL) denoted as $L_1T_0D_0$, insecticide treated targets (ITT) denoted as $L_0T_1D_0$, treatment with trypanocidal drugs (TTD) denoted as $L_0T_0D_1$ and combinations of two ($L_1T_0D_1$) or all the above methods ($L_1T_1D_1$). Summary statistics on tsetse and trypanosomiasis control methods as well as their combinations are presented in Table 4.3.

Table 4.3: Tsetse and Trypanosomiasis Control Technologies and their combinations

Control Methods	Overall N=536		Sub-County		χ^2
			Lamu East (n=254)	Lamu West (n=282)	
	n	*Proportion (%)*	*Proportion (%)*	*Proportion (%)*	
$L_0T_0D_0$	208	38.81	29.13	47.52	19.019***
$L_1T_0D_0$	46	8.58	5.12	11.70	0.895
$L_0T_1D_0$	37	6.90	14.57	0.00	52.612***
$L_0T_0D_1$	71	13.25	0.00	25.18	34.378***
$L_1T_0D_1$	44	8.21	0.00	15.60	22.162***
$L_1T_1D_1$	130	24.25	51.18	0.00	138.762***

***, **, * = significant at 1%, 5%, and 30%, respectively

Note: $L_0T_0D_0$ = non-use of any tsetse and trypanosomiasis control method, $L_1T_0D_0$ = use of insecticide treated livestock, $L_0T_1D_0$ = use of insecticide treated targets, $L_0T_0D_1$ = use of trypanocidal drugs, $L_1T_0D_1$ = combination of insecticide treated livestock and trypanocidal drugs and $L_1T_1D_1$ = combination of all the three practices.

The findings show that 38.8 percent of all the households were non-users ($L_0T_0D_0$) of any of the three methods of tsetse fly and trypanosomiasis control methods, neither as single control methods nor in any of their combinations. The households that used insecticide treated livestock denoted as combination $L_1T_0D_0$ were 8.6 percent of the pooled households. However, the percentage of households using insecticide treated livestock ($L_1T_0D_0$) was higher in Lamu West (11.7 percent) than in Lamu East (5.12 percent). The percentage in Lamu East was lower probably because the households in the sub-county had other tsetse fly and trypanosomiasis control techniques at their disposal owing to the fact that the Kenya Tsetse and Trypanosomiasis Eradication Council (KENTTEC) piloted the Pan African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC) project in Lamu East. This increased the opportunity of farmers to access other technologies including tsetse targets, tsetse traps, crush pens, trypanocides and insecticides for spraying.

The insecticide treated targets method otherwise denoted here as combination $L_0T_1D_0$ was used by 14.6 percent of the households in Lamu East sub-county while none of those in Lamu West sub-county used this method. This could be because it is only in Lamu East where the government piloted PATTEC project that supported the deployment of insecticide treated targets as a public good.

The proportion of households in Lamu West that used treatment with trypanocidal drugs, combination $L_0T_0D_{1,}$ was 25.18 percent compared to none in Lamu East sub-county. A higher percentage of Lamu West sub-county households used combination $L_0T_0D_1$ probably because tsetse fly densities and trypanosomiasis disease prevalence in the area was higher making them to often use more of trypanocidal drugs to treat their livestock whenever they are trypanosome-infected.

The results in Table 4.3 also provide proportions of households that used more than one method of tsetse fly and trypanosomiasis control in the study area. Overall, households that used insecticide treated livestock alongside use of trypanosidal drugs, combination $L_1T_0D_{1,}$ were 8.2 percent. The proportion of households which used this combination in Lamu West sub-county was 15.6 percent which was significantly higher than that of households in Lamu East sub-county (0 percent) probably because the control measures put in place in Lamu East had reduced the tsetse fly population and disease prevalence in this area hence no much use of trypanocidal drugs for treatment or for prophylaxis.

The study found that 24.3 percent of all the households used a combination of all the three methods ($L_1T_1D_1$), 51.2 percent of the households in Lamu East sub-county were combining all the three methods ($L_1T_1D_1$) while no household in Lamu West sub-county used this combination.

The combination of the three methods was not used in Lamu West area apparently because the insecticide treated tsetse target screens method was not available in the sub-county to complete the choice set of tsetse and trypanosomiasis control methods from which the farmers in this area could choose.

4.1.4 Household perceptions on tsetse and trypanosomiasis control methods

The summary statistics for household perceptions on tsetse fly and trypanosomiasis control methods are presented in Table 4.4. The study found that 71.6 percent of all the households perceived use of insecticide treated livestock to be highly available. The number of households that held this perception were however more in Lamu East sub-County (81.5 percent) compared to Lamu West Sub-county (62.77 percent). This may be due to the fact that Lamu East was in the project area where farmers accessed training from KENTTEC and the County Government of Lamu. The χ^2 parameters for perception of farmers in the two areas concerning the availability, ease of use and effectiveness of the methods were statistically significant at 1 percent level.

On availability of the method, 71.64 percent of all households said ITL was highly available. On ease of use of the method, 75.6 percent of all households said ITL was easy to use, 84.3 percent of these were from Lamu East while 68.1 percent were from Lamu West. The cost of ITL was perceived as high by 76.1 percent of all the households; on the other hand 73.6 percent of Lamu East households perceived the cost of the method as high while 78.4 percent of Lamu West households perceived the cost as high although the difference in perception was not statistically significant.

Table 4.4: Perceptions of households on Tsetse and Trypanosomiasis control methods

Tsetse fly Control Methods	Attribute	Overall	Sub-county: Lamu East (n=254)	Sub-county: Lamu West (n=282)	χ^2
		Proportion (%)	*Proportion (%)*	*Proportion (%)*	
Insecticide Treated Livestock (ITL)	Availability (High)	71.64	81.50	62.77	23.076***
	Ease of use (Easy)	75.75	84.25	68.09	19.012***
	Cost of Technology (High)	76.12	73.62	78.37	1.656
	Effectiveness (Yes)	80.78	91.73	70.92	37.280***
Insecticide Treated Targets (ITT)	Availability (High)	47.20	95.28	3.90	447.707***
	Ease of use (Easy)	44.78	94.49	0	482.501***
	Cost of Technology (High)	26.49	55.91	0	214.473***
	Effectiveness (Yes)	43.28	91.34	0	454.145***
Trypanocidal Drugs (TTD)	Availability (High)	64.56	47.24	80.14	63.205***
	Ease of use (Easy)	70.65	55.51	84.34	53.479***
	Cost of Technology (High)	77.80	66.93	87.59	33.022***
	Effectiveness (Yes)	76.49	62.29	82.98	13.923***

***, **, * = significant at 1%, 5%, and 10%, respectively

The proportion of all the households that perceived ITL as effective was 80.8 percent. However the number of households that perceived this method as effective were more in Lamu East area compared to Lamu West area (91.7percent and 70.9 percent respectively).

Of all the households studied, 47.2 percent said the availability of ITT method was high. 95.3 percent of Lamu East households said availability of the method was high while 3.9 percent of Lamu West households said availability of the method was high.

The method was introduced only in Lamu East hence the higher proportion of households in the sub-county compared to Lamu West households. The proportion of all households that said the ITT method was easy to use was 44.8 percent compared to 94.5 percent of the households in Lamu East and none in Lamu West which said so. The proportion of all households that said the cost of ITT method was high was 26.5 percent compared to 55.9 percent of Lamu East and none in Lamu West households that said the cost of the method was high. 43.3 percent of all the households said the method was effective compared to 91.3 percent of project households that said the method was effective.

The perception of households on the availability of TTD method among the pooled households was found to be 64.5 percent compared to 47.2 percent of Lamu East households and 80.1 percent of Lamu West households. 70.7 percent of all the households said the method was easy to use, 55.5 percent of Lamu East households said the method was easy to use while 84.3 percent of Lamu West households said it was easy to use. The perceptions of the households in the two sub-counties were statistically significant at 1 percent level.

The proportion of all households that said the TTD method was highly available was 64.6 percent compared to that of Lamu East households (47.2 percent) and that of Lamu West household (80.1 percent). 70.7 percent of all the households perceived TTD as easy to use while 55.5 percent of the Lamu East households it was easy to use compared to 84.3 percent of Lamu West households which said so. Approximately 77.8 percent of all the households said the cost of the TTD method was high, 66.9 percent of Lamu East households said the cost was high while 87.6 percent of Lamu West households said the cost of the method was high. The proportion of households saying the method was costly was higher in Lamu West area than in Lamu East area probably because of unavailability of project inputs in the area. 76.5 percent of all the households said TTD method was effective, 62.3 percent of Lamu East households said the method was effective and 82.9 percent of Lamu West households said the method was effective. The perceptions of households in the two sub-counties concerning TTD were statistically significant at 1 percent.

4.1.5 Livestock composition and herd structure

The study found that the proportion of indigenous cattle was higher among the non-user households (95.8 percent) compared to 92 percent among the user households. This was possibly because the indigenous cattle are known to be less vulnerable to trypanosomiasis and hence are more likely to survive in the scenarios where control interventions are not being applied by households.

The proportion of exotic breeds of cattle was found to be 5.7 percent among the user households compared to 3.8 percent among the non-user households implying that the user households had controlled tsetse flies and trypanosomiasis to a level that the improved breeds whose susceptibility to the disease was high could now be introduced. The scenario was the same for cattle crosses where user households had higher proportions than that of the non-user households. Figure 4.1 presents the composition of cattle in Lamu County by household category.

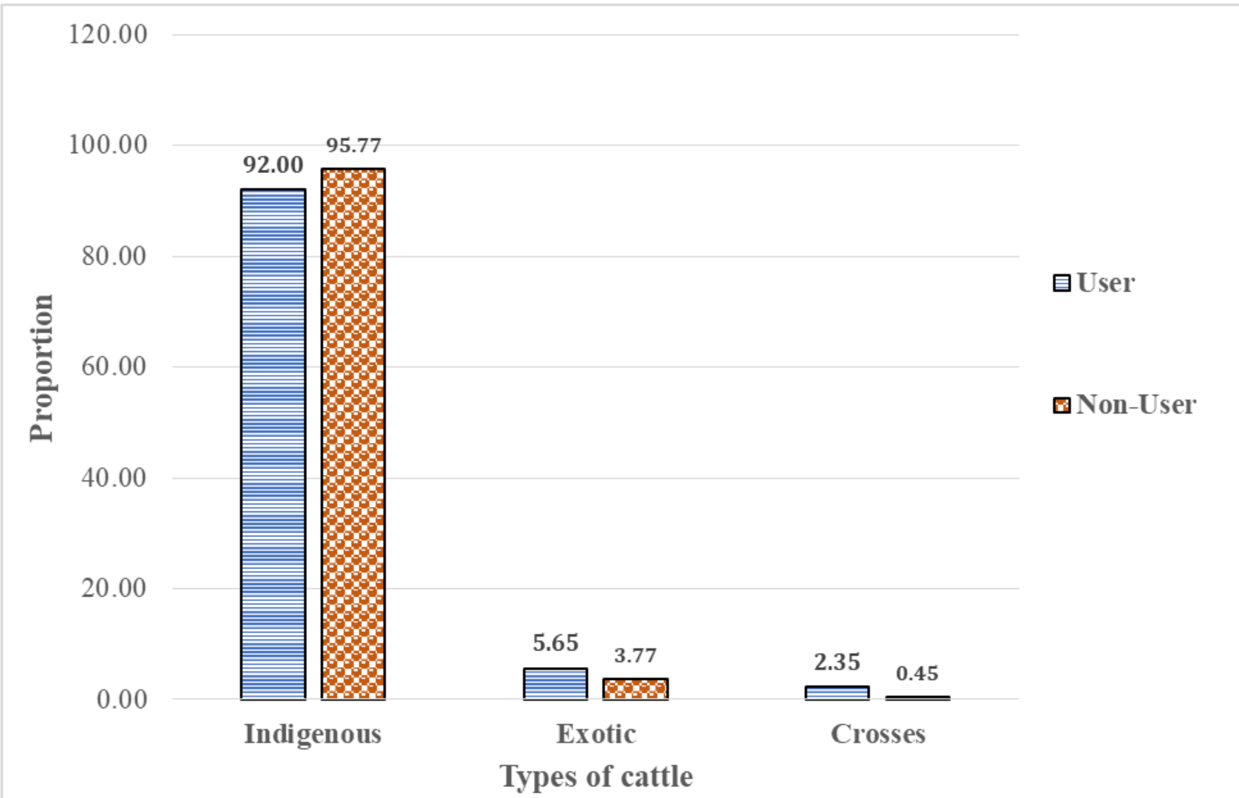

Figure 4.1: Cattle composition in Lamu County by household category

4.1.6 Cattle herd structure

The study analyzed the structure of cattle owned in the household by age and sex. It was found that the proportion of mature cattle namely bulls (13.6 percent), Cows (54.8 percent) and heifers (13.1 percent) were higher among the user households than those of non-user households which were 12.86 percent, 43.7 percent and 10.8 percent for bulls, cows and heifers respectively. On the other hand, the proportion of young bulls (6.7 percent), bull-calves (4.6 percent) and female calves (7.3 percent) were lower among the user households than in non-user households whose proportions were 12.9 percent, 6.6 percent and 12.6 percent for young bulls, bull-calves and female calves respectively. This is possibly because households introduced mature animals into the farm either by way of gifts in, purchasing or dowry. The higher proportion of calves among the non-user households could be due to the fact that they had more indigenous cattle which are generally less susceptible to animal African trypanosomiasis. Figure 4.2 shows the herd structure for cattle in the study area.

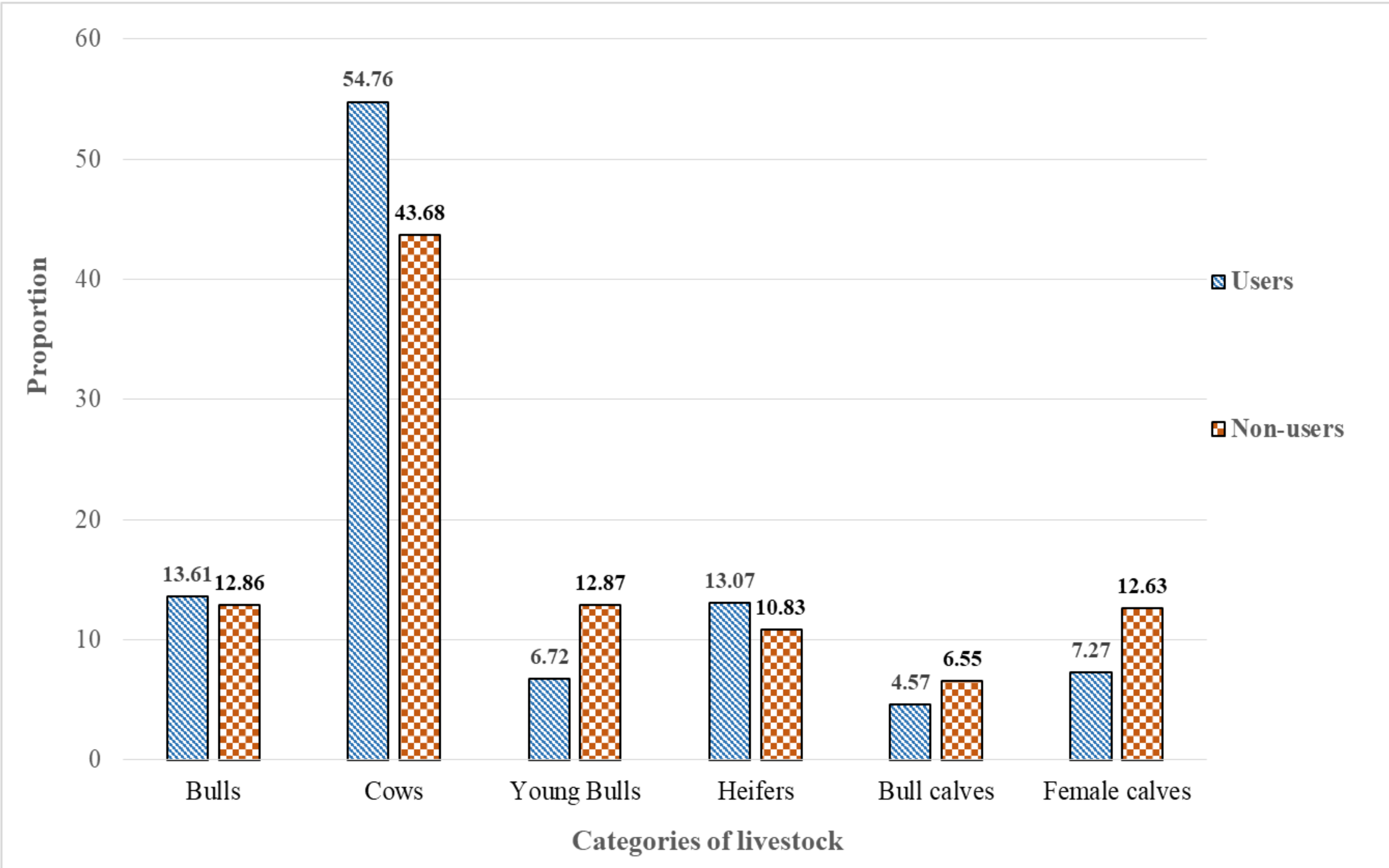

Figure 4.2: Herd structure for cattle in the study area

4.1.7 Sheep, goats and donkey herd structures

The study found that the proportions of mature goats among user households (male=21.5 percent, female=54.8 percent) were higher than those of non-user households (males=20.3, females=52.1). The proportion of kids in the herd (23.7 percent) was lower for user households than for non-user households (27.5 percent).

The proportion of male sheep (33.2 percent) and that of lambs (23.2 percent) were higher among the user households than in the non-user household where the proportions were 28.6 percent and 19.7 percent for male sheep and lambs respectively. In donkeys the proportion of mature males (41.4 percent) and young donkeys (16.6 percent) were as well higher in user households than non-user households which had males (35.5 percent) and young donkey (15.1 percent). Figure 4.3 shows the herd structure for goats, sheep and donkeys in the study area.

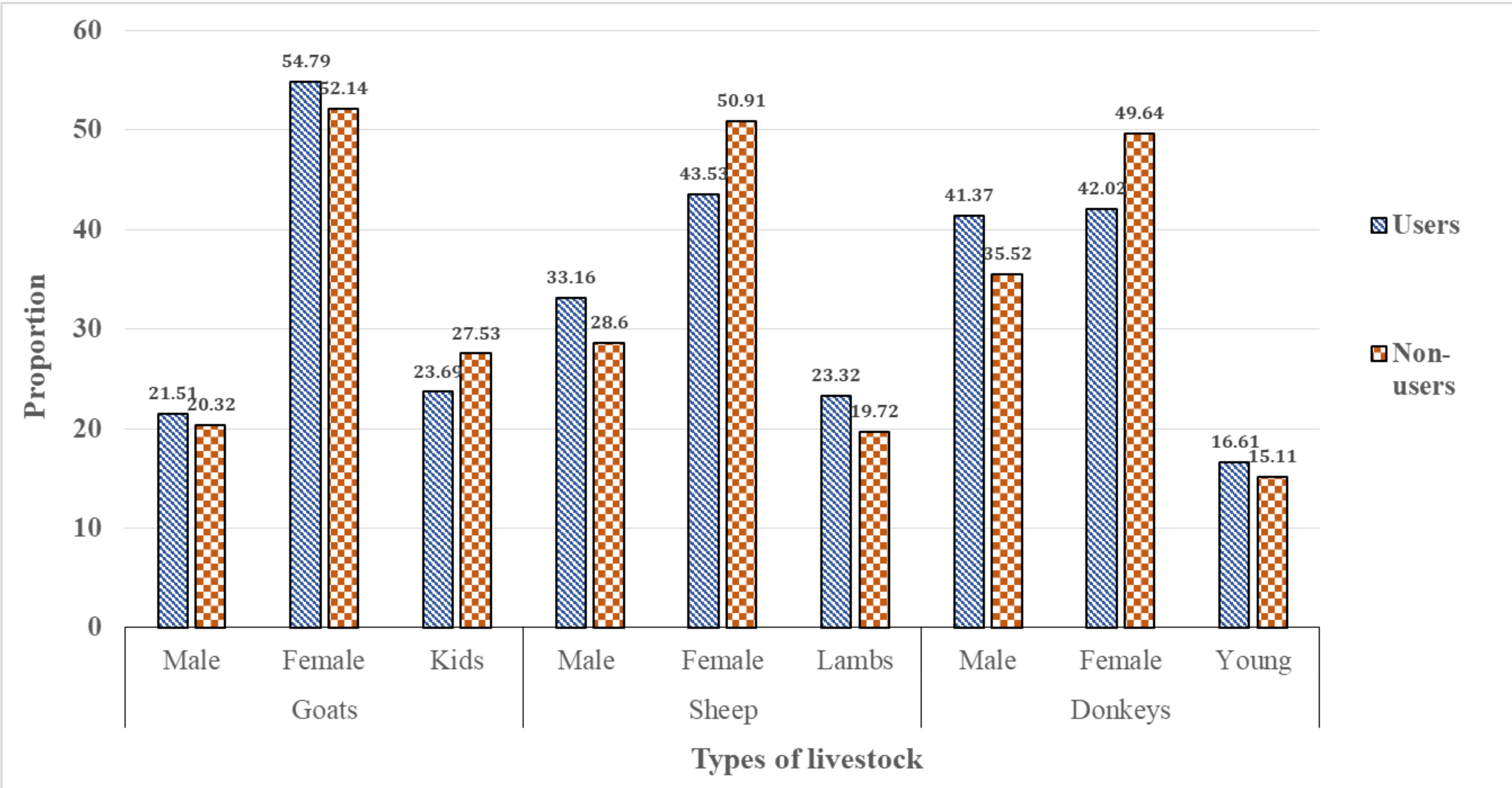

Figure 4.3: Herd structure for goats, sheep, and donkey

4.2 Factors influencing choice and integration of tsetse fly and trypanosomiasis control methods

4.2.1 Factors influencing choice of control methods

A Multivariate Probit (MVP) model was used to analyze the factors that influence choice of tsetse and trypanosomiasis control methods by farmers. Users of the control methods, as well as non-users were included in the analysis. The results are presented in Table 4.5. First, the null hypothesis of the multivariate probit model states that the coefficients of independent variables included in the model are jointly not statistically different from zero. This hypothesis is scientifically tested using the model fitness statistics; Wald Chi-square (χ^2). The Wald χ^2 = 453.58, and its corresponding probability value, $p < 0.001$, are statistically significant at 1 percent level. This test result indicated that at least one of the covariates included in the model is statistically different from zero. Based on this result, the null hypothesis that the coefficients of independent variables included in the model are jointly not statistically different from zero is rejected. Thus, alternative hypothesis that variables included in the multivariate probit model are jointly statistically different from zero is accepted. These test results indicate that all the variables jointly influence choice of individual technologies or their combined application.

The second assumption of multivariate probit model is that probability of using livestock integration practices can be appropriately predicted by univariate probit models; that is, estimating separate probit regression. The likelihood ratio test is the appropriate model fitness test that compares models to determine which regression fits the data significantly better. In this study, the goodness of fit of multivariate probit is compared to that of univariate probit model. The likelihood ratio test of the associations of the trypanocidal drug, insecticide treated livestock, and insecticide treated targets is statistically significant at 1% level (β =134.833, $p < 0.001$). The statistic implies that multivariate probit coefficients maximized the value of likelihood function. For this reason, multivariate probit model predicts the response variables significantly better than univariate probit model. The null assumption that the probability of using livestock integration practices can be appropriately predicted by univariate probit models is rejected.

Another testable assumption of multivariate probit model is interdependence assumption, which states that regression equations are correlated. This assumption is validated by inspecting the correlation coefficients (*rhos*). Besides showing direction of the relationships among equations, correlation coefficients provide information about the strength of relationships. The correlation coefficients of all the equations are positive and statistically significant, implying that the probability of using one tsetse fly and trypanosomiasis control method increases chances of livestock keeping household using another method (Appendix 5). In other words, the control methods are complementary and, thus, interdependent. Therefore, it was desirable statistically to use multivariate probit because uptake of one technology is dependent on the decision to uptake another. Therefore, multivariate probit was the most appropriate model to estimate determinants of choice of integrated tsetse fly and trypanosomiasis control methods. The results of model specification test is shown in Appendix 6.

First, several socio-economic variables were significantly related to the probability of households using integrated tsetse fly and trypanosomiasis control methods. The coefficients of sex of household head for insecticide treated livestock (β = 0.365, p < 0.001), insecticide treated targets (β = 0.436, $p < 0.05$) and trypanocidal drugs (β = 0.277, $p < 0.05$) were statistically significant.

This result indicates that male-headed households were more likely to use the three practices compared to female-headed households.

Table 4.5: Factors affecting choice and combination of tsetse fly and trypanosomiasis control methods

Control Method	Insecticide Treated Livestock (ITL)			Insecticide Treated Targets (ITT)			Trypanocidal Drugs (TTD)		
	Coefficient	Std. Error	P-Value	Coefficient	Std. Error	P-Value	Coefficient	Std. Error	P-Value
Sex of HH Head	0.365***	0.137	0.008	0.436**	0.172	0.011	0.277**	0.138	0.044
Size of Household	-0.060***	0.019	0.002	-0.065**	0.028	0.020	-0.006	0.019	0.744
Age of HH Head	0.054***	0.006	0.000	0.052***	0.007	0.000	0.041***	0.006	0.000
Occupation HHH	-0.021	0.141	0.881	-0.488***	0.175	0.005	-0.335**	0.151	0.027
TLU	0.011***	0.008	0.163	-0.002	0.009	0.820	0.006	0.008	0.416
Land Acreage	-0.006***	0.005	0.208	0.004	0.003	0.241	-0.010	0.010	0.335
Off-farm income	0.345*	0.086	0.000	0.566***	0.125	0.000	0.889***	0.103	0.000
Access to Credit	0.154	0.159	0.333	0.297	0.199	0.136	-0.138	0.157	0.380
Extension Services	-0.045	0.139	0.749	0.111	0.179	0.534	-0.053	0.140	0.707
Group Membership	0.076	0.130	0.560	0.036	0.167	0.831	0.161	0.132	0.224
Tech. Availability	0.022	0.169	0.896	1.065***	0.367	0.004	0.207	0.162	0.200
Ease of use	-0.204	0.177	0.250	0.541	0.376	0.150	-0.109	0.156	0.484
Technology Cost	0.133	0.152	0.382	-0.196	0.181	0.279	-0.266*	0.161	0.097
Tech Effectiveness	-0.172	0.189	0.363	1.021***	0.323	0.002	0.602***	0.162	0.000
Location	0.528	0.156	0.001				-0.266*	0.151	0.079

Log pseudo likelihood = – 607.183 Wald chi^2 (44) = 453.58 Prob > chi^2 = 0.000
Likelihood ratio test of rho21 = rho31 = rho32 = 0: chi^2 (3) = 134.833 Prob > chi^2 = 0.000
***, **, * = significant at 1%, 5%, and 10%, respectively

The coefficient of household size had a significant relationship with the probability of farmers using insecticide treated livestock (β = -0.060, p < 0.001), as well their likelihood of applying insecticide treated targets (β = -0.065, p < 0.05). This result suggests a large number of people in a household undermine the use of insecticide treated livestock and insecticide treated targets. Furthermore, the coefficient of age of household head had a positive cross-cutting influence on the chances of households to use insecticide treated livestock (β = 0.054, p < 0.001), insecticide treated targets (0.052, p < 0.001) and trypanocidal drugs (β = 0.041, p < 0.001). The last socio-economic characteristic that was significantly associated with the likelihood of applying insecticide treated livestock was the coefficient of farming as a primary occupation of the household head (β = -0.488, p < 0.001). Similarly, coefficient of farming as a primary occupation of the household head (β = -0.335) was statistically significant (p < 0.001). Unexpectedly, the result suggests that having agriculture as the main activity of the household made households less likely to use insecticide treated livestock and trypanocidal drugs.

Furthermore, farm and off-farm variables were significant determinants of choice of tsetse fly and trypanosomiasis control methods. While coefficients of tropical livestock units, land acreage, and off-farm income were statistically significantly associated with the likelihood of livestock keeping households using insecticide treated livestock, only non-farm income was significantly related to use of insecticide treated targets and trypanocidal drugs. Whereas coefficient of tropical livestock units (β = 0.011, p < 0.001) showed a positive influence on use of insecticide treated livestock, size of land holding was negatively (β = -0.006, p < 0.001) related to the chances of livestock keepers using the practice. On the other hand, while the effect size of off-farm income was marginally associated with use of insecticide treated livestock (β = 0.345, p <

0.1), its effects on insecticide treated targets equation (0.566, $p < 0.000$) and on trypanocidal drugs equation ($\beta = 0.889$, $p < 0.001$) were highly significant. These results portray socio-economic factors as crucial determinants of choice of tsetse fly and trypanosomiasis control methods.

Besides the importance of background socio-economic factors that influence use of tsetse fly and trypanosomiasis control methods, characteristics of the practices also play a central role in adoption processes. Some of the crucial technology characteristics include ease of use, availability, cost, and effectiveness of the technology. The coefficient of technology availability ($\beta = 1.065$, $p < 0.001$) and coefficient of effectiveness of the technology ($\beta = 1.021$, $p < 0.001$) significantly affected the probability of livestock keepers to use insecticide treated targets. At the same time, as expected the coefficient of cost of the practice ($\beta = -0.266$. $p < 0.1$) and that of effectiveness of the technology ($\beta = 0.602$, $p < 0.001$) were negatively and positively associated with use of trypanocidal drugs respectively. These results suggest that farmers may also be sensitive to characteristics of the technology when making adoption choices. In addition, choice of technology may differ spatially, implying that accounting for the influence of location characteristics is crucial to unearthing the underlying reason for choice of technology. The coefficient ($\beta = -0.266$, $p < 0.1$) for location was statistically significantly related with use of trypanocidal drugs. Thus, farmers in Lamu East were less likely to use trypanocidal drugs compared to their counterparts in Lamu West sub-county.

4.2.1.1 Predicted probabilities of joint use and marginal success

The results show that the probability of farmers fully integrating the three methods of controlling tsetse flies and trypanosomiasis was 19 percent. This indicates that joint uptake of all the three methods or any two of them was possible. However, the results further show marginal success of single method uptake. Insecticide treated targets had the highest probability (46.1 percent) of being applied singly as compared to other methods namely insecticide treated livestock and treatment with trypanocidal drugs. The results for predicted probabilities of joint use and marginal success is shown in Table 4.6.

Table 4.6: Predicted probabilities of joint use and marginal success

Probabilities	Control Methods	Success (%)	Failure (%)
Marginal Success	Insecticide Treated Livestock (ITL)	0.410	
	Insecticide Treated Targets (ITT)	0.319	
	Trypanocidal Drugs (TTD)	0.461	
Predicted Probability	Joint Use	0.189	0.388

4.2.2 Factors influencing level of integration of tsetse and trypanosomiasis control methods

A truncated regression model was used to analyze the factors that influence integration level of tsetse fly and trypanosomiasis control methods by livestock farmers in Lamu County. Table 4.7 presents truncated regression results of the intensity of application of tsetse fly control methods. The Wald χ^2 value (332.77) was statistically significant (p-value = 0.000). This indicates that the truncated regression model fits the data well and suggests goodness of fit. Eight out of thirteen variables included in the model were statistically significant. The null hypothesis that all variables included in the model have no effect on the intensity of application of tsetse fly control methods is thus rejected. It is concluded that all variables jointly affect the level of integration of tsetse fly and trypanosomiasis control methods.

The results indicate that the livestock diversity in the farm had a positively significant marginal effect (dy/dx =0.26, P<0.001) on the integration index for tsetse and trypanosomiasis control methods. The marginal effect of gender (dy/dx =0.14, P<0.001) was positively and statistically associated with the integration index for tsetse and trypanosomiasis control methods while size of the household had a negative and significant marginal effect (dy/dx =0.01, P<0.05) on tsetse fly and trypanosomiasis control methods integration index. The age of the household head was found to have a significant and positive marginal effect (dy/dx =0.01, P<0.05) on the tsetse fly and trypanosomiasis control methods integration index while occupation of the household head had a negative and significant marginal effect (dy/dx = -0.097, P<0.05).

The marginal effect of off-farm income on the tsetse fly and trypanosomiasis control methods integration index was found to be positive and significant (dy/dx = 0.093, P<0.001) and the tropical livestock units also had a positive and significant marginal effect (dy/dx = 0.003, P<0.1). Distance to the market however had a negative and significant marginal effect (dy/dx = -0.11, P<0.001) on the tsetse fly and trypanosomiasis control methods integration index as was expected.

Table 4.7: Determinants of integration of Tsetse and Trypanosomiasis control methods

Variable	Coef.	Std. Err.	P Value	dy/dx
Livestock diversity	0.285***	0.058	0.000	0.257
Gender of the HH head	0.155***	0.033	0.000	0.140
Household size	-0.010*	0.005	0.059	-0.009
Age of the HH head	0.005***	0.002	0.005	0.004
Education of the HH head	0.003	0.004	0.462	0.002
Occupation of the HH head	-0.108***	0.032	0.001	-0.097
Log of off-farm income	0.103***	0.017	0.000	0.093
Tropical livestock units	0.004*	0.002	0.073	0.003
Acreage	-0.001	0.000	0.110	-0.001
Access to credit	0.020	0.036	0.576	0.018
Distance to the market	-0.126***	0.032	0.000	-0.114
Extension service availability	-0.022	0.036	0.531	-0.020
Group membership	0.026	0.036	0.458	0.024

Log pseudolikelihood = – 6.583 Wald χ^2 (13)= 332.77; Prob > chi2 = 0.0000

Note: ***, **, * = significant at 1%, 5%, and 10%, respectively

4.3 Effect of integration levels of tsetse fly and trypanosomiasis control methods on livestock herd structure in Lamu County

4.3.1 Effect of integration levels on livestock herd structure

A multivariate tobit regression model was used to analyze the effect of integration levels of tsetse fly and trypanosomiasis control methods on the herd structure of livestock owned by households in the study area. The results are presented in table 4.8 below. The likelihood ratio test and the log pseudo likelihood (Appendix 12) suggest joint significance of the error correlation. This implies that the multivariate tobit model is efficient in estimating the determinants of herd structure in the households. The significance of these statistics is further reinforced by the significance of the error linkage (rho) of all the four equations of livestock types. The significance of the *rhos* of all equations supports interdependence of the equations assumption of the multivariate tobit model.

The second objective focused on the influence of integrated tsetse fly and trypanosomiasis control methods on herd structure. The coefficients of integrated tsetse fly and trypanosomiasis control methods for cattle ($\beta = 0.153$, $p < 0.001$), goats ($\beta = -0.183$, $p < 0.1$), sheep ($\beta = -0.829$, $p < 0.05$), and donkeys ($\beta = 0.429$, $p < 0.001$) were statistically significant albeit at different levels. While the signs of the coefficients of integrated tsetse fly and trypanosomiasis control methods for cattle and donkey herd structures were expected, the direction of their relationships with goat and sheep strategies were surprising. These results indicate that the effects of use of multiple tsetse fly and trypanosomiasis control methods on herd structures depends on the type of livestock.

Table 4.8: Determinants of household livestock herd structure

Variable	Cattle		Goats		Sheep		Donkey	
	Coefficient	**P-Value**	**Coefficient**	**P-Value**	**Coefficient**	**P-Value**	**Coefficient**	**P-Value**
Integration Index	0.153***	0.002	-0.183*	0.095	-0.828**	0.039	0.429***	0.002
Sex of HH Head	0.022	0.583	-0.080	0.270	-0.318	0.218	-0.066	0.539
Size of Household	0.002	0.654	0.009	0.295	0.039	0.215	0.008	0.546
Age of HH Head	-0.002	0.307	-0.008***	0.008	0.012	0.240	0.000	0.959
Education of HHH	-0.007*	0.094	0.010	0.191	0.049**	0.041	-0.008	0.465
Off-farm Income	-0.121***	0.000	0.085*	0.090	-0.203	0.220	-0.069	0.292
Occupation HHH	-0.060	0.127	0.067	0.338	-0.282	0.208	-0.350***	0.000
Land Acreage	0.000	0.860	0.002**	0.010	0.001	0.771	0.000	0.967
Access to Credit	-0.142***	0.002	0.211***	0.004	-0.133	0.629	-0.119	0.287
Distance to Market	-0.096***	0.007	0.065	0.313	-0.062	0.767	0.181*	0.053
Extension Services	0.126***	0.002	-0.100	0.136	-0.199	0.360	0.130	0.221
Group Membership	0.062*	0.088	-0.023	0.724	-0.106	0.618	0.100	0.306

Log pseudo likelihood = –1211.154 Wald chi^2 (48) = 181.25 Prob > chi^2 = 0.000

Likelihood ratio test of rho12 = rho13 = rho14 = rho23 = rho24 = rho34 = 0: chi^2 (6) = 149.335 Prob > chi^2 = 0.000

***, **, * = significant at 1%, 5%, and 10%, respectively

The effect of integrated tsetse fly and trypanosomiasis control methods were adjusted by including socio-economic variables in the multivariate tobit model. The coefficients of education level of household heads were significantly related with cattle herd structure (β = -0.007, p < 0.1) and sheep (0.049, p < 0.05) equation but insignificant with respect to goats and donkey equations. On the other hand, the coefficient of age of the household head (β = 0.008, p < 0.001) was only statistically significantly associated with goat herd structure. While the effect size of off-farm income on cattle (β = -0.121, p < 0.1) and goats (0.085, p < 0.001) equations were significant, those for sheep and goat were not statistically significant. Besides, the slopes of occupation of the household head (β = -0.350, p < 0.001) and land area (β = 0.002, p < 0.05) had significant relationship with donkey herd structure respectively. Thus, inter-household differences in socio-economic characteristics explain the differences in herd structure because they do not have uniform effects across livestock types.

Furthermore, multivariate tobit model controlled for institutional factors. The results presented in Table 4.8 indicates that the coefficients of household access to credit (β = -0.142, p > 0.001), distance to the market (β = -0.096, p < 0.001), extension services (0.126, p < 0.001), and group membership (β = 0.062, p < 0.1) significantly influenced cattle herd structure. However, coefficients of access to credit (β = 0.211, p < 0.001) and distance to market (β = 0.181, p < 0.001) were only significantly related to goat and donkey herd structure equations respectively. These results appear to indicate that most institutions tend to focus on cattle production than other livestock types.

4.4 Impact of multiple application of tsetse fly and trypanosomiasis control methods on household income among livestock farmers in Lamu County

The Wald χ^2 and the log likelihood tests were statistically significant indicating the goodness of fit of the endogenous switching regression (ESR) in estimating the treatment effects of isolated and multiple use of tsetse fly and trypanosomiasis control methods on household income (Appendices 13, 14, 15, 16 and 17). The correlation coefficients (rho_2) are significant, which indicates presence of sample selection bias. Additionally, the likelihood ratio (LR) test was statistically significant, implying that outcome equations are independent.

The identification of an instrument in addition to predictors of the selection equation is important for the satisfaction of ESR rule of thumb. The study used geographical location of the household, group membership and distance to the market as instruments. Falsification test was performed in the identification of the instruments (Di Falco *et al*., 2015). The falsification test holds that a valid instrument will have an effect on the selection variable but has an insignificant effect on the outcome variable. Falsification instrument showed that the geographical location, group membership and distance to the nearest market were valid instruments, jointly and significantly explaining selection equations and insignificantly explaining farm income. However, the joint effects of the instruments were insignificant in the outcome equations. Therefore, group membership and distance to the market were valid instruments in ESR for the selection equation.

4.4.1 OLS estimates of outcome variable

Full information ESR OLS estimates of the determinants of household income are presented in Table 4.9. The estimates account for endogeneity in household incomes, meaning the coefficients are unbiased. Column 2 of the table presents OLS estimates of non-users of tsetse and trypanosomiasis control methods ($L_0T_0D_0$). Columns 3, 4, 5, 6, and 7, respectively, are the OLS estimated coefficients of insecticide treated livestock ($L_1T_0D_0$), insecticide treated targets ($L_0T_1D_0$), trypanocidal drugs ($L_0T_0D_1$), a combination of insecticide treated livestock and trypanocidal drugs ($L_1T_0D_1$) and a combination of all the three practices ($L_1T_1D_1$).

The results in Table 4.9 show that the slope of sex of the household head ($\beta = 0.058$, $p < 0.05$) was significantly associated with household income of non-users. The coefficients of age of the household were statistically significant for non-users ($\beta = 0.002$, $p < 0.05$) and users of insecticide treated livestock ($\beta = 0.070$, $p < 0.1$). Household size was another crucial socioeconomic factor that had a significant influence on household income. While the coefficient of household size was negatively associated with household income for users of trypanocidal drugs ($\beta = 0.086$, $p < 0.1$), the slopes for households that used trypanocidal drugs in combination with insecticide treated livestock was positive ($\beta = 0.056$, $p < 0.1$). The association between education level of household head was significant for users of insecticide treated targets ($\beta = 0.151$, $p < 0.05$), trypanocidal drugs ($\beta = 0.070$, $p < 0.1$) and full integration of tsetse fly and trypanosomiasis control methods. Additionally, while the slope coefficient of tropical livestock units was significantly negative with relation to non-users ($\beta = -0.039$, $p < 0.05$), its values for insecticide treated livestock (0.118, $p < 0.001$) and a combination of insecticide treated livestock and trypanocidal drugs ($\beta = 0.028$, $p < 0.05$) were positive. Besides socio-economic factors, credit coefficient ($\beta = 0.043$, $p < 0.05$) was significantly associated with income of non-users of integrated tsetse fly and trypanosomiasis control methods. These results show the critical role of socio-economic and institutional characteristics in influencing household income.

Table 4.9: Ordinary Least Squares (OLS) Estimates of household incomes

Variables	$L_0T_0D_0$ (n=208)	$L_1T_0D_0$ (n=46)	$L_0T_1D_0$ (n=37)	$L_0T_0D_1$ (n=71)	$L_1T_0D_1$ (n-44)	$L_1T_1D_1$ (n=130)
Sex of household head	0.058**	-0.007	0.377	0.130	0.234	0.175
	(0.017)	(0.518)	(0.729)	(0.465)	(0.178)	(0.170)
Age of household head	0.002**	0.070*	0.050	0.022	0.001	-0.001
	(0.001)	(0.037)	(0.039)	(0.020)	(0.013)	(0.011)
Household size	-0.001	-0.008	-0.096	-0.086*	0.056*	0.046
	(0.002)	(0.093)	(0.095)	(0.044)	(0.03)	(0.029)
Education of household head (year)	0.002	-0.017	0.151**	0.070*	0.004	0.050***
	(0.002)	(0.059)	(0.069)	(0.036)	(0.018)	(0.018)
Land area (Acres)	0.000	0.057	-0.003	-0.005	-0.038	-0.009
	(0.001)	(0.038)	(0.007)	(0.027)	(0.030)	(0.019)
Tropical livestock units	-0.039**	0.118***	0.024	0.045	0.028**	-0.018
	(0.001)	(0.041)	(0.074)	(0.031)	(0.005)	(0.011)
Credit (1=Yes, 0 otherwise)	0.043**	-0.286	0.947	-0.087	-0.102	-0.093
	(0.018)	(0.563)	(1.205)	(0.422)	(0.175)	(0.203)
Constant	11.06	16.26***	18.16***	22.316***	21.283	11.237***
	(0.038)	(2.09)	(3.259)	(1.069)	(0.91)	(0.722)

***, **, * = significant at 1%, 5%, and 10%, respectively, figures in parentheses are the std. err.

Note: $L_0T_0D_0$ = non-use of any tsetse and trypanosomiasis control method, $L_1T_0D_0$ = use of insecticide treated livestock, $L_0T_1D_0$ = use of insecticide treated targets, $L_0T_0D_1$ = use of trypanocidal drugs, $L_1T_0D_1$ = combination of insecticide treated livestock and trypanocidal drugs and $L_1T_1D_1$ = combination of all the three practices.

4.4.2 Treatment effects of tsetse fly and trypanosomiasis control methods

The study explored the impact of tsetse fly and trypanosomiasis control methods on household income. The impact was measured by average treatment effect on the treated (ATT) and average treatment effect on the untreated (ATU). The ATT computes average difference in outcomes of integrating tsetse fly and trypanosomiasis control methods with and without use. The ATT and ATU compared expected household income of non-users of tsetse fly and trypanosomiasis control methods with actual/observed and counterfactual scenarios. The difference between the actual and counterfactual scenarios is the average treatment effect (ATE). Table 4.10 presents the expected household incomes under actual and counterfactual scenarios of tsetse fly and trypanosomiasis control methods.

4.4.2.1 Impact of using insecticide treated livestock

For insecticide treated livestock ($L_1T_0D_0$), cells a and c provide the actual and counterfactual cases of expected household income of users, respectively. On the other hand, cells b and d represent the actual and counterfactual situations of the expected household income for non-users of insecticide treated livestock ($L_0T_0D_0$), respectively. The expected annual household income by livestock keepers that used insecticide treated livestock was approximately KES 60,400, while the non-users was about KES 54,200 on average. This result may be interpreted that livestock keepers that used insecticide treated livestock earned approximately 11.4 percent (approximately KES 6,200) more than non-users. Nevertheless, this may be a misleading interpretation. A focus on the treatment effect provides a more accurate interpretation and conclusion of the treatment effect of insecticide treated livestock.

Table 4.10: Endogenous switching regression estimates of tsetse fly and trypanosomiasis control treatment Effects

Combination of control methods	HH type and treatment effect	Household decision and annual income (Kshs)		
		To use	Not to use	ATE
$L_1T_0D_0$	User household (ATT)	(a) 60,438.08	(c) 39,066.65	21,371.43 (7532.945)***
	Non-user households (ATU)	(d) 28,198.51	(b) 54,157.11	-25,958.60 (0.142)***
	Heterogeneous effects	32,239.57	-15,090.46	47,330.03
$L_0T_1D_0$	User household (ATT)	(e) 85,574.18	(g) 46,556.67	39,017.51 (0.136)***
	Non-user households (ATU)	(h) 85,855.99	(f) 54,157.11	31,698.88(0.096)***
	Heterogeneous effects	-281.81	-7,600.44	7,318.63
$L_0T_0D_1$	User household (ATT)	(i) 105,141.68	(k) 77,809.95	27,331.73 (10319.23)
	Non-user households (ATU)	(l) 143,567.2	(j) 54,157.112	89,410.088 (4971.743)***
	Heterogeneous effects	-38,425.52	23,652.838	-62,078.358
$L_1T_0D_1$	User household (ATT)	(m) 75,090.46	(o) 52,351.66	22,738.80 (7261.45)***
	Non-user households (ATU)	(p) 55,447.35	(n) 54,157.11	1,290.24 (2180.274)
	Heterogeneous effects	19,643.11	-1,805.45	21,448.56
$L_1T_1D_1$	User household (ATT)	(q) 175,449.7	(s) 117,144.7	5,8305 (14192.62)***
	Non-user households (ATU)	(t) 346,402.5	(r) 54,157.11	292,245.39 (13945.48)***
	Heterogeneous effects	-170,952.8	62,987.59	-233,940.39

***, **, * = significant at 1%, 5%, and 10%, respectively

Note: $L_0T_0D_0$ = non-use of any tsetse and trypanosomiasis control method, $L_1T_0D_0$ = use of insecticide treated livestock, $L_0T_1D_0$ = use of insecticide treated targets, $L_0T_0D_1$ = use of trypanocidal drugs, $L_1T_0D_1$ = combination of insecticide treated livestock and trypanocidal drugs and $L_1T_1D_1$ = combination of all the three practices. ATT = Treatment Effect on the Treated, ATU = Treatment Effect on the Untreated and ATE = Average Treatment Effect.

The counterfactual scenario (c) shows that insecticide treated livestock using households would have earned almost KES 39,000 had they not used. In other words, insecticide treated livestock users would have earned about 35 percent (KES 21,400) less if they had not used the control method. In the second counterfactual case shown in cell d, livestock keeping households that did not use insecticide treated livestock would have earned KES 26,000 (45%) less had they used insecticide treated livestock. This result shows that insecticide treated livestock significantly reduced livestock income. However, transitional heterogeneity of insecticide treated livestock was positive, implying that the effect is significantly higher for livestock keeping households that used the method compared to non-users. Adjusting for potential heterogeneity shows that insecticide treated livestock users would have earned significantly lower livestock income than non-user households in the counterfactual scenario (c). This result also highlights presence of heterogeneity that make the use decision more "deserving users" of insecticide treated livestock than non-users regardless of the use status. Counterfactual scenario d shows that non-users would have earned less livestock income had they decided to use.

4.4.2.2 Impacts of using insecticide treated targets

Rows 4 to 6 of the table present treatment effects of using insecticide treated targets ($L_0T_1D_0$). The average actual household income of insecticide treated targets users was approximately KES 85,500 compared to about KES 54,200 earned by non-users ($L_1T_0D_0$). The expected outcomes indicate that users earned about 57 percent (KES 31,300) more than non-users. However, this interpretation may be misleading. Turning to the treatment effects, insecticide treated target users would have earned about KES 46,600, which is approximately 45 percent less than what they actually earned. Counterfactual scenario (h) indicates that non-users would have earned approximately KES 85,900 had they decided to use insecticide treated targets. This can be inferred to mean that households that did not use insecticide treated targets earned 37 percent less income for their decision not to use the control method. These findings show that use of insecticide treated targets significantly increases household income. The transitional heterogeneity effect is negative, suggesting that effect is smaller for the households using insecticide treated targets compared to non-using households.

Furthermore, counterfactual scenario g suggests that insecticide treated targets users would have earned significantly lower livestock income compared to non-using households. This finding is a further indication of sample heterogeneity. This highlights potential individual characteristics that influenced users' decision to use insecticide treated targets irrespective of the adverse effects of tsetse and trypanosomiasis on livestock production. Despite the heterogeneity, insecticide treated targets users were still better off using the control method than not using. On the other hand, had the non-using households used insecticide treated targets, they would have earned significantly higher incomes than users. The counterfactual situation of non-users shows that they would have earned almost equal amount of household income, on average, as users had they chosen to use insecticide treated targets.

4.4.2.3 Impact of using trypanocidal drugs

Turning to the treatment effect of trypanocidal drug use, cells i and j represent the actual expected livestock incomes for users and non-users, respectively. On the other hand, cells k and l represent the counterfactual cases of user and non-users, respectively. The result indicated the expected household income for trypanocidal drug users and non-users were approximately KES 105,100 and KES 54,200, respectively. Trypanocidal drug users earned 94 percent (KES 50,900) more than non-users which may also lead to a misconstrued conclusion. Accounting for potential heterogeneity in the decision to use or not to use trypanocidal drug indicates that users earned 35 percent (approximately KES 27,300) more than they would have earned if they had not used. However, the difference in incomes between the actual and the counterfactual case for users was insignificant. Turning to non-user livestock keeping households, the counterfactual case shows that they would have earned almost three times their actual household income if they had used trypanocidal drugs. The results suggest potential heterogeneity in livestock keeping household in decision on either to use or not to use trypanocidal drugs.

The ATE column in Table 4.10 shows a negative transitional heterogeneity for use or non-use of trypanocidal drugs. This implies that the impact of trypanocidal drugs is smaller for livestock keeping household that used the drug to control tsetse flies and trypanosomiasis compared to non-users. Further correction of the potential sample heterogeneity indicates that trypanocidal drug using households would have earned significantly higher household income than households that did not use the drug in the counterfactual case (k). This reveals important sources of heterogeneity that makes trypanocidal drug users better income-earning households relative to non-users irrespective of the effect of tsetse and trypanosomiasis on livestock production. Notwithstanding the fact that trypanocidal drug users would still have earned more from livestock production, they were still better off using the drugs than not using. Turning to counterfactual case for non-users (l), non-users would have earned much more than users had they used trypanocidal drug.

4.4.2.4 Impact of combined use of insecticide treated livestock and trypanocidal drugs

Turning to the treatment effect of combining insecticide treated livestock and trypanocidal drugs ($L_1T_0D_1$), cells m and n represent the actual expected livestock incomes for users and non-users, respectively. On the other hand, cells o and p represent the counterfactual cases of user and non-users, respectively. The result indicated that the expected household incomes for users of this combination was approximately KES 75,100. The users earned 39 percent (KES 20,900) more than non-users which may also be a misconstrued conclusion. Accounting for potential heterogeneity in the decision to use or not to use combination $L_1T_0D_1$ indicates that users would have earned 30 percent (approximately KES 22,700) less had they decided not to use. Turning to non-user livestock keeping households, the counterfactual case shows that they would have earned 2 percent (KES 1,300) more than they actually earned. The results suggest that non-user households were worse-off without using $L_1T_0D_1$. The counterfactual case for users of $L_1T_0D_1$ (0) shows that they would be worse-off than non-users had they not used trypanocidal drug and insecticide treated livestock. This results indicates that users of $L_1T_0D_1$ were deserving users of the two methods compared to non-users regardless of status of use. They would have been worse-off without using $L_1T_0D_1$.

4.4.2.5 Impact of combined use of insecticide treated livestock, insecticide treated targets and trypanocidal drugs

The last three rows of Table 4.10 show treatment effects for full integration of tsetse and trypanosomiasis control methods. The actual expected household incomes for users and non-users are presented in cells q and r, respectively. Cells s and t represent the counterfactual scenarios for users and non-users respectively. The actual household incomes earned by users who fully integrated the three tsetse and trypanosomiasis control methods and non-users were approximately KES 175,400 and KES 54,200, respectively. The findings suggest that users of the three methods ($L_1T_1D_1$) earned 223 percent (about KES 121,200) more than non-users. Similar to the previous interpretation, it cannot be concluded that users of the three methods made 223 percent more household income than non-users at this point.

Treatment effect of full integration of tsetse and trypanosomiasis control methods indicates that users earned almost 50 percent more than they would have earned without use (counterfactual s). In other words, users of the three methods would have earned about KES 117,100 had they not used. The counterfactual situation for non-users (t) suggests that they earned 5.4 times less as a result of their decisions not to use a combination of insecticide treated livestock, insecticide treated targets, and trypanocidal drugs. These results imply that use of a combination of three control methods significantly improves household income for livestock keepers. Nevertheless, the negative transitional heterogeneity is an indication that the effect of use of a combination of the three methods is smaller for livestock keeping households that used compared to non-users. Additionally, sample heterogeneity is revealed by counterfactual case s, which shows that user households would still have earned more livestock income than non-users. Again, this finding shows that users of a combination of the three control methods were better income-earners than non-users regardless of the status of use. Nonetheless, they were still better off using the three practices in combination than not using. Lastly, counterfactual t suggests that non-users would have earned more than users had they used the three control methods simultaneously.

CHAPTER 5 : DISCUSSION

5.1 Factors influencing choice and integration of tsetse fly and trypanosomiasis control methods

Tsetse fly is an important disease transmitting vector, with negative implication on livestock and human health and welfare. Out of the twenty-three known tsetse fly species and sub-species, *Glossina pallidipes* and *Glossina austeni* are common in the coastal region of Kenya. These species attack and suck blood of cattle, goats, sheep, and donkey, causing Nagana in livestock and sleeping sickness in humans (Saarman *et al*., 2018). Besides, the fly is also a major livestock production constraint, causing an estimated economic loss of KES 200 million annually across thirty-eight of the forty-seven counties across the country (Mureithi, 2020). To underline the seriousness of the fly in Kenya, the Kenya Tsetse and Trypanosomiasis Eradication Council (KENTTEC) was established as a public body responsible for the control and eradication of the fly in the country. This is an indication of the importance of the fly to livestock and human health in the country.

There are several tsetse fly control methods. Traditional tsetse fly control methods include bush burning, smoke, and livestock enclosures (Torr *et al*., 20011). In Kenya, KENTTEC coordinates programs that promote use of integrated tsetse fly and trypanocidal methods across the country. Among integrated tsetse and trypanosomiasis control methods promoted by KENTTEC include stationary baits (insecticide treated targets), mobile targets (insecticide treated livestock), aerial spraying and Sequential Aerosol Technique (SIT), and trypanocidal drugs (Shaw *et al*., 2013). Insecticide treated livestock is sometimes baited with attractants. Besides controlling tsetse fly. Insecticide treated livestock also eradicate ticks and other vectors. On the other hand, trypanocidal drugs are administered in doses for control of nagana. The integrated methods complement each other for effective control of insects (Bouyer *et al*., 2011). Additionally, they are meant to replace the unsustainable traditional control methods.

The dissemination of integrated tsetse fly and trypanosomiasis control methods recognizes that uptake of the control methods is not a straight forward decision. Technology adoption literature identifies several factors that influences farmers' decision to use a given practice. Despite feasibility assessments by KENTTEC and PATTEC indicating that livestock keeping households in Lamu suffered dire consequences of tsetse fly infestation, the rollout of tsetse fly eradication project in 2010 did little to understand how the socio-economic and institutional profiles of livestock keeping households influence decision to apply the practices. Therefore, there was little understanding of the factors that led to differentiated patterns in uptake of the control methods.

Technology adoption studies identify several factors that underline farmers' decision to use a given practice. Guided by random utility theory, studies have demonstrated that household and farm characteristics, profitability, institutional environment, labour supply, and risk and uncertainty perceptions are important drivers of technology adoption (Gedikoglu & McCann, 2012). The random utility model postulates that farmers are profit-oriented and will choose technology that yields maximum returns. Nevertheless, most livestock technology adoption studies ignore that farmers are guided by multiple goals that sometimes may be conflicting (Gedikoglu & McCann, 2012). Consequently, they may adopt multiple tsetse fly and trypanosomiasis control methods to meet a broader set of goals. To this end, limited information is available about drivers of integration of tsetse fly and trypanosomiasis control methods in Lamu County. Given above-mentioned background, the first objective was to simultaneously determine drivers of choice and integration of tsetse fly and trypanosomiasis control methods in Lamu County.

5.1.1 Factors influencing choice of tsetse fly and trypanosomiasis control methods

Farm households play a crucial role in adoption of new and improved technologies. For this reason, research studies have continuously been interested in establishing the influence of household socio-economic characteristics on technology use decisions. The interest of this study was to determine how age, sex, education, and occupation of the household heads affected the choice of tsetse fly and trypanosomiasis control methods. The study established that the socio-economic variables of interest had significant effects on use of tsetse fly and trypanosomiasis control methods. The positive relationship between age of the households and chances of farmers applying and integrating the three tsetse fly and trypanosomiasis methods could be argued that farmers gain experience over the years of livestock rearing and therefore an understanding of the several available technologies. It is likely that the technologies are used singularly at different times or combined for effective results. This results are in line with those found by Karanja *et. al*. (2015), that farmers with higher age were likely to adopt east coast fever vaccine compared to younger farmers. The results are however contrary to those by Mwaseba and Kigoda (2017), who found that more middle aged farmers accepted recommended tsetse control methods compared to older farmers. Although acceptance could be synonymous to uptake of control methods the level of uptake as well as combination of several methods could be different, thus validating the results found in this study.

The results show that off-farm income had a positive effect on choice of all the three methods. As expected an increase in off-farm income will probably increase uptake of new technologies in agriculture. In the case of this study, tsetse fly and trypanosomiasis control technologies are cost intensive particularly if a farmer has to purchase trypanocidal drugs, insecticides or use of specialized materials for example insecticide treated targets and spray pumps. It is therefore likely that farmers who earn income from other activities can use part of it to obtain these technologies. The results are in line with those found by Karanja *et.al.* (2015), that farmers who earned income from off-farm activities had a higher probability of up-taking east coast fever vaccine.

Sex of the household head was found to have a significant effect on choice and integration of insecticide treated livestock, and insecticide treated targets. A household whose head was a male, was likely to use insecticide treated livestock and insecticide treated targets to control Tsetse flies and trypanosomiasis disease as compared to use of trypanocidal drugs. This results corroborates those found by Mwaseda and Kigoda (2017) that more male respondents agreed to use recommended tsetse fly control methods as compared to female counterparts among communities neighbouring Serengeti National Park in Tanzania. Similarly, Mose *et.al*. (2013), found that sex affected farmer preferences for alternative trypanosomiasis control technologies. Insecticide treated livestyock entails singular methods including dipping, spraying and application of pour-on insecticides on the animals. These methods are not only labour intensive but also require that animals be restrained in a crush pen. This is perhaps the reason why such methods are mostly done by men, and thus justifying the positive effect on their choice. The negative effect of household size on choice of insecticide treated livestock and insecticide treated targets was unexpected. The two technologies are labour intensive and thus it would be argued that larger households are likely to provide labour required when applying them. On the contrary, larger households demand more in terms of consumption expenditure thus reducing the amount that can be used to acquire the control technologies. Perhaps, this could explain the negative effect observed by this study.

The number of household members was negatively associated with use of insecticide treated livestock and use of trypanocidal drugs. The negative effect of household size on choice of insecticide treated livestock and insecticide treated targets was unexpected. The two technologies are labour intensive and thus it would be argued that larger households are likely to provide labour required when applying them. On the contrary, larger households demand more in terms of consumption expenditure thus reducing the amount that can be used to acquire the control technologies. Perhaps, this could explain the negative effect observed by this study.

The results further show that livestock owners whose major occupation was farming were unlikely to use insecticide treated targets as well as use of trypanocidal drugs. An explanation for this could be that first, insecticide treated targets was found in designated geographical zones and therefore the distance to such zones could be long. On the other hand, individuals who solely depend on farming are likely to diversify the enterprises and thus they are unlikely to graze in areas further away from the farm. This allows them to attend to other farm enterprises. Secondly, treatment with trypanocidal drugs is a costly technology and therefore individuals who solely depend on farming may lack money to purchase the required drugs.

The results further indicate that farmers who perceived technologies to be readily available as well as those who considered technology effectiveness, were more likely to use insecticide treated targets. In Lamu East, this method was introduced as part of the interventions to control tsetse fly and trypanosomiasis in the area. Such intervention may have improved the availability of insecticide treated targets hence the observed response. Generally, availability and effectiveness of a technology positively influences its uptake. The probability that farmers will adopt a given technology is usually higher if they are sure that the technology is effective. Perhaps, farmers in the study area considered insecticide treated targets an effective method compared to insecticide treated livestock and treatment with trypanocidal drugs. These findings support those found earlier by Howley *et. al*. (2012), that the success of reproductive technologies is likely to affect the probability of farmers choosing such technologies. The cost of technology had a negative influence on choice of trypanocidal drugs. This results are similar to those found by Aenishaenslin *et.al*. (2015), that cost of any technology affects its acceptability and uptake. In their study they argued that acceptability and uptake of tick control interventions depended on the cost of such interventions. Treatment with trypanocidal drugs is a costly method in terms of purchasing the required drugs for treatment and thus, it is unlikely that farmers will choose it particularly those who consider cost of a technology before making the choice. A similar argument was put forward by Saini *et.al*. (2017), that uptake of tsetse flies control technology depends on cost effectiveness of the technology in question.

Location of the farmers was found to be significant and positively influencing choice of insecticide treated livestock. This means that farmers in Lamu East were more likely to use insecticide treated livestock compared to their counterparts in Lamu West. Probably, these spatial differences in the use of insecticide treated livestock as compared to other methods of controlling tsetse fly and trypanosomiasis due to differences in access to private and public support service as well as their acquisition and application. From the descriptive statistics discussed earlier, a larger proportion of farmers in Lamu East perceived insecticide treated targets as being readily available, effective and easy to use in terms of its application. These perceptions explain the likelihood of choice of insecticide treated livestock by farmers in Lamu East sub-county.

Having explained the relationship between independent and dependent variables, it was crucial to test whether household socio-economic variables, institutional factors, and technology characteristics jointly had no effect on choice of tsetse fly and trypanosomiasis control methods. Results in Appendix 7 shows that the test statistic (χ^2 = 139.13, p < 0.001) for social variables (age, sex, education and occupation) included in multivariate probit model is statistically significant, implying that their coefficient are statistically different from zero. Based on these result, the null hypothesis that the effects sizes of social characteristics on choice of tsetse fly and trypanosomiasis control methods are not significant is false. Thus, the alternative hypothesis that household social factors have significant influence on choice of tsetse fly and trypanosomiasis control methods is accepted. Similarly, test statistic for economic variables (off-farm income, land and livestock ownership) were statistically significant (χ^2 = 104, p < 0.001: Appendix 8), leading to rejection of null hypothesis that economic factors do not influence choice of tsetse fly and trypanosomiasis control methods. Therefore, economic factors have a significant effect on use of tsetse fly and trypanosomiasis control methods.

The study was also interested in establishing the effect of institutional variables on choice of tsetse fly and trypanosomiasis control methods. The null hypothesis tested stated that institutional factors, that is extension education, credit, and group membership, jointly had no influence on choice of tsetse fly and trypanosomiasis control methods. The test statistic for the hypothesis was statistically insignificant (χ^2 = 8.45, p = 0.4896: Appendix 9), hence the null hypothesis is accepted and conclusion made that institutional factor did not have a significant effect on farmers' choices of control methods.

With the exception of insecticide treated livestock (χ^2 = 3.92, p = 0.4168), farmers' perceptions of technology attributes test statistics for insecticide treated targets (χ^2 = 149.98, p < 0.001) and of trypanocidal drugs (χ^2 = 19.32, p > 0.001) were statistically significant. In this regard, the null hypothesis that technological attributes do not have effect on use of insecticide treated livestock is accepted (Appendix 10). On the other hand, null hypothesis is rejected for insecticide treated targets and trypanocidal drugs, an alternative hypothesis that states that technological attributes of trypanocidal drugs and insecticide treated targets have a significant effect on choice of tsetse fly and trypanosomiasis control methods is true.

5.1.2 Factors influencing integration of tsetse and trypanosomiasis control methods in Lamu County

The gender of the household head was positively associated with the level of integration of tsetse fly and trypanosomiasis control methods applied by livestock farmers. This finding suggests that male-headed households are likely to use more tsetse fly control methods compared to their female-headed counterparts. Male-headed households were 14 percent more likely to use a combination of insecticide treated livestock, insecticide treated targets, and treatment with trypanocidal drugs than the male-headed households. Men were possibly more concerned with the role of livestock in sustaining household welfare, and were more positioned to mobilize resources for livestock production compared to women. As a matter of priority, male-headed households may have allocated more resources to the control of tsetse flies compared to their female counterparts. A similar argument was put forward by Mose *et.al* (2013) that sex of farmers affected their preferences for alternative trypanosomiasis control technologies.

The marginal effect of size of the household was found to be significant but had a negative effect on integration of tsetse fly and trypanosomiasis control methods. This suggests that large-sized households are less likely to use multiple tsetse fly control methods ceteris paribus. Increasing household size by one member resulted in 1 percent decrease in the level of application of tsetse fly and trypanosomiasis control methods. Larger household size would have provided motivation for diversification into other farm activities as well as non-farm activities. This could have reduced the amount of labour allocated to livestock production, resulting in low application levels of tsetse fly control methods.

The age of the household head was found to have a significant and positive effect on the tsetse fly and trypanosomiasis control methods integration index. A one year increase in the age of the household head lead to a 5% increase in the control methods integration index. This was possibly because older farmers are assumed to have gained knowledge and experience over time and are better able to evaluate technology information than younger farmers. This is consistent with the results from the studies by Mignouna *et al*, (2011); Kariyasa and Dewi (2011) have who have shown that age had a significant positive influence on technology uptake.

The occupation of the household head was negative and statistically associated with the level of use of tsetse fly control measures. Compared to household heads with non-farm activities as the primary occupation, households whose heads' main occupation was farming were less likely to use multiple tsetse fly control methods. Farming as the primary occupation of the household head reduced the intensity of use of tsetse fly control methods by 9.7 percent. This result was unexpected and could be attributed to the possibility that household heads with farming as their primary occupation are more experienced in livestock keeping to the effect that they were aware of the risks and benefits of intensive use of the tsetse fly control measures. Repeated exposure of farmers to the tsetse fly control methods could have allowed the farmers to identify and compare risks and effectiveness of each method, which limited intensive use.

The results further indicate that off-farm income had a positive marginal effect on integration of tsetse fly and trypanosomiasis control methods. The finding was expected as an increase in income is an incentive to invest in several technologies when need arises. Amare *et.al.* (2019) argue that income from off-farm activities is an impetus to technology adoption for example the index based livestock insurance. Probably the results found in this study would mean that farmers who earn off-farm income spend it to boost agricultural activities.

Tropical livestock units was positively related with the level of use of insecticide treated livestock, insecticide treated targets, and treatment with trypanocidal drugs to control tsetse fly and the disease it transmits. An increase in livestock ownership by one tropical livestock unit resulted in an increase in the use of tsetse fly control methods by 0.3 percent. This finding was expected because the number of livestock kept encourages use of different control methods as farmers seek to reduce the effect of trypanosomiasis on livestock. Livestock is a resource and an important source of household livelihood and wealth in the study area. This probably encouraged farmers to apply multiple control methods as they sought to shield their sources of household livelihood against losses associated with trypanosomiasis. Karanja *et.al.* (2015), found similar results that larger herd sizes had a positive influence on the level of uptake of technologies for example east coast fever vaccine.

As expected, the distance to the nearest market had a negative and significant marginal effect on the level of use of the three methods of tsetse fly control. Households residing over 5km from the main market were 11 percent less likely to intensively use the three tsetse fly control methods compared to households living less than 5km from the nearest market. This finding suggests that distance increases transaction costs of accessing, acquiring and using tsetse fly control methods. The transaction costs could have been a major disincentive deterring farmers from accessing protected grazing lands, crush pens, and cattle dips, as well as acquisition of trypanocidal drugs or insecticides, thereby negating intensive use of the tsetse fly and disease control methods.

5.2 Effect of level of integration of tsetse fly and trypanosomiasis control methods on livestock herd structure

The level of integration of tsetse fly and trypanosomiasis control methods was statistically significant across the four equations albeit with different signs and significance levels. The strength of the significance of the integration of the control methods was strongest for the cattle and donkey equations. The use of one additional tsetse and trypanosomiasis control method increased the herd structure index of cattle and donkeys about 0.15 and 0.42 times, respectively. In contrast, integration of tsetse fly and trypanosomiasis control methods reduced the goat and sheep herd structure indices 0.18 and 0.82 times, respectively.

The differences in the effect of the level of integration of tsetse fly and trypanosomiasis control methods on the four types of livestock could be attributed to the importance of the different types of livestock on the livelihoods of the households. Cattle and donkey have diverse roles in the livelihoods of Lamu residents, economically and socially, compared to goats and sheep. This would have influenced the prioritization of the use of the practices on different livestock types.

The donkey is the main source of draught power in Lamu County and cattle source of milk and meat. Toaff-Rosenstein (2018) argued that improvements in herd sizes and structure requires reduction in mortality as the herd size grows large. Therefore, prevention and treatment of livestock using integrated technologies was important in reducing the risk of transmission of diseases.

Education of the household head was negatively and positively associated with the herd structure of cattle and sheep, respectively. The negative causal effect on cattle herd structure was unexpected. In other words, an increase in the level of education by one year reduced the herd structure of cattle by 0.7 percent while it increased the herd structure of sheep by 4.9 percent. Education possibly was a source of knowledge and innovation for households which allowed households heads to make decisions with respect to the appropriate level of herd structure of sheep. Given the multiplicity of economic roles of cattle, households would have used their knowledge in cattle keeping to specialize in a given cattle enterprise or probably well-educated household heads were responding to land carrying capacity hence destocking where land carrying capacity was limiting. This finding corroborates Mabonga and Ogallo (2018) who established education was an important variable in influencing herd structure in Uasin Gishu County. Mabonga and Ogallo (2018) argued that low education was associated with the failure of farmers to perform basic livestock management tasks, which negatively impact on herd structure.

The direction of the relationships between off-farm income and cattle and goat herd structures was negatively and positively significant respectively. Increasing off-farm income by one Kenya shilling resulted in 0.12 decrease and 0.08 increase in cattle and goat herd structures, respectively, holding other factors constant. Off-farm income could have fortified goat herd structure by increasing opportunities for continued within livestock type diversification. Additionally, off-farm income possibly decreased risks associated with financial constraints which allowed households to improve goat herd structure. On the other hand, off-farm income could have encouraged diversification to goats at the expense of cattle as suggested. Mabonga and Ogallo (2018) also found that monthly income was an important determinant of herd structure.

The land area had a positive and significant effect on goat herd structure. An additional acre of land improved goat herd structure 0.002 times. Land is an important resource that possibly supported browsing of goats. The availability of browsing area may have encouraged farmers to increase the herd size of goats. In turn, an increase in herd size was then accompanied with corresponding improvements in the composition of the goat herd structure.

Farming as a primary occupation of the household head was negatively related with donkey herd structure. To have farming as the primary occupation reduced the likelihood of improving donkey herd structure index 0.35 times. Farming as the main occupation could have allowed household to establish costs and benefits associated with having diverse donkey herd structure. The donkey's productive roles are less diverse and this could have reduced the incentive for improving the herd structure.

Credit was positively associated with goat herd structure but negatively related with cattle herd structure. Households that had access to credit were 0.21 times more likely to have diverse goat herd structure compared to who had no access. In contrast, households with access to credit reduced likelihood of improvement of cattle herd structure by 0.14. This suggests that the rearing of the two livestock types are in competition for financial resources. Another possible explanation is that the investment choices and sources of credit had differing results. Possibly, credit represented a significant financial burden that negated benefits associated with investment in cattle. In contrast, credit could have expanded investment choices for goats, resulting in improved goat herd structure. This study is in line with Petrus *et al*. (2011) who reported that credit constraint disabled farmers from expanding herd size and improvement in herd structure among smallholder pig farmers in Namibia.

Distance to the nearest market negatively influenced cattle herd structure. Households with farms that were located more than 5km from the main market were 0.89 times less likely to improve cattle herd structure. Longer distance from the market may have reduced household access to productive inputs. In turn, the low access to productive inputs may have dis-incentivized farmers to improve cattle herd structure. In other words, households' cattle herd structure may have been negated by high transaction costs incurred when acquiring cattle production inputs. In contrast, distance to the market was positive and significantly associated with donkey herd structure. Household living more than 5 km from the market were 0.18 times more likely to improve donkey herd structure than households living closer to the nearest market. This could be explained by the possibility that donkeys require little inputs from the market compared to cattle and other livestock types, or the farther the distances to the markets, the need for more donkeys as a source of transport and draught power. This finding is in line with results reported by Beyene *et al*. (2013) in a study that analyzed the trend in herd composition among pastoralist communities in Ethiopia.

Access to extension services positively influenced cattle herd structure. Households who had contact with extension agents were 0.12 times more likely to have an improved cattle structure compared to their counterparts with no access to extension. This could be explained by the possibility that extension provided information that enhanced farmers' knowledge in herd improvement. This finding contrasts results by Gizaw *et al*. (2017) who established that farmers with no access to extension were more likely to have an improved animal herd structure in terms of sex and breed.

Additionally, group membership was positively associated with the likelihood of households improving cattle herd structure. Households that belonged to rural agricultural and social groups were 0.06 times more likely to improve cattle herd structure or composition. This result is plausible since group membership facilitates farmer access to extension information and advisory services. The information obtained through groups possibly enables farmers to adopt strategies for improving the herd structure. This finding is in agreement with observations made by Hennessy and Heanue (2012) who argued that groups facilitate farmer learning and build confidence in application of new technologies.

Furthermore, the study hypothesized that level of integration of tsetse fly and trypanosomiasis control methods has no effect on herd structure. Post-estimation hypothesis test was performed to test this claim. Results presented in Appendix 11 show that the coefficients of integrated tsetse fly and trypanosomiasis control methods were highly significant ($\chi^2 = 24.11$, $p < 0.001$). Therefore, the null hypothesis is false. Thus, the alternative that the level of integration significantly affects herd structures is true. As such, use of multiple tsetse fly and trypanosomiasis control methods has a bearing on herd structures of donkeys, goats, sheep, and cattle.

5.3 Impact of tsetse fly and trypanosomiasis control on household income

The role of livestock is more pronounced in rural areas of developing countries. Livestock serves diverse functions, including economic, social, and cultural roles (Herrero *et al*., 2013; Bettencourt *et al*., 2015). Economically, livestock serves as source of household income through the sale of animal products and by-products. Second, livestock like cattle, goats, and sheep are important capital assets which can be mobilized and converted into cash whenever households are pressed with planned and unplanned financial needs (Narain *et al*., 2008; Bettencourt *et al*., 2015). Livestock as a capital asset also acts as collateral for financial intermediation (Alushula, 2019). Additionally, livestock are used to secure livelihoods of households during economic crisis, helping poor and vulnerable households to escape poverty, especially during years of extreme crop failure (Bettencourt *et al*., 2015). Livestock also provides manure and draught power, which are critical inputs to crop production and transportation of agricultural output (Bettencourt *et al*., 2015; McRoberts *et al*., 2018). As a result, livestock production is vital to economic development in rural areas, strengthening the rural markets through marketing of agricultural inputs and output and contributing to household wellbeing and wealth.

Livestock diseases present important challenges to the economic and social wellbeing of livestock keeping households (Njisane *et al*., 2020). African Animal Trypanosomiasis (AAT), and tsetse fly that transmits it, constrains livestock production in the region (Meyer *et al*., 2016; Olaide *et al*., 2019). The AAT directly results in animal death and animal productivity losses and also indirectly lowers value of animal and animal products (Auty *et al*., 2015; Olaide *et al*., 2019). For instance, AAT causes death of at least 3 million cattle and other livestock, resulting in nearly $5 billion in losses in agricultural production (Oluwafemi et al., 2007; Vreysen *et al*., 2013; Shaw *et al*., 2014). The AAT also increases economic costs involved in tsetse fly control and animal treatment. The tsetse fly also transmits Human African Trypanosomiasis (HAT) or sleeping sickness, which is a significant burden to the already weak health care system in many African countries (MacMillan, 2020).

Kenya is one of the countries with large areas that are infested with tsetse fly, with over 138,000 km^2 of land being infested. The infested land area covers 38 out of 47 counties (KENTTEC, 2011; Mureithi, 2020). Like other Sub-Saharan Africa countries, tsetse fly and AAT result in considerable losses which impact agricultural economy. The direct agricultural output losses associated with pest and disease amounts to about $200 million (Mureithi, 2020). Although the country has been successful in controlling HAT, the risk of infection is still high, especially in counties that border game parks (Okeyo *et al*., 2018). According to Ouma *et al*. (2005) and Messina *et al*. (2012), Kenya is infested with eight species of tsetse fly, with G. *pallidipes* being the most epidemiologically important. The high population densities of G. *pallidipes* are found along the Kenya Coastal strip and Lake Victoria Basin in Western region.

Kenya was one of first six countries in Eastern Africa region that benefited from the PATTEC commissioned tsetse fly and trypanosomiasis control programs. The first phase of the program promoted the use of packages of tsetse fly and trypanosomiasis control practices in Meru-Mwea, Lake Bogoria, and Lake Victoria Basin. Among promoted tsetse fly and trypanosomiasis control methods were use of insecticide treated livestock, trypanocidal drugs, and insecticide treated targets. The project was implemented between 2005 and 2011, covering land area of 24,000 km^2 out of the 138,000 km^2 infested by tsetse fly.

In response to the tsetse fly menace, KENTTEC piloted an integrated approach to control tsetse fly and trypanosomiasis in parts of Lamu County in 2010, with the view of using the results to inform a wide-scale roll-out in coastal counties. With community involvement, the PATTEC project promoted deployment of insecticide treated targets, in farmlands and in conservation areas, insecticide treated livestock and treatment with trypanocidal drug (KENTTEC, 2011). Adoption of integrated tsetse fly and trypanosomiasis control methods was to improve the efficiency and efficacy of the practices. insecticide treated livestock involves treatment of animal with insecticides and the animals act as baits that attract and kill tsetse flies on contact during grazing. Insecticide treated livestock practices include spraying, dipping and application of pour-on on livestock. The insecticide treated targets method involves using insecticide treated clothes, nets or traps to attract and kill the tsetse fly on contact. On the other hand, treatment with trypanocidal drug are injectable drugs that are often used for prophylaxis and curative purposes.

This section verifies and discusses results of effect of integrated tsetse fly and trypanosomiasis control methods on household income. The results are discussed in sub-sections. The first sub-section discusses ordinary least square (OLS) results. The OLS results capture covariates of household income. They are the first two tiers of endogenous switching regression. The first tier captures the influence of socio-economic and institutional characteristics on household income of users of control methods. The second tier provides OLS estimates of non-users. The OLS estimates are unbiased because sample selection problem has been adjusted for in the third tier (select equation) of endogenous switching regression. The select equation is estimated using probit regression but the results and discussion are not presented herein because they are similar to multivariate regression results that have already been discussed in an earlier sub-section.

5.3.1 Determinants of household income for farmers in Lamu County

Several independent variables significantly influenced incomes of users and non-users of integrated tsetse fly and trypanosomiasis control methods. First, the direction of relationship between tropical livestock unit was negative for non-user households. This sign was unexpected and could be attributed to an increasing economic burden of treatment of livestock as diversity increases, which negatively impacts on household income. However, coefficients of tropical livestock units returned plausible positive results for households that used insecticide treated livestock alone and a combination of insecticide treated livestock and trypanocidal drugs. This is a further highlight of sample heterogeneity.

Furthermore, education of the household head was positive and significantly associated with household income of users of trypanocidal drugs, insecticide treated targets, and a combination of the three methods. This is a further illustration of the presence of heterogeneity. The positive and significant association between education of household head and household income was expected because household heads with higher levels of education were possibly more knowledgeable and innovative in exploiting available opportunities and resources for the generation of household income. Tuyen *et al.* (2014) and Tuyen (2015) reported similar results in Vietnam.

Tropical livestock units is equally important for both users of insecticide treated livestock and its combination with trypanocidal drugs. Livestock possibly generated income, which, to a larger extent, was an important pathway to increased farm and household incomes for both users of $L_1T_0D_0$ and $L_1T_0D_1$. This finding is comparable to earlier results reported by Kaphle and Bastakoti (2017), Meurs *et al.* (2017), Saxena *et al*. (2017), and Naz and Khan (2018). These studies demonstrated that livestock is an important source of farm and household income. That is, livestock directly provides products that are sources of household financial resources and indirectly through its contribution to nutritional and household resilience to consumption shortfalls.

A further interesting result is that the gender of the household head was significantly associated with household income of non-users but insignificant with respect to the use of either isolated or a combination of the practices. This result suggests that female household headship increases household income among non-users. Female-headed households may have had access to productive off-farm resources and engage in diverse activities compared to male-headed households. This finding is in line with results reported by Obisesan (2014) who established gender as a key determinant of adoption of technology of improved cassava production in Nigeria and hence the differences in income between males and females.

The age of the household head was positive and significantly associated with incomes for non-users and households using insecticide treated livestock. Household size was negatively and positively associated with incomes for households that used trypanocidal drugs and a combination of insecticide treated livestock and trypanocidal drugs respectively. The findings show that individual household characteristics may be important sources of heterogeneity that explains differences in incomes between users and non-users of tsetse fly and trypanosomiasis control methods and within users.

Additionally, access to credit services had positive and significant influence on household incomes for non-users. The differences in the significance levels of credit with respect to users and non-users in the outcome equation is another indication of heterogeneity in the sample. Households that had access to credit possibly invested in both on-farm and off-farm activities, which resulted in positive returns. Credit may have allowed farming households to acquire improved production technologies which transformed and enhanced both farm and non-farm productivity. This finding underscores results by Khan *et al*. (2018) who established that credit led to the development of the livestock sector in Pakistan, translating into enhanced farm and household incomes.

5.3.2 Treatment effects of tsetse and trypanosomiasis control methods in Lamu County

The study was interested in determining treatment effect of use of tsetse fly and trypanosomiasis control methods. The treatment effects were calculated for each practices or multiple application of the practices. The incomes were then compared to the incomes of non-users and the counterfactual situation of both use and non-use. Heterogeneities were computed to establish who the most deserving in each counterfactual case. The results revealed that households were better off adopting than not adopting the practices.

The control of tsetse flies and trypanosomiasis in Lamu County had a positive and significant effect on household income consistent with Weyori *et al.* (2019) who applied Difference in Difference (DID) in their study of impact of trypanosomiasis rational chemotherapy (TRYRAC) on household income and found a significant increase in household income of between 29 percent and 47 percent for intervention participants. The results of this study are also consistent with the findings of Taye *et al*. (2012) that cows in Southern Tsetse Eradication Project (STEP) and community tsetse controlled areas were able to give 26-27 percent, 25-29 percent and 17-21 percent more daily milk yield at the beginning, middle and end of lactation, respectively, than those in tsetse-challenged areas. In addition, cows in STEP and community tsetse controlled areas had lactation length longer by 1.20 to 1.35 months; age at first calving was shorter by 5.30 to 5.10 months; and calving interval was shorter by 4.20 to 3.20 months than cows in tsetse-challenged area, respectively implying potential increased income to households involved in tsetse control.

Gechere *et al*. (2012) studied the effects of tsetse control in Southern Ethiopia and found that the mean cattle herd size was lower in tsetse controlled blocks whereas the number of calves in the herds were higher and no cattle mortality reported all potentially translating to increased income for farmers. A study by Megersa *et al*. (2017) on effects of insecticide treated nets in protecting cattle against tsetse and other biting flies found that the body condition score was better and milk production was 56 percent higher for cattle which were protected compared to those that were not protected. This reduced the challenges of tsetse and other biting flies and improved the performance of animals which may lead to increased income from livestock.

The findings of this study further indicate that the effects of tsetse fly and trypanosomiasis control varied depending on the method or combination of methods used. An integrated cost benefit analysis of tsetse fly and trypanosomiasis control under different scenarios in Cameroon found that the benefit cost ratio of using insecticide treated cattle alone as a barrier was 4.5 compared to 3.8 for a combination of insecticide treated cattle, traps and targets (Meyer A, *et al*., 2018). It confirms the finding of this study that the ATE for use of single methods alone, that is, either insecticide treated livestock ($L_1T_0D_0$), insecticide treated targets ($L_0T_1D_0$) or trypanocidal drugs ($L_0T_0D_1$) was lower than the combinations namely ($L_1T_0D_1$) and ($L_1T_1D_1$). In Zambia Insecticide Treated Cattle (ITC) plus use of targets had a BCR of 2.3, targets plus traps had a BCR of 2.0, aerial spraying plus ITC had a BCR of 2.8 and aerial spraying and barrier traps had a BCR of 2.5 confirming different returns for different methods (Meyer A, *et al*., 2018).

The third null hypothesis of the study stated that multiple application of tsetse fly and trypanosomiasis control methods has no impact on household income of livestock keeping households. Households that used insecticide treated livestock earned approximately KES 21,400 annually more than what they would have earned without using the control method. Insecticide treated targets earned users KES 39,000, while use of trypanocidal drugs earned households KES 27,300 more than what they would have earned in their counterfactual scenarios. Whereas joint use of insecticide treated livestock and trypanocidal drugs had significantly higher income for users than their counterfactual scenarios, the impact was relatively lower than use insecticide treated targets and trypanocidal drugs singly. Furthermore, full integration of the three methods resulted in KES 5,800 more household income than the counterfactual situation. It is evident from the results presented in Table 4.10 that multiple application of tsetse fly and trypanosomiasis control methods resulted in significantly higher incomes for users. Additionally, had non-users used the three practices, they would have earned significantly higher household income than not using. Thus, the null hypothesis is rejected and a conclusion made that multiple application of tsetse fly and trypanosomiasis control methods has a significant impact on household income.

CHAPTER 6 : CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study focused on three aspects; factors that influence choice and integration of tsetse fly and trypanosomiasis control methods, effect of integration of tsetse fly control methods on livestock herd structure as a pathway to increased household income and finally impact of multiple application of tsetse fly and trypanosomiasis control methods on household income. The study concludes that firstly, household social and economic factors including age, sex, education, occupation, off-farm income, land and livestock ownership have significant influence on choice of tsetse fly and trypanosomiasis control methods. The technological attributes which include availability, cost and effectiveness of technology also had significant influence on choice of tsetse fly and trypanosomiasis control methods mainly insecticide treated targets and trypanocidal drugs. On the other hand the institutional factors including access to extension education, credit, and group membership did not have a significant effect on farmers' choices of control methods.

Secondly, there were positive effects of level of integration of the tsetse fly and trypanosomiasis control methods mainly on cattle and donkey herd structures which could possibly be the main pathway to increased household incomes. It implies that the higher the level of integration of the control methods, the better were the herd structures for cattle and donkeys suggesting that Lamu households achieved healthier cattle and donkey herds by applying more methods of control as opposed to when they applied fewer or none. In contrast, integration of tsetse fly and trypanosomiasis control methods reduced the goat and sheep herd structure indices. This is an indication that cattle and donkeys have diverse roles in the livelihoods of Lamu residents, economically and socially, compared to goats and sheep. The donkey was the main source of draught power in Lamu County and cattle main source of milk and meat.

Thirdly, accounting for endogeneity and self-selection, this study has demonstrated that the control of tsetse fly and trypanosomiasis in Lamu County had a positive and significant effect on household income and that the effects of tsetse fly and trypanosomiasis control varied depending on the method or combination of methods used. Households, whether they use a single method of tsetse fly and trypanosomiasis control or any combination of the control methods, are generally better off controlling than if they do not engage in control of the vector and the disease.

6.2 Recommendations

i. The national institutions and devolved units of government to design farmer outreach programs that take into consideration key household characteristics as well as technological attributes which may stimulate adoption of appropriate tsetse fly and trypanosomiasis control technologies.

ii. The Ministry in charge of livestock matters and the Kenya Tsetse and Trypanosomiasis Eradication Council during the periodic review of agricultural policy, national livestock policy and strategies in the livestock sector, to recognize the demographic, farm-specific, social, and household characteristics like gender of household head, household size, occupation of household head, availability and effectiveness of technology that may encourage or limit adoption of tsetse fly and trypanosomiasis control methods.

iii. The Kenya Tsetse and Trypanosomiasis Eradication Council and the Ministry of Agriculture Livestock, Fisheries and Cooperatives to develop sustainable land management guidelines for training of extension workers and farmers in areas where tsetse fly and trypanosomiasis have been successfully controlled thereby stimulating growth in livestock herd sizes, herd composition and structure as a pathway to increased household income.

iv. The Kenya Tsetse and Trypanosomiasis Eradication Council in collaboration with the Regional Economic Communities and the African Union to prepare bankable proposals for resource mobilization from the National Government, County governments and from development partners to eradicate tsetse fly and trypanosomiasis in the vast land areas of Kenya which are still heavily infested by tsetse flies. This will contribute to the alleviation of poverty among the rural households of Kenya.

v. Conduct further research using either longitudinal or panel data collected over a longer period of time to estimate the impact of tsetse and trypanosomiasis control on different types of outcomes including incomes from livestock, crops and aggregated household income among others.

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APPENDICES

Appendix 1: Household Questionnaire

IMPACT OF TSETSE FLY AND TRYPANOSOMIASIS CONTROL ON HOUSEHOLD INCOME IN LAMU COUNTY, KENYA

Questionnaire No. [ ]

COMPLETE OR TICK [√] APPROPRIATELY

Section A: Background Information

Consent:

Hello. My name is [______________________________]. We are conducting a **Survey on Impact of Tsetse and Trypanosomiasis Control in this area**. This study will help us understand the Benefits of the PATTEC initiatives towards eradication of tsetse flies and trypanosomiasis. Your voluntary participation is highly valuable and your responses will be treated strictly as confidential. Your answers will be used strictly for the purposes of the report to be developed and nothing else.

Name of Respondent: [______________________]	Phone contact: [______________________]
County: [______________________]	Sub-county: [______________________]
Division: [______________________] Sub-Location: [______________________]	Location: [______________________] Village: [______________________]
Total Size of farm (acres): [____________________] GPS reading: [____________________]	Number of members in household: [__________]
Name of Interviewer: [______________________]	Date of Interview: [_____/______/__________]

Section B: Characteristics of the Household

B1	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**
Name of HH head	Sex of HH head	Age (Years)	Occupation	Education (Years)	Marital status	Religion
[___________________]	(1) Male [___] (2) Female[___]	[___]	(1) farmer [___] (2) Teacher [___] (3) Fisherman [___] (4)Other (Specify) ________________	[___]	(1) Married [___] (2) Single [___] (3) Widow [___] (4) Widower[___]	(1) Islam [__] (2)Christianity [__] (3) Buddhism [__] (4)Others Specify) _______________

B8	**B9**	**B10**	**B11**	**B12**	**B13**
Give a breakdown of your household (HH) members	No. of members living in the HH	Does the member Work in the HH?	If YES, what is the Key role in the household?	No. of hours worked per day?	What is the Level of Education of member?
Family Members					
(a) Household head	[______]	(1) Yes [_] (2) No[_]	[______]	[______]	[______]
(b) Spouse	[______]	(1) Yes [_] (2) No[_]	[______]	[______]	[______]
(c) Children ≥18 yrs	[______]	(1) Yes [_] (2) No[_]	[______]	[______]	[______]
(d) Children10-17 yrs	[______]	(1) Yes [_] (2) No[_]	[______]	[______]	[______]
(e) Children <10 yrs	[______]	(1) Yes [_] (2) No[_]	[______]	[______]	[______]

B8	B9	B10	B11	B12	B13
Others living in the household					
(a) ≥18 yrs	[_____]	(1) Yes [_] (2) No[_]	[_____]	[_____]	[_____]
(b) 10-17	[_____]	(1) Yes [_] (2) No[_]	[_____]	[_____]	[_____]
(c) <10 yrs	[_____]	(1) Yes [_] (2) No[_]	[_____]	[_____]	[_____]

Key role: (1) Decision making (2) Grazing of cattle (3) Spraying/dipping of cattle (4) Tilling of land (5) Marketing (6) Others Specify_______________.

Level of Education: (1) Primary (2) Secondary (3) College (4) University (5) None (6) Other Specify_________

C. Household Livestock Production

C1	***C2***	***C3***
What types of livestock do you own in your HH? ***(Indicate all that apply)***	Give the number of livestock in your HH by types	Give the number of cattle kept in 2016
(1) Cattle [____] (2) Indigenous cattle [____] (3) Sheep [____] (4) Indigenous sheep [____] (5) Goats [____] (6) Indigenous goats [____] (7) Donkeys [____] (8) Camels [_____] (9) Poultry [_____]	(1) Cattle number [____] (2) Indigenous cattle number [___] (2) Sheep number [__] (4) Indigenous sheep number [__] (5) Goats number [__] (6) Indigenous goats number [__] (7) Donkeys number [___] (8) Camels number [___] (9) Poultry number [___]	(1) Local Zebu [___________] (2) Dairy crosses [_________] (3) Exotic dairy breeds [___] (4) Other (Specify) [______]

C1	*C2*	*C3*
(10) Indigenous poultry [____] (99) Other [_____] Specify [_________]	(10) Indigenous poultry number [_____] (99) Others Specify________________	

C4. Please, give the Livestock and livestock products off-take in your farm during 2016.

i. Cattle

Class	No. Of Existing stock in the farm	No. of cattle Deaths	No. Of Cattle Sold		Bought		Gifts in	Gifts out
			No.	Price/unit (Kshs)	No.	Price/unit (Kshs)		
Bulls	[______]	[______]	[______]	[______]	[______]	[______]	[______]	[______]
Castrates	[______]	[______]	[______]	[______]	[______]	[______]	[______]	[______]
Cows	[______]	[______]	[______]	[______]	[______]	[______]	[______]	[______]
Heifers	[______]	[______]	[______]	[______]	[______]	[______]	[______]	[______]
Young bulls	[______]	[______]	[______]	[______]	[______]	[______]	[______]	[______]
Female calves<1 year	[______]	[______]	[______]	[______]	[______]	[______]	[______]	[______]
Male calves <1 year	[______]	[______]	[______]	[______]	[______]	[______]	[______]	[______]
Other (specify) ____________	[______]	[______]	[______]	[______]	[______]	[______]	[______]	[______]

ii. Goats

Class	No. Of Existing stock in the farm	No. of Deaths	Goats Sold		Bought		Gifts in	Gifts out
			No.	Price/unit (Kshs)	No.	Price/unit (Kshs)		
Males goats	[______]	[______]	[______]	[______]	[______]	[______]	[______]	[______]
Female goats	[______]	[______]	[______]	[______]	[______]	[______]	[______]	[______]
Kids	[______]	[______]	[______]	[______]	[______]	[______]	[______]	[______]
Other (specify) ____________	[______]	[______]	[______]	[______]	[______]	[______]	[______]	[______]

iii. Sheep

Class	No. Of Existing stock in the farm	No. of Deaths	Sheep Sold		Bought		Gifts in	Gifts out
			No.	Price/unit (Kshs)	No.	Price/unit (Kshs)		
Male Sheep	[______]	[______]	[______]	[______]	[______]	[______]	[______]	[______]
Female sheep	[______]	[______]	[______]	[______]	[______]	[______]	[______]	[______]
Lambs	[______]	[______]	[______]	[______]	[______]	[______]	[______]	[______]
Other (specify) ____________	[______]	[______]	[______]	[______]	[______]	[______]	[______]	[______]

iv. Donkeys

Class	No. Of Existing stock in the farm	No. of Deaths	Donkeys Sold		Bought		Gifts in	Gifts out
			No.	Price/unit (Kshs)	No.	Price/unit (Kshs)		
Males	[_____]	[_____]	[_____]	[_____]	[_____]	[_____]	[_____]	[_____]
Females	[_____]	[_____]	[_____]	[_____]	[_____]	[_____]	[_____]	[_____]
Young	[_____]	[_____]	[_____]	[_____]	[_____]	[_____]	[_____]	[_____]
Other (specify) ___________	[_____]	[_____]	[_____]	[_____]	[_____]	[_____]	[_____]	[_____]

D. Household Milk Production

D1	D2	D3	D4	D5	D6	D7
Do you produce milk in your farm?	If Yes, Total amount of milk produced in the household per day	How many litres of milk is consumed at home?	How many litres of milk is given out to neighbours or relatives?	How many litres of milk is Sold?	How many litres are fed to calves?	Price per litre of milk
(1) Yes [_____] (2) No [_____]	[_____]	[_____]	[_____]	[_____]	[_____]	[_____]

E. Other Sources of Household Income

E1	**E2**	**E3**
Apart from cattle rearing, are there other sources of Income for the household?	If Yes, name the other sources of income for the household?	How much income (**KES**) did your HH get from the following source(s) during the year 2016)?
(1) Yes [_____] (2) No [_____]	(1) Crop farming [___] (2) Livestock farming [___] (3) Formal employment [___] (4) Fishing [___] (5) Bee keeping [____] (6) Small businesses [___] (7) Land leasing [___] (8) Other(Specify) [___]	(1) Crop farming [_________________] (2) Livestock farming [_____________] (3) Formal employment [_____________] (4) Fishing [____________] (5) Bee keeping [__________________] (6) Small businesses [______________] (7) Land leasing [_________________] (8) Other Specify [__________________]

E4	***E5***	***E6***	***E7***	***E8***
Does your HH own land?	Total area (**acres**) owned by HH?	What portion of the land was under the following uses during the year 2016	**What crops** did your HH produce during the last season & from how many **acres**?	In a good season, how much harvest do you produce from your farm?

E4	*E5*	*E6*	*E7*	*E8*
(1) Yes [_] (2) No [_]	[_____]	(1) Cultivation acres [___] (2) Homestead acres [___] (3) Grazing acres [___] (4) Others acres [___]	(1) Maize acreage [_________] (2) Beans acreage [_________] (3) Coconuts acreage [_______] (4) Maize + beans acreage [____] (5) Vegetable acreage [_______] (6) Other acreages (Specify) [______________________]	(1) Maize 90Kgs bags/ac [____] (2) Beans 90Kgs bags/ac [_____] (3) Coconut bags/ac [__] (4) Vegetables 10kg bags/ac [___] (5) Other 90Kgs bags/ac [_____] Specify [__________________]

F. Tsetse and trypanosomiasis control

F1	F2
In your opinion how would you rate the tsetse and trypanosomiasis problem in this area over the last one year?	Name the major methods which you have used to control tsetse in your livestock during 2016
(5) Very high [___] (4) High [___] (3) Moderate [___] (2) Low [___] (1) Not a problem[___]	(1) Insecticide Treated Cattle (dipping or spraying or use of pour-on) [___] (2) Grazing in protected areas (Insecticide Treated Targets) [___] (3) Treatment with trypanocidal drugs [___] (4) Indigenous methods(bush clearing, avoidance of the tsetse infested areas) [___] (5) Other (specify) [________________]

	F3		F4	
	How much money did you spend in a month to apply the following tsetse control methods on CATTLE?		How much money did you spend in a month to apply the following tsetse control methods on GOATS?	
Method applied	No. of times applied per month	Price per head (KES)	No. of times applied per month	Price per head (KES)
Insecticide Treatment				
(1) dipping or	[________]	[________]	[________]	[________]
(2) spraying or	[________]	[________]	[________]	[________]
(3) use of pour-on	[________]	[________]	[________]	[________]
Treatment against disease				
(1) trypanocidal drugs	[________]	[________]	[________]	[________]
(2) Ethno veterinary practices	[________]	[________]	[________]	[________]
(3) other drugs	[________]	[________]	[________]	[________]
Indigenous methods				
(1) bush clearing,	[________]	[________]	[________]	[________]
(2) avoidance of the tsetse infested areas)	[________]	[________]	[________]	[________]
(3) other method (specify) [__________________]	[________]	[________]	[________]	[________]

	F5		F6	
	How much money did you spend in a month to apply the following tsetse control methods on SHEEP?		How much money did you spend in a month to apply the following tsetse control methods on DONKEYS?	
Method	No. of times applied	Price per head (KES)	No. of times applied	Price per head (KES)
Insecticide Treated Cattle				
(1) dipping	[_______]	[_______]	[_______]	[_______]
(2) spraying	[_______]	[_______]	[_______]	[_______]
(3) use of pour-on	[_______]	[_______]	[_______]	[_______]
Treatment against disease				
(1) trypanocidal drugs	[_______]	[_______]	[_______]	[_______]
(2) ethno veterinary practices	[_______]	[_______]	[_______]	[_______]
(3) other drugs	[_______]	[_______]	[_______]	[_______]
Indigenous methods				
(1) bush clearing	[_______]	[_______]	[_______]	[_______]
(2) avoidance of the tsetse infested areas)	[_______]	[_______]	[_______]	[_______]
(3) other method (specify) [_______________]	[_______]	[_______]	[_______]	[_______]

Section G: Labour costs

G1	G2
What amount of time (Hrs) did you spend per day to carry out the following activities?	Cost of labour per day (KSh)
(1) Spraying [_____] (2) Dipping [_____] (3) Servicing of targets [_____] (4) Grazing/Feeding [_____]	[_____] [_____] [_____] [_____]

Other costs

G3	G4	G5
Cost of livestock feeding in the household	Cost of labor	Cost of treating other livestock diseases
(1) [________________________]	(1) [________________________]	(1) [________________________]
(2) [________________________]	(2) [________________________]	(2) [________________________]
(3) [________________________]	(3) [________________________]	(3) [________________________]
(4) [________________________]	(4) [________________________]	(4) [________________________]
(5) [________________________]	(5) [________________________]	(5[________________________]
Other (specify)……………..	Other (Specify)………………………	Other (Specify)………………

H. Characteristics of the tsetse and trypanosomiasis control technology applied

H1	**H2**	**H3**	**H4**
In your opinion, what would be your rating on the AVAILABILITY of the following technologies?			
Insecticide Treated Cattle (dipping or spraying or use of pour-on)	Indigenous methods (bush clearing, avoidance of the tsetse infested areas)	Treatment with trypanocidal drugs	Grazing in protected areas (Insecticide Treated Targets)
(1) High [____] (0) Low [____]	(1) High [____] (0) Low [____]	(1) High [____] (0) Low [____]	(1) High [____] (0) Low [____]

H5	**H6**	**H7**	**H8**
In your opinion, what would be your rating on the EASE OF USE of the following technologies?			
Insecticide Treated Cattle (dipping or spraying or use of pour-on)	Indigenous methods (bush clearing, avoidance of the tsetse infested areas)	Treatment with trypanocidal drugs	Grazing in protected areas (Insecticide Treated Targets)
(1) Easy to use [____] (0) Not Easy [____]	(1) Easy to use [____] (0) Not Easy [____]	(1) Easy to use [____] (0) Not Easy [____]	(1) Easy to use [____] (0) Not Easy [____]

H9	H10	H11	H12
Are these technologies applied at community level or at individual farm level?			
Insecticide Treated Cattle (dipping or spraying or use of pour-on)	Indigenous methods (bush clearing, avoidance of the tsetse infested areas)	Treatment with trypanocidal drugs	Grazing in protected areas (Insecticide Treated Targets)
(1)Community level [____] (0) Farm level [____]	(1) Community level [____] (0) Farm level [____]	(1)Community level [____] (0) Farm level [____]	(1)Community level [____] (0) Farm level [____]

H13	H14	H15	H16
What is your rating of the COST of the technologies that you applied on your livestock to control tsetse and trypanosomiasis?			
Insecticide Treated Cattle (dipping or spraying or use of pour-on)	Indigenous methods (bush clearing, avoidance of the tsetse infested areas)	Treatment with trypanocidal drugs	Grazing in protected areas (Insecticide Treated Targets)
(1) Low [____] (0) High [____]	(1) Low [____] (0) High [____]	(1) Low [____] (0) High [____]	(1) Low [____] (0) High [____]

H17	H18	H19	H20
What is your perception of the PERFORMANCE/EFFECTIVENESS of the technologies that you applied on your livestock to control			

tsetse and trypanosomiasis?			
Insecticide Treated Cattle (dipping or spraying or use of pour-on)	Indigenous methods (bush clearing, avoidance of the tsetse infested areas)	Treatment with trypanocidal drugs	Grazing in protected areas (Insecticide Treated Targets)
(1) High [____] (0) Low [____]	(1) High [____] (0) Low [____]	(1) High [____] (0) Low [____]	(1) High [____] (0) Low [____]

H21	**H22**	**H23**	**H24**
How would you rate your ACCESSIBILITY TO CREDIT during 2016?	How would you rate the AVAILABILITY OF EXTENSION SERVICES in this area? i.e trainings and demonstrations	Are you a member of any groups?	If yes, name the type of groups.
(1) High [____] (0) Low [____]	(1) High [____] (0) Low [____]	(1) Yes [____] (0) No [____]	Farmers SACCO: [_____] Farmers Association: [_____] Women Group: [_____] Farmers Field School: [_____] Tsetse and Trypanosomiasis Control Group: [_____]

H25	H26	H27
What is the distance (Km) from your home to the nearest market or shopping centre?	What is the distance (Km) from your home to the nearest community tsetse control structures?	How was the availability of livestock markets during the year 2016?
[_____]	Crush pen [________] Dip [________] Protected grazing area[________]	(1) High [____] (0) Low [____]

Section I: Household asset ownership

I1. Could you tell me if you have the following in your household?

Asset	**Ownership**	
TV	1= Yes [_____]	0= No. [_____]
Radio	1= Yes [_____]	0= No. [_____]
Mobile phone	1= Yes [_____]	0= No. [_____]
Bicycle etc	1= Yes [_____]	0= No. [_____]
Car	1= Yes [_____]	0= No. [_____]
Motorcycle	1= Yes [_____]	0= No. [_____]
Cattle	1= More than 3 heads [_____]	0= 1-3 heads or none [_____]
Donkeys	1= More than 3 [_____]	0= 1-3 or none [_____]
Goats	1= More than 10 [_____]	0= 1-10 or none [_____]
Sheep	1= More than 10 [_____]	0= 1-10 or more [_____]

I1. Could you tell me if you have the following in your household?		
Asset	**Ownership**	
I2. Type of dwelling unit		
Roofing material	1= Iron sheet or Tiles	0= Grass thatch
Walling material	1= Bricks or Stone	0= Mud or Timber
Floor material	1= cement	0= dust

THANK YOU VERY MUCH FOR YOUR COOPERATION AND TIME!

Appendix 2: Tests for multicollinearity

Multivariate Probit Model for ITL

Variable	VIF	1/VIF
Sex of HH Head	1.25	0.80
Size of Household	1.06	0.94
Age of HH Head	1.10	0.91
Education of HHH	1.10	0.91
Occupation HHH	1.29	0.77
TLU	1.12	0.89
Land Acreage	1.05	0.95
Off-farm income	1.23	0.81
Access to Credit	1.17	0.86
Distance to Market	1.09	0.92
Extension Services	1.13	0.88
Group Membership	1.10	0.91
Tech. Availability	1.63	0.61
Ease of use	1.73	0.58
Technology Cost	1.37	0.73
Tech Effectiveness	1.69	0.59
Location	1.52	0.66
Mean VIF	1.27	

Multivariate Probit Model for ITT

Variable	VIF	1/VIF
Sex of HH Head	1.23	0.82
Size of Household	1.06	0.95
Age of HH Head	1.08	0.92
Education of HHH	1.09	0.92
Occupation HHH	1.21	0.83
TLU	1.12	0.90
Land Acreage	1.05	0.95
Off-farm income	1.21	0.83
Access to Credit	1.10	0.91
Distance to Market	1.08	0.93
Extension Services	1.09	0.92
Group Membership	1.10	0.91
Tech. Availability	1.61	0.62
Ease of use	1.73	0.58
Technology Cost	1.32	0.76
Tech Effectiveness	1.60	0.63
Mean VIF	1.27	

Multivariate Probit Model for TTD

Variable	VIF	1/VIF
Sex of HH Head	1.25	0.80
Size of Household	1.06	0.94
Age of HH Head	1.10	0.91
Education of HHH	1.10	0.91
Occupation HHH	1.29	0.77
TLU	1.12	0.89
Land Acreage	1.05	0.95
Off-farm income	1.23	0.81
Access to Credit	1.17	0.86
Distance to Market	1.09	0.92
Extension Services	1.13	0.88
Group Membership	1.10	0.91
Tech. Availability	1.63	0.61
Ease of use	1.73	0.58
Technology Cost	1.37	0.73
Tech Effectiveness	1.69	0.59
Location	1.52	0.66
Mean VIF	1.27	

Appendix 3: Pairwise correlation test for Multicollinearity

	SexHHH	hhsize	age	EducYrs	occupa~n	tlu	Acreage
SexHHH	1.0000						
hhsize	-0.0809	1.0000					
age	0.0753	-0.0228	1.0000				
EducYrs	-0.0726	-0.1070	0.0095	1.0000			
occupation	-0.3045	-0.0293	-0.0683	-0.0292	1.0000		
tlu	-0.1112	0.0321	-0.0996	-0.0452	0.0561	1.0000	
Acreage	-0.0847	0.1066	0.0344	0.0156	0.1191	0.0172	1.0000
lnoffarmin~1	0.1467	-0.0776	0.2214	0.1677	-0.0775	-0.2302	-0.0585
credit	0.0592	0.0012	-0.0321	0.1043	-0.0788	0.0055	-0.0284
dismkt1	0.1126	-0.0921	-0.0334	0.0278	-0.0675	-0.1165	-0.0538
exten	0.1577	0.0077	0.0557	0.0284	-0.0941	0.1012	0.0184
GRPmember	0.0885	0.0240	0.0252	0.0238	-0.1355	0.0455	0.0245

	lnoffa~1	credit	dismkt1	exten	GRPmem~r
lnoffarmin~1	1.0000				
credit	0.0490	1.0000			
dismkt1	-0.0101	0.0337	1.0000		
exten	0.0336	0.1578	-0.0045	1.0000	
GRPmember	0.0379	0.2284	-0.0720	0.1226	1.0000

Appendix 4: White test for heteroskedascticity

Multivariate Probit Model for ITL

```
White's test for Ho: homoskedasticity
         against Ha: unrestricted heteroskedasticity

         chi2(159)    =    268.55
         Prob > chi2  =    0.0000

Cameron & Trivedi's decomposition of IM-test
---------------------------------------------------
              Source |       chi2     df      p
---------------------+-----------------------------
  Heteroskedasticity |     268.55    159    0.0000
            Skewness |     104.15     17    0.0000
            Kurtosis |      44.90      1    0.0000
---------------------+-----------------------------
               Total |     417.60    177    0.0000
---------------------------------------------------
```

Multivariate Probit Model for ITT

```
White's test for Ho: homoskedasticity
         against Ha: unrestricted heteroskedasticity
         chi2(142)    =    211.59
         Prob > chi2  =    0.0001

Cameron & Trivedi's decomposition of IM-test
---------------------------------------------------
              Source |       chi2     df      p
---------------------+-----------------------------
  Heteroskedasticity |     211.59    142    0.0001
            Skewness |      90.93     16    0.0000
            Kurtosis |       4.73      1    0.0296
---------------------+-----------------------------
               Total |     307.25    159    0.0000
---------------------------------------------------
```

Multivariate Probit Model for TTD

```
White's test for Ho: homoskedasticity
         against Ha: unrestricted heteroskedasticity

         chi2(159)    =    218.74
         Prob > chi2  =    0.0012

Cameron & Trivedi's decomposition of IM-test
---------------------------------------------------
              Source |       chi2     df      p
---------------------+-----------------------------
  Heteroskedasticity |     218.74    159    0.0012
            Skewness |     115.17     17    0.0000
            Kurtosis |      42.62      1    0.0000
---------------------+-----------------------------
               Total |     376.53    177    0.0000
```

Appendix 5: Multivariate Probit Results

```
Multivariate probit (SML, # draws = 5)          Number of obs   =        536
                                                Wald chi2(50)   =     517.23
Log pseudolikelihood = -602.98117               Prob > chi2     =     0.0000
```

	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
ITL						
SexHHH	.3722976	.1405197	2.65	0.008	.096884	.6477112
hhsize	-.0586841	.0191082	-3.07	0.002	-.0961354	-.0212327
age	.0549061	.0060091	9.14	0.000	.0431285	.0666837
EducYrs	.0012695	.0140324	0.09	0.928	-.0262334	.0287724
occupation	-.020163	.1424257	-0.14	0.887	-.2993122	.2589862
tlu	.0120921	.0081718	1.48	0.139	-.0039244	.0281086
Acreage	-.0064627	.0050874	-1.27	0.204	-.0164339	.0035085
lnoffarmincome1	.3376313	.0883352	3.82	0.000	.1644976	.5107651
credit	.2022567	.1573872	1.29	0.199	-.1062166	.51073
dismkt1	-.0057197	.1277543	-0.04	0.964	-.2561135	.2446742
exten	-.0807874	.1398457	-0.58	0.563	-.3548799	.1933052
GRPmember	.0592764	.1296795	0.46	0.648	-.1948908	.3134436
ITC_avail	-.055875	.1623751	-0.34	0.731	-.3741243	.2623743
ITC_easeuse	-.1917051	.1770713	-1.08	0.279	-.5387586	.1553483
ITC_cost	.2141957	.1476372	1.45	0.147	-.0751679	.5035593
ITC_effect	-.220913	.1887602	-1.17	0.242	-.5908762	.1490502
PProject	.5884535	.1541842	3.82	0.000	.2862582	.8906489
_cons	-5.751161	.9776044	-5.88	0.000	-7.66723	-3.835091
ITT						
SexHHH	.372034	.1738167	2.14	0.032	.0313596	.7127084
hhsize	-.0500611	.0276596	-1.81	0.070	-.104273	.0041508
age	.048198	.0071558	6.74	0.000	.0341729	.0622231
EducYrs	-.0125313	.0216911	-0.58	0.563	-.0550451	.0299825
occupation	-.4422623	.165919	-2.67	0.008	-.7674575	-.1170672
tlu	-.0042008	.0099609	-0.42	0.673	-.0237237	.0153222
Acreage	.0046116	.0033582	1.37	0.170	-.0019703	.0111935
lnoffarmincome1	.622164	.1362066	4.57	0.000	.355204	.8891239
credit	.303677	.1968756	1.54	0.123	-.082192	.6895461
dismkt1	.1533235	.1731286	0.89	0.376	-.1860023	.4926493
exten	.0454211	.1781309	0.25	0.799	-.3037091	.3945513
GRPmember	.0484555	.1652039	0.29	0.769	-.2753381	.3722492
ITT_avail	1.108296	.349311	3.17	0.002	.4236592	1.792933
ITT_easeuse	.4949897	.3738216	1.32	0.185	-.2376871	1.227667
ITT_cost	-.2018396	.1805985	-1.12	0.264	-.5558061	.1521269
ITT_effect	1.033597	.3257028	3.17	0.002	.3952307	1.671962
_cons	-12.71455	1.593957	-7.98	0.000	-15.83865	-9.590456
TTD						
SexHHH	.1859526	.1345629	1.38	0.167	-.0777858	.4496911
hhsize	-.0051783	.018235	-0.28	0.776	-.0409182	.0305615

```
             age |   .0393395   .0057087     6.89   0.000     .0281507    .0505283
        EducYrs |   -.019932   .0140323    -1.42   0.155    -.0474347    .0075707
     occupation |  -.2618452   .1480286    -1.77   0.077    -.5519759    .0282856
            tlu |   .0048007   .0079192     0.61   0.544    -.0107207     .020322
        Acreage |   -.012768   .0096827    -1.32   0.187    -.0317458    .0062098
lnoffarmincome1 |   .8864501   .0999395     8.87   0.000     .6905724    1.082328
         credit |  -.0230341   .1577221    -0.15   0.884    -.3321638    .2860957
        dismkt1 |   .2058856    .126658     1.63   0.104    -.0423595    .4541307
          exten |   -.054464   .1330992    -0.41   0.682    -.3153336    .2064056
      GRPmember |   .1594378   .1272978     1.25   0.210    -.0900613    .4089369
      TTD_avail |    .120015   .1686844     0.71   0.477    -.2106004    .4506303
    TTD_easeuse |  -.1117621   .1671406    -0.67   0.504    -.4393518    .2158275
       TTD_cost |  -.3003351   .1494648    -2.01   0.044    -.5932808   -.0073894
     TTD_effect |   .5776944   .1480352     3.90   0.000     .2875508     .867838
       PProject |   -.241351   .1595662    -1.51   0.130     -.554095    .0713931
          _cons |  -10.92354   1.168215    -9.35   0.000     -13.2132   -8.633879
----------------+----------------------------------------------------------------
    /atrho21 |   .4235625   .1078364     3.93   0.000     .2122072    .6349179
-------------+----------------------------------------------------------------
    /atrho31 |   .7880719   .1100227     7.16   0.000     .5724313    1.003712
-------------+----------------------------------------------------------------
    /atrho32 |   .8355307   .1103436     7.57   0.000     .6192613      1.0518
-------------+----------------------------------------------------------------
       rho21 |   .3999274   .0905888     4.41   0.000     .2090782    .5614293
-------------+----------------------------------------------------------------
       rho31 |   .6573154   .0624859    10.52   0.000     .5171426    .7631489
-------------+----------------------------------------------------------------
       rho32 |   .6834346    .058804    11.62   0.000     .5506135    .7825052
------------------------------------------------------------------------------
Likelihood ratio test of  rho21 = rho31 = rho32 = 0:
             chi2(3) =  136.294   Prob > chi2 = 0.0000
```

Appendix 6: MVP model specification test results

```
Ramsey RESET test using powers of the fitted values of ITL
       Ho:  model has no omitted variables
                 F(3, 517) =      2.18
                  Prob > F =      0.0895

      Source |       SS           df       MS      Number of obs   =       536
-------------+----------------------------------   F(2, 533)       =    116.49
       Model |  39.4502278         2  19.7251139   Prob > F        =    0.0000
    Residual |  90.2512648       533  .169326951   R-squared       =    0.3042
-------------+----------------------------------   Adj R-squared   =    0.3016
       Total |  129.701493       535  .242432696   Root MSE        =    .41149

------------------------------------------------------------------------------
         ITL |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        _hat |   1.047379    .183835     5.70   0.000     .6862489    1.408509
      _hatsq |  -.0561511   .2035622    -0.28   0.783    -.4560339    .3437316
       _cons |  -.0058555   .0385986    -0.15   0.879    -.0816795    .0699685
------------------------------------------------------------------------------
```

Appendix 7: Test for the influence of socio-demographic factors

```
( 1) [ITL]SexHHH = 0
( 2) [ITT]SexHHH = 0
( 3) [TTD]SexHHH = 0
( 4) [ITL]hhsize = 0
( 5) [ITT]hhsize = 0
( 6) [TTD]hhsize = 0
( 7) [ITL]age = 0
( 8) [ITT]age = 0
( 9) [TTD]age = 0
(10) [ITL]occupation = 0
(11) [ITT]occupation = 0
(12) [TTD]occupation = 0
     chi2( 12) = 139.13
     Prob > chi2 = 0.0000
```

Appendix 8: Test for the influence of economic factors

```
 ( 1)  [ITL]tlu = 0
 ( 2)  [ITT]tlu = 0
 ( 3)  [TTD]tlu = 0
 ( 4)  [ITL]Acreage = 0
 ( 5)  [ITT]Acreage = 0
 ( 6)  [TTD]Acreage = 0
 ( 7)  [ITL]lnOFF_1 = 0
 ( 8)  [ITT]lnOFF_1 = 0
 ( 9)  [TTD]lnOFF_1 = 0
           chi2(9) = 104.56
         Prob > chi2 =  0.0000
```

Appendix 9: Test for the influence of institutional factors

```
( 1)  [ITL]credit = 0
( 2)  [ITT]credit = 0
( 3)  [TTD]credit = 0
( 4)  [ITL]exten = 0
( 5)  [ITT]exten = 0
( 6)  [TTD]exten = 0
( 7)  [ITL]GRPmember = 0
( 8)  [ITT]GRPmember = 0
( 9)  [TTD]GRPmember = 0
          chi2(  9) = 8.45
        Prob > chi2 = 0.4896
```

Appendix 10: Test for the influence of technology factors

Insecticide treated targets

```
 ( 1)  [ITT]ITT_avail = 0
 ( 2)  [ITT]ITT_easeuse = 0
 ( 3)  [ITT]ITT_cost = 0
 ( 4)  [ITT]ITT_effect = 0

           chi2(  4) =  149.98
         Prob > chi2 =    0.0000
```

Insecticide treated livestock

```
 ( 1)  [ITL]ITC_avail = 0
 ( 2)  [ITL]ITC_easeuse = 0
 ( 3)  [ITL]ITC_cost = 0
 ( 4)  [ITL]ITC_effect = 0

           chi2(  4) =    3.92
         Prob > chi2 =    0.4168
```

Trypanocidal drug

```
(1)  [TTD]TTD_avail = 0
 ( 2)  [TTD]TTD_easeuse = 0
 ( 3)  [TTD]TTD_cost = 0
 ( 4)  [TTD]TTD_effect = 0

           chi2(  4) =   19.32
         Prob > chi2 =    0.0007
```

Appendix 11: Test for the influence of integration of tsetse fly and trypanocidal drug on herd structure

```
( 1)  [cattle_number_index]index_count11 = 0
 ( 2)  [number_goats_index]index_count11 = 0
 ( 3)  [number_sheep_idex]index_count11 = 0
 ( 4)  [number_donkey_index]index_count11 = 0

           chi2(  4) =   24.11
         Prob > chi2 =    0.0001
```

Appendix 12: Multivariate Tobit Results

```
Multivariate Tobit/mixed model (MSL,# draws = 5)  Number of obs   =        536
                                                  Wald chi2(48)   =     181.25
Log pseudolikelihood = -1211.1541                 Prob > chi2     =     0.0000

------------------------------------------------------------------------------------
                    |               Robust
                    |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------------+---------------------------------------------------------------
cattle_number_index |
      index_count11 |   .1533083   .0504092     3.04   0.002     .0545079    .2521086
             SexHHH |   .0224152   .0408693     0.55   0.583    -.0576872    .1025175
             hhsize |   .0023295   .0052011     0.45   0.654    -.0078644    .0125234
                age |  -.0017208   .0016834    -1.02   0.307    -.0050203    .0015787
            EducYrs |  -.0069072   .0041217    -1.68   0.094    -.0149856    .0011713
    lnoffarmincome1 |  -.1205774    .027834    -4.33   0.000     -.175131   -.0660238
         occupation |  -.0599291   .0393071    -1.52   0.127    -.1369696    .0171114
            Acreage |  -.0000805   .0004562    -0.18   0.860    -.0009747    .0008137
             credit |  -.1424017   .0450533    -3.16   0.002    -.2307045   -.0540989
            dismkt1 |  -.0964638   .0357917    -2.70   0.007    -.1666142   -.0263134
              exten |   .1260818   .0407426     3.09   0.002     .0462277    .2059358
          GRPmember |   .0618528   .0362037     1.71   0.088    -.0091051    .1328108
              _cons |   1.457779   .2811399     5.19   0.000     .9067548    2.008803
--------------------+---------------------------------------------------------------
number_goats_index  |
      index_count11 |  -.1834652   .1099847    -1.67   0.095    -.3990312    .0321008
             SexHHH |  -.0799789   .0724472    -1.10   0.270    -.2219728    .0620149
             hhsize |    .009386   .0089596     1.05   0.295    -.0081746    .0269466
                age |   -.007855   .0029531    -2.66   0.008    -.0136431    -.002067
            EducYrs |   .0102206   .0078137     1.31   0.191     -.005094    .0255352
    lnoffarmincome1 |    .085099   .0502499     1.69   0.090    -.0133891     .183587
         occupation |   .0670064   .0699041     0.96   0.338    -.0700031    .2040159
            Acreage |   .0024974   .0009758     2.56   0.010     .0005849    .0044099
             credit |   .2107247   .0736322     2.86   0.004     .0664082    .3550412
            dismkt1 |   .0653676   .0648002     1.01   0.313    -.0616385    .1923737
              exten |  -.0998738   .0670744    -1.49   0.136    -.2313371    .0315896
          GRPmember |  -.0230328   .0652651    -0.35   0.724      -.15095    .1048844
              _cons |  -.3099231   .5247382    -0.59   0.555    -1.338391    .7185448
--------------------+---------------------------------------------------------------
number_sheep_idex   |
      index_count11 |  -.8283896    .401377    -2.06   0.039    -1.615074   -.0417051
             SexHHH |  -.3175364   .2575415    -1.23   0.218    -.8223086    .1872357
             hhsize |   .0394016    .031748     1.24   0.215    -.0228233    .1016264
                age |   .0116987   .0099481     1.18   0.240    -.0077993    .0311967
            EducYrs |   .0487756   .0238317     2.05   0.041     .0020662    .0954849
    lnoffarmincome1 |  -.2030325   .1654592    -1.23   0.220    -.5273267    .1212616
         occupation |  -.2824299   .2241963    -1.26   0.208    -.7218466    .1569869
            Acreage |   .0013237   .0045408     0.29   0.771     -.007576    .0102235
             credit |  -.1325175   .2745888    -0.48   0.629    -.6707017    .4056667
            dismkt1 |  -.0620975   .2093525    -0.30   0.767    -.4724208    .3482258
              exten |  -.1987289    .217101    -0.92   0.360    -.6242392    .2267813
          GRPmember |  -.1062349   .2132385    -0.50   0.618    -.5241748    .3117049
              _cons |   .2433119   1.813888     0.13   0.893    -3.311843    3.798467
--------------------+---------------------------------------------------------------
number_donkey_index |
      index_count11 |   .4294226   .1389536     3.09   0.002     .1570786    .7017666
             SexHHH |  -.0660878   .1076435    -0.61   0.539    -.2770652    .1448895
             hhsize |   .0082775   .0136977     0.60   0.546    -.0185695    .0351245
                age |    .000232   .0045152     0.05   0.959    -.0086176    .0090816
            EducYrs |  -.0075941   .0103984    -0.73   0.465    -.0279746    .0127864
```

```
lnoffarmincome1 |  -.0689312   .0654452    -1.05   0.292    -.1972015     .059339
     occupation |  -.3495648   .0990516    -3.53   0.000    -.5437023   -.1554273
        Acreage |  -.0001072   .0026201    -0.04   0.967    -.0052425     .005028
         credit |  -.1188415   .1116071    -1.06   0.287    -.3375874    .0999043
        dismkt1 |   .1811588   .0936589     1.93   0.053    -.0024093    .3647269
          exten |    .130033   .1061433     1.23   0.221    -.0780041    .3380701
      GRPmember |   .1002588    .098013     1.02   0.306    -.0918432    .2923609
          _cons |  -.0836769   .6632996    -0.13   0.900     -1.38372    1.216366
--------------------+----------------------------------------------------------------
   /lnsigma1 |  -.9980337   .0384236   -25.97   0.000    -1.073342   -.9227248
-----------------------------------------------------------------------------
   /lnsigma2 |  -.4252026   .0430021    -9.89   0.000    -.5094852   -.3409199
-----------------------------------------------------------------------------
   /lnsigma3 |   .2959134   .1133175     2.61   0.009     .0738152    .5180116
-----------------------------------------------------------------------------
   /lnsigma4 |  -.2444477   .0724001    -3.38   0.001    -.3863494    -.102546
-----------------------------------------------------------------------------
    /atrho12 |  -.4676732   .0477009    -9.80   0.000    -.5611652   -.3741812
-----------------------------------------------------------------------------
    /atrho13 |  -.1945233   .0785408    -2.48   0.013    -.3484605   -.0405862
-----------------------------------------------------------------------------
    /atrho14 |   .2478288    .069178     3.58   0.000     .1122425    .3834151
-----------------------------------------------------------------------------
    /atrho23 |   .5745968      .1033     5.56   0.000     .3721325    .7770611
-----------------------------------------------------------------------------
    /atrho24 |  -.0097792   .0672848    -0.15   0.884     -.141655    .1220965
-----------------------------------------------------------------------------
    /atrho34 |   .1103127   .0951378     1.16   0.246    -.0761539    .2967793
-----------------------------------------------------------------------------
      sigma1 |   .3686035   .0141631    26.03   0.000     .3418639    .3974346
-------------+---------------------------------------------------------------
      sigma2 |   .6536374   .0281078    23.25   0.000     .6008048    .7111158
-------------+---------------------------------------------------------------
      sigma3 |   1.344354   .1523388     8.82   0.000     1.076608    1.678686
-------------+---------------------------------------------------------------
      sigma4 |   .7831369   .0566992    13.81   0.000     .6795331    .9025366
-------------+---------------------------------------------------------------
       rho12 |  -.4363174   .0386199   -11.30   0.000    -.5088415   -.3576435
-------------+---------------------------------------------------------------
       rho13 |  -.1921064   .0756423    -2.54   0.011    -.3350095   -.0405639
-------------+---------------------------------------------------------------
       rho14 |   .2428766   .0650972     3.73   0.000     .1117735    .3656696
-------------+---------------------------------------------------------------
       rho23 |   .5187272   .0755043     6.87   0.000     .3558555    .6510166
-------------+---------------------------------------------------------------
       rho24 |  -.0097789   .0672783    -0.15   0.884     -.140715    .1214934
-------------+---------------------------------------------------------------
       rho34 |   .1098674   .0939894     1.17   0.242    -.0760071    .2883625
-------------+---------------------------------------------------------------
Likelihood ratio test of  rho12 = rho13 = rho14 = rho23 = rho24 = rho34 = 0:
             chi2(6) =  149.335   Prob > chi2 = 0.0000
```

Appendix 13: ESR Estimates of the effect of ITL on household income

```
Endogenous switching regression model             Number of obs   =        254
                                                  Wald chi2(7)    =      19.99
Log likelihood = -143.66205                       Prob > chi2     =     0.0056
------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
lnincome2_1  |
      SexHHH |  -.0074985   .5184502    -0.01   0.988    -1.023642    1.008645
         age |   .0695365   .0368397     1.89   0.059    -.0026679    .1417409
      hhsize |  -.0079116   .0931281    -0.08   0.932    -.1904394    .1746162
     EducYrs |  -.0168438   .0590106    -0.29   0.775    -.1325025    .0988149
     Acreage |   .0567996   .0379957     1.49   0.135    -.0176707    .1312698
         tlu |   .1176381   .0406936     2.89   0.004       .03788    .1973961
      credit |   -.285658   .5634141    -0.51   0.612    -1.389929    .8186133
       _cons |   16.25998    2.09039     7.78   0.000     12.16289    20.35706
-------------+----------------------------------------------------------------
lnincome2_0  |
      SexHHH |   .0747193   .0350931     2.13   0.033     .0059381    .1435006
         age |   .0034248   .0017021     2.01   0.044     .0000887    .0067609
      hhsize |  -.0026283    .004236    -0.62   0.535    -.0109307    .0056741
     EducYrs |    .003536   .0038514     0.92   0.359    -.0040126    .0110845
     Acreage |   .0018264   .0028688     0.64   0.524    -.0037964    .0074491
         tlu |  -.0773496   .0016886   -45.81   0.000    -.0806593     -.07404
      credit |    .122412   .0368469     3.32   0.001     .0501934    .1946306
       _cons |   22.18007   .0785503   282.37   0.000     22.02611    22.33402
-------------+----------------------------------------------------------------
ITLonly      |
      SexHHH |  -.2042832   .2623354    -0.78   0.436     -.718451    .3098847
         age |   .0679325   .0104947     6.47   0.000     .0473633    .0885017
      hhsize |  -.0553178   .0348803    -1.59   0.113     -.123682    .0130464
     EducYrs |  -.0572704    .029206    -1.96   0.050    -.1145131   -.0000276
     Acreage |   .0212695   .0161511     1.32   0.188    -.0103861     .052925
         tlu |  -.0379759   .0133983    -2.83   0.005    -.0642361   -.0117156
      credit |  -.4334476    .293272    -1.48   0.139     -1.00825    .1413549
    PProject |   -.063184   .2194725    -0.29   0.773    -.4933422    .3669742
     dismkt1 |   .6691893   .2181549     3.07   0.002     .2416135    1.096765
       _cons |   -3.21068   .6208074    -5.17   0.000     -4.42744    -1.99392
-------------+----------------------------------------------------------------
       /lns1 |   .4905672   .2144046     2.29   0.022      .070342    .9107924
       /lns2 |   -1.45611   .0582639   -24.99   0.000    -1.570305   -1.341915
         /r1 |   1.078734   .5082876     2.12   0.034     .0825088     2.07496
         /r2 |   .5957714   .2609532     2.28   0.022     .0843124     1.10723
-------------+----------------------------------------------------------------
     sigma_1 |   1.633242   .3501746                      1.072875   2.486292
     sigma_2 |   .2331414   .0135837                      .2079817   .2613447
       rho_1 |   .7927292   .1888697                      .0823221    .968958
       rho_2 |   .5340337   .1865315                      .0841132   .8030812
------------------------------------------------------------------------------
LR test of indep. eqns. :           chi2(1) =     5.18   Prob > chi2 = 0.0228
------------------------------------------------------------------------------
```

Appendix 14: ESR Estimates of the effect of ITT on household income

Endogenous switching regression model

Log likelihood = -105.32092

Number of obs	=	245
Wald chi2(7)	=	12.89
Prob > chi2	=	0.0748

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnincome2_1						
SexHHH	.3765747	.7293757	0.52	0.606	-1.052975	1.806125
age	.050287	.0385607	1.30	0.192	-.0252905	.1258645
hhsize	-.0959908	.0947879	-1.01	0.311	-.2817718	.0897901
EducYrs	.1513259	.068778	2.20	0.028	.0165236	.2861282
Acreage	-.0034397	.0069469	-0.50	0.620	-.0170553	.0101759
tlu	.0240788	.0738638	0.33	0.744	-.1206915	.1688491
credit	.9467207	1.205451	0.79	0.432	-1.415919	3.309361
_cons	18.16011	3.259287	5.57	0.000	11.77203	24.5482
lnincome2_0						
SexHHH	.1138448	.0351043	3.24	0.001	.0450418	.1826479
age	.0031403	.0014568	2.16	0.031	.000285	.0059957
hhsize	.0000564	.0041277	0.01	0.989	-.0080338	.0081466
EducYrs	.0039858	.0037764	1.06	0.291	-.0034159	.0113875
Acreage	.0002377	.0028756	0.08	0.934	-.0053984	.0058739
tlu	-.0779425	.0016828	-46.32	0.000	-.0812408	-.0746442
credit	.0954353	.0374604	2.55	0.011	.0220142	.1688564
_cons	22.14014	.0785512	281.86	0.000	21.98618	22.2941
ITTonly						
SexHHH	.4534678	.2846759	1.59	0.111	-.1044868	1.011422
age	.0448547	.0118953	3.77	0.000	.0215402	.0681691
hhsize	-.0265545	.0320926	-0.83	0.408	-.0894548	.0363457
EducYrs	.0032281	.0276698	0.12	0.907	-.0510037	.0574599
Acreage	.0204299	.0185355	1.10	0.270	-.015899	.0567588
tlu	.0298	.0203764	1.46	0.144	-.0101371	.069737
credit	1.000362	.5630172	1.78	0.076	-.1031318	2.103855
PProject	9.552449	225.907	0.04	0.966	-433.2171	452.322
dismkt1	.5746779	.251871	2.28	0.023	.0810199	1.068336
GRPmember	-.0398777	.2478156	-0.16	0.872	-.5255873	.4458319
_cons	-13.26592	225.9095	-0.06	0.953	-456.0404	429.5085
/lns1	.5412294	.1846908	2.93	0.003	.1792421	.9032168
/lns2	-1.448114	.0530332	-27.31	0.000	-1.552057	-1.344171
/r1	.4411067	.5977302	0.74	0.461	-.730423	1.612636
/r2	1.323608	.3409968	3.88	0.000	.6552668	1.99195
sigma_1	1.718118	.3173206			1.19631	2.467528
sigma_2	.2350131	.0124635			.2118118	.2607558
rho_1	.4145613	.4950036			-.6233241	.9235487
rho_2	.8676785	.0842719			.5752049	.9634544

LR test of indep. eqns. : chi2(1) = 14.42 Prob > chi2 = 0.0001

Appendix 15: ESR Estimates of the effect of TTD on household income

Endogenous switching regression model

	Number of obs	=	279
	Wald chi2(7)	=	13.32
Log likelihood = -218.63958	Prob > chi2	=	0.0647

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnincome2_1						
SexHHH	.1300072	.4650504	0.28	0.780	-.7814748	1.041489
age	.0217376	.0197445	1.10	0.271	-.0169608	.0604361
hhsize	-.085611	.0444625	-1.93	0.054	-.1727559	.0015338
EducYrs	.0698568	.0363734	1.92	0.055	-.0014338	.1411475
Acreage	-.0050837	.0269004	-0.19	0.850	-.0578074	.0476401
tlu	.0448728	.0312965	1.43	0.152	-.0164672	.1062127
credit	-.0867912	.4215138	-0.21	0.837	-.9129431	.7393607
_cons	22.31589	1.068853	20.88	0.000	20.22098	24.4108
lnincome2_0						
SexHHH	.0552775	.036613	1.51	0.131	-.0164825	.1270376
age	.0037757	.0016242	2.32	0.020	.0005923	.0069591
hhsize	-.0002139	.0042766	-0.05	0.960	-.0085959	.008168
EducYrs	.0027341	.0039098	0.70	0.484	-.0049289	.0103972
Acreage	.0010382	.0029614	0.35	0.726	-.0047659	.0068424
tlu	-.0787325	.0017886	-44.02	0.000	-.082238	-.0752269
credit	.1183176	.0379549	3.12	0.002	.0439273	.1927078
_cons	22.22615	.0812347	273.60	0.000	22.06694	22.38537
TTDonly						
SexHHH	-.5332342	.2202266	-2.42	0.015	-.9648704	-.1015981
age	.0477761	.0086267	5.54	0.000	.0308681	.0646841
hhsize	.0192707	.0242275	0.80	0.426	-.0282143	.0667558
EducYrs	-.05546	.0217202	-2.55	0.011	-.0980307	-.0128892
Acreage	.0039157	.0154302	0.25	0.800	-.0263269	.0341583
tlu	-.0468505	.0113427	-4.13	0.000	-.0690817	-.0246193
credit	-.2794559	.2299598	-1.22	0.224	-.7301687	.171257
dismkt1	.808871	.1777093	4.55	0.000	.4605671	1.157175
_cons	-2.32671	.537444	-4.33	0.000	-3.380081	-1.27334
/lns1	.2365271	.1358723	1.74	0.082	-.0297778	.502832
/lns2	-1.413009	.0641444	-22.03	0.000	-1.53873	-1.287289
/r1	-.5033937	.3962028	-1.27	0.204	-1.279937	.2731496
/r2	.7971948	.2263775	3.52	0.000	.353503	1.240887
sigma_1	1.266842	.1721288			.9706612	1.653397
sigma_2	.2434097	.0156134			.2146535	.2760182
rho_1	-.4647819	.3106142			-.8564681	.2665531
rho_2	.6624656	.1270293			.3394785	.8457083

LR test of indep. eqns. : chi2(1) = 7.28 Prob > chi2 = 0.0070

Appendix 16: ESR Estimates of the effect of ITL and TTD on household income

Endogenous switching regression model — Number of obs = 252

Wald chi2(7) = 43.00

Log likelihood = -66.630174 — Prob > chi2 = 0.0000

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnincome2_1						
SexHHH	.2341392	.178063	1.31	0.189	-.1148579	.5831363
age	-.0005641	.0131105	-0.04	0.966	-.0262601	.0251319
hhsize	.0573416	.029367	1.95	0.051	-.0002166	.1148999
EducYrs	.0040752	.0177436	0.23	0.818	-.0307016	.0388521
Acreage	-.0363774	.0300098	-1.21	0.225	-.0951957	.0224408
tlu	.0283333	.0048527	5.84	0.000	.0188222	.0378443
credit	-.0906482	.1738759	-0.52	0.602	-.4314388	.2501424
_cons	21.38097	.9078935	23.55	0.000	19.60154	23.16041
lnincome2_0						
SexHHH	.0749514	.0344786	2.17	0.030	.0073746	.1425282
age	7.46e-07	.0015037	0.00	1.000	-.0029465	.002948
hhsize	-.0002592	.0040719	-0.06	0.949	-.00824	.0077216
EducYrs	.0038852	.0037604	1.03	0.302	-.003485	.0112554
Acreage	.002106	.0028599	0.74	0.461	-.0034992	.0077113
tlu	-.0771008	.0016297	-47.31	0.000	-.0802949	-.0739066
credit	.1241395	.0360076	3.45	0.001	.0535659	.194713
_cons	22.2203	.0781632	284.28	0.000	22.0671	22.37349
ITLTTD_1						
SexHHH	.8539574	.2860316	2.99	0.003	.2933457	1.414569
age	.0804273	.0132745	6.06	0.000	.0544098	.1064449
hhsize	-.0379357	.0419976	-0.90	0.366	-.1202495	.044378
EducYrs	.0563208	.0341679	1.65	0.099	-.010647	.1232886
Acreage	-.1049528	.0432438	-2.43	0.015	-.1897091	-.0201964
tlu	-.0005912	.0114257	-0.05	0.959	-.0229853	.0218028
credit	-.5212382	.3038285	-1.72	0.086	-1.116731	.0742548
GRPmember	.2993449	.2918383	1.03	0.305	-.2726477	.8713375
dismkt1	.207791	.3027627	-0.69	0.093	-.801195	.3856131
_cons	-4.25793	.9168793	-4.64	0.000	-6.05498	-2.460879
/lns1	-.8238543	.1221547	-6.74	0.000	-1.063273	-.5844354
/lns2	-1.482227	.0506133	-29.29	0.000	-1.581427	-1.383027
/r1	.1890497	.5934258	0.32	0.750	-.9740434	1.352143
/r2	-.4640747	.227063	-2.04	0.041	-.9091099	-.0190394
sigma_1	.4387374	.0535938			.3453237	.5574205
sigma_2	.2271313	.0114959			.2056813	.2508182
rho_1	.1868293	.5727121			-.7504758	.8745581
rho_2	-.4333993	.1844126			-.7207047	-.0190371

LR test of indep. eqns. : chi2(1) = 4.89 Prob > chi2 = 0.0270

Appendix 17: ESR Estimates of the effect of all methods combined on household income

```
Endogenous switching regression model              Number of obs    =        338
                                                   Wald chi2(7)     =      16.41
Log likelihood = -79.947022                        Prob > chi2      =     0.0216

------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
lnincome_1   |
      SexHHH |   .1754355   .1703198     1.03   0.303    -.1583851    .5092562
         age |  -.0008247   .0107911    -0.08   0.939    -.0219749    .0203255
      hhsize |   .0464709   .0287134     1.62   0.106    -.0098064    .1027482
     EducYrs |   .0503373   .0178914     2.81   0.005     .0152707    .0854039
     Acreage |  -.0093667   .0185362    -0.51   0.613     -.045697    .0269636
         tlu |  -.0180137   .0112932    -1.60   0.111    -.0401479    .0041205
      credit |  -.0932291   .2028238    -0.46   0.646    -.4907565    .3042983
       _cons |    11.2368   .7217467    15.57   0.000     9.822204     12.6514
-------------+----------------------------------------------------------------
lnincome_0   |
      SexHHH |   .0575452   .0171424     3.36   0.001     .0239467    .0911437
         age |   .0024829   .0007506     3.31   0.001     .0010117     .003954
      hhsize |  -.0009678    .002033    -0.48   0.634    -.0049525    .0030168
     EducYrs |   .0021725   .0018367     1.18   0.237    -.0014274    .0057724
     Acreage |   -.000397   .0014321    -0.28   0.782     -.003204    .0024099
         tlu |  -.0391662    .000828   -47.30   0.000    -.0407889   -.0375434
      credit |   .0433844   .0182479     2.38   0.017     .0076191    .0791496
       _cons |   11.06037   .0384836   287.40   0.000     10.98494     11.1358
-------------+----------------------------------------------------------------
ALLCOMBINED  |
      SexHHH |   .5427871   .2080608     2.61   0.009     .1349954    .9505787
         age |   .0688347    .009677     7.11   0.000     .0498682    .0878013
      hhsize |  -.0762059   .0303636    -2.51   0.012    -.1357174   -.0166943
     EducYrs |   .0196571   .0230269     0.85   0.393    -.0254747    .0647889
     Acreage |   .0091331   .0188438     0.48   0.628    -.0278001    .0460663
         tlu |   .0459707   .0151642     3.03   0.002     .0162493     .075692
      credit |   1.416738   .3271392     4.33   0.000     .7755573    2.057919
   GRPmember |   .0937669   .1821849    -0.51   0.017    -.4508428     .263309
       _cons |  -15.78318   1460.522    -0.01   0.991    -2878.354    2846.788
-------------+----------------------------------------------------------------
       /lns1 |  -.1833203   .0853791    -2.15   0.032    -.3506603   -.0159803
       /lns2 |   -2.15638   .0520276   -41.45   0.000    -2.258352   -2.054408
         /r1 |  -.4950888   .3561067    -1.39   0.164    -1.193045    .2028676
         /r2 |   1.107936   .2445109     4.53   0.000     .6287031    1.587168
-------------+----------------------------------------------------------------
     sigma_1 |   .8325015   .0710783                      .7042229    .9841467
     sigma_2 |   .1157433   .0060219                      .1045225    .1281687
       rho_1 |   -.458246   .2813281                     -.8315209    .2001297
       rho_2 |   .8033314   .0867179                      .5571586     .919714
------------------------------------------------------------------------------
LR test of indep. eqns. :            chi2(1) =    21.48   Prob > chi2 = 0.0000
------------------------------------------------------------------------------
```