THE POTENTIAL OF ON-FARM PLANTATION FORESTRY FOR POVERTY ALLEVIATION, FOOD SECURITY AND CARBON TRADE IN SOUTH WESTERN UGANDA

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DECLARATION

I, Isaac Kiyingi, declare that this thesis is as a result of my own original effort and work, and that to the best of my knowledge, the findings have never been previously presented to Lilongwe University of Agriculture and Natural Resources or elsewhere for the award of any academic qualification. Where assistance was sought it has been accordingly acknowledged.

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CERTIFICATE OF APPROVAL

We, the undersigned, certify that this thesis is as a result of the authors own work, and to the best of our knowledge, it has not been submitted for any other qualification within Lilongwe University of Agriculture and Natural Resources or elsewhere. The thesis is accepted in form and content, and that satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate through an oral examination held on 14th March, 2016.

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DEDICATION

I dedicate this thesis to the most important people in my life; Judith, Bbosa, Kirabo, Kisakye and Maama. Thank you for your support.

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ABSTRACT

The economic importance of forest plantations is increasing worldwide. Forestry development is being redefined, with growing emphasis on poverty alleviation and livelihoods improvements. To address the problem of high rural poverty and food insecurity, government and international donors have funded on-farm plantation forestry projects as one of the tools for improving the welfare of rural communities. In the wake of climate change, tree farming has been promoted with the dual purpose of sequestering carbon and improving rural livelihoods. Tree farmers can now benefit from selling carbon credits in addition to the traditional wood products. However, there is a dearth of empirical evidence regarding whether and under what conditions on-farm plantation forestry can deliver favorable livelihood outcomes.

Therefore, the study assessed the factors influencing adoption of on-farm plantation forestry and the impact of adoption on poverty alleviation and food security in south western Uganda. The study also assessed the economic carbon sequestration potential of *Pinus caribaea* and *Eucalyptus grandis* plantations under the small-scale Clean Development Mechanism (CDM) of the Kyoto protocol.

Results from Propensity Score Matching (PSM) and endogenous switching regression models indicated that adoption of carbon forestry increased calorie acquisition per adult equivalent by between 22 and 26.9% but the impact on consumption expenditure per adult equivalent was mixed. In comparison, results from Propensity Score Matching (PSM) and endogenous switching regression models indicated that adoption of eucalyptus woodlot farming in general (all eucalyptus) increased consumption

expenditure by 32 and 28.3% respectively. PSM and switching regression results also indicated that adoption of eucalyptus woodlot farming increased calorie acquisition per adult equivalent by 36 and 13.1% respectively.

Benefit incidence analysis of the Farm Income Enhancement and Forest Conservation (FIEFOC) and Trees for Global Benefits (TGB) projects indicated that the farm forestry subsidies in both projects were not well targeted to the poor in the population.

The study indicated that whereas *E.grandis* has a higher biological potential to sequester carbon than *P.caribaea,* it is currently not economically viable for participation in the CDM forest carbon offset scheme. The study also confirmed the importance of farmers' access to extension services, landholding, education, forestry skills training and farmers' perceptions in adopting on-farm plantation forestry.

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LIST OF ABBREVIATIONS AND ACRONYMS

AEV	Annual Equivalent Value
AR	Afforestation and Reforestation
ATTs	Average Treatment Effects on the Treated
CDM	Clean Development Mechanism
CER	Certified Emission Reductions
CO2	Carbon dioxide
ECOTRUST	Environmental Conservation Trust of Uganda
FAO	Food and Agricultural Organization
FD	Forest Department
FIEFOC	Farm Income Enhancement and Forest Conservation Project
GHG	Greenhouse Gases
Ha	Hectare
Kcal	Kilo calorie
LULUCF	Land Use, Land-Use Change and Forestry.
MDGs	Millennium Development Goals
MFPED	Ministry of Finance, Planning and Economic Development
MWLE	Ministry of Water Lands and Environment

NAADS	National Agricultural Advisory Services
NFA	National Forestry Authority
NGO	Non-Governmental Organization
NPV	Net Present Value
PES	Payment for Ecosystem Services
PSM	Propensity Score Matching
SPGS	Sawlog Production Grant Scheme
TGB	Trees for Global Benefits
UNFCCC	United Nations Framework Convention on Climate Change
VER	Voluntary Emission Reductions
VIF	Variance Inflation Factor

CHAPTER ONE

INTRODUCTION

1.1. Background

The economic importance of forest plantations is increasing worldwide. In some countries, plantation forests already provide the bulk of wood products. It is estimated that the worldwide plantation forest area will exceed 200 million hectares by 2050 and it will supply most of the future demand for wood (Food and Agriculture Organization of the United Nations [FAO], 2014). The expansion of planted forests has been justified by the growing demand for forest products and services (Sloan & Sayer, 2015). Recent models indicate that if global plantation forests were to expand by 2.4% per annum, planted forests could replace natural forests as a source of timber and fibre (Sloan & Sayer, 2015; FAO, 2015).

On-farm plantation forestry, also known as farm forestry, is one of several interventions that have received enormous support from governments in sub-Saharan Africa (FAO, 2014). The importance of farm forestry as a livelihood improvement strategy is highlighted by the higher poverty rates in the rural areas of Sub-Saharan Africa. It is estimated that more than 90% of the poor in sub-Saharan Africa live in the rural areas and they mainly depend on agricultural production as a source of livelihood (Oksanen *et al.*, 2003; Chamshama & Nwonwu, 2004; Sloan & Sayer, 2015). Farm forestry has been promoted for the dual purpose of contributing to reforestation of degraded landscapes and contributing to rural livelihood improvement (Oksanen *et al.*, 2003; Cohen, 2014; Laurance *et al.*, 2014). It also provides a variety of wood and non-wood forest products for cash income and daily subsistence needs (Curtis & Race, 1998; Higman *et al.*, 1999; Sayer *et al.*, 2008; Sayer, 2009; Kohl *et al.*, 2015). Trees also contribute to crop and livestock production by providing soil nutrients and animal fodder (World Bank, 2001).

The Food and Agriculture Organization recognized that planted forests provided a diverse range of goods and services, including timber, fuel wood, non-wood forest goods, conservation, carbon sequestration, recreation, erosion control, rehabilitation of degraded lands and amenity enhancement (Tiarks *et al.*, 1998; FAO, 2014; Griscom, 2014; Miura *et al.*, 2015). The increased demand for forest products such as timber, wood for household and industrial energy and more recently forest carbon offsets has provided an opportunity for investment in plantation forestry (Cossalter & Pye-Smith, 2003). However, concerns have also been raised about the potential competition between farm forestry and other land use options available to rural households (Arnold, 2001; Piketty, 2014). This is important given the long-term nature of tree growing, especially from the perspective of the poor (Oksanen *et al.*, 2003).

1.2. On-farm Plantation Forestry and carbon offsets

In the wake of climate change, on-farm plantation forestry has evolved to include carbon forestry where farmers grow trees to benefit from selling carbon credits. The United Nations Framework Convention on Climate Change (UNFCCC) was agreed in 1992 to stabilize greenhouse gases (GHG) at a level that would prevent dangerous changes to the climate (Smith & Scherr, 2002). The convention was operationalized by the Kyoto protocol, which legally bound 39 developed countries to reduce their GHG emissions by an average of 5.2% relative to 1990 levels (UNFCCC, 2001). Under the Kyoto Protocol, Annex I countries were allowed to meet emissions reduction targets using flexible mechanisms such as the Clean Development Mechanism (Niles *et al.*, 2002). The Clean Development Mechanism (CDM) includes carbon sequestration using afforestation/reforestation (AR) projects in developing countries (Stern, 2007). A similar opportunity has been provided by a market for voluntary CO_2 emission reductions. The number of AR projects participating in the voluntary carbon market has rapidly increased over recent years (Hamilton *et al.*, 2008). The traded volume of forest related Voluntary Emission Reductions (VER) was 7.9 $MtCO_2e$ (million tonnes of carbon dioxide equivalent) in 2006 (Hamilton *et al.*, 2008).

AR projects in CDM and voluntary carbon market provide cash incentives for afforestation and reforestation activities in rural communities (Nelson &De Jong, 2003). In principle the farmers get paid for the amount of carbon their trees sequester from the atmosphere. This provides an opportunity for capital inflows into impoverished rural communities in developing countries (Asquith *et al.*, 2002). These projects have the dual mandate of mitigating greenhouse gas emissions and contributing to livelihood improvement (Montagnini & Nair, 2004).

1.3. Plantation Forestry in Uganda

Uganda has suffered an alarmingly high rate of forest resource degradation in recent years (Ministry of Water Lands and Environment [MWLE], 2001; National Forestry Authority [NFA], 2008). According to NFA (2008), degradation of protected forests has continued at an alarming rate of 2% per annum. The deforestation rate is even higher on private land, which holds 70% of the country's forest resources. The escalation of the problem has partly been attributed to lack of alternative livelihoods and escalating poverty among forest user groups (MWLE, 2001). This has been exacerbated by the rapid human population increase and high dependence on woody biomass fuel for domestic cooking (MWLE, 2001; Kiyingi *et al.*, 2010). In an effort to address the interrelated problems of deforestation and high rural poverty, government instituted forest sector reforms (MWLE, 2001). The reforms included a new forest policy, a strategic forest sector plan, and new legislation (MWLE, 2002).

Among the key components of the Uganda forestry sector reforms was the transition from the classical state-dominated sector to a model of engaging farmers in small-medium scale tree planting on-farm (Jacovelli, 2010). As part of this effort, the Ugandan government has promoted on-farm plantation forestry through projects such as Farm Income Enhancement and Forest Conservation Project (FIEFOC), National Agricultural Advisory Services (NAADS) and Sawlog Production Grant Scheme (Ministry of Agriculture, Animal Industry and Fisheries [MAAIF], 2012). The key objectives of government support to farm forestry were to alleviate high rural poverty and address the high deforestation rate (MWLE, 2001; MWLE, 2002; Sawlog Production Grant Scheme [SPGS], 2005).

The key appeal of on-farm plantation forestry is that in addition to addressing the problem of deforestation, it is seen as a tool for improving the welfare of rural communities through supplying the wood products market (FAO, 2014). The assumption is that facilitating poor households to participate in farm forestry would improve their incomes and enable them to eventually escape poverty by producing products and services for home consumption as well as cash income. Unlike commercial plantation forestry, on-farm plantation forestry can be adopted by small-medium scale farmers and therefore is seen as being more pro-poor. This is evidenced in the Uganda Forest Policy (MWLE, 2001) and the Uganda Forest Plan (MWLE, 2002), which set out to raise the incomes and quality of life of poor people through promotion of tree growing on-farm.

The number of farmers growing trees has increased in the recent past due to the publicity given to tree farming as an income generating activity and due to increased demand for timber, poles and firewood (Kaboggoza, 2011). There is a big market for saw logs, chips, transmission, building and fencing poles, and firewood. The market will continue to expand as the country's gross domestic product (GDP) and population rise (Kaboggoza, 2011). According to recent estimates and projections, the annual demand for sawn timber will be about 879,500 m^3 by 2030, which equals 1,832, 300 m^3 of round wood (NFA, 2010). The latest estimates based on the yield model for *Pinus caribaea* and *Eucalyptus grandis* indicate that the growing stock in forest plantations is estimated to yield 2,350,330 m^3 (Kaboggoza, 2011).

It is estimated that most of the growing stock in plantations has been established by private tree farmers. Whereas, most of this estate has been established by private farmers who lease state owned forest land, a substantial amount has also been established on-farm by small-medium tree farmers. This indicates that private sector investment has become increasingly central to development of the plantation forestry sub-sector. Involvement by small-scale growers in farm forestry presents an opportunity to increase long-term wood supply while contributing significant social, economic and environmental benefits (FAO, 2011).

In addition to government efforts to promote farm forestry, a number of projects trading carbon credits under the voluntary carbon market have also promoted small-scale farm forestry in Uganda. Typically, the projects provide direct cash payments to small–scale farmers for afforestation and reforestation activities on their land. Although most forest carbon projects are targeting individual land owners, there are also a few projects which have adopted the community based approach to carbon trade. The community based approach generally provides monetary incentives to community groups for AR activities (Masiga *et al.*, 2012).

Although the different types of farm-based plantation forestry have been widely promoted as a tool for poverty alleviation among small-scale farmers, there is lack of empirical evidence to support this claim. Accordingly, this study assessed the factors influencing adoption of on-farm plantation forestry and the impact of adoption on poverty alleviation and food security in south western Uganda. The study also assessed the economic carbon sequestration potential of *Pinus caribaea* and *Eucalyptus grandis* plantations under the Clean Development Mechanism (CDM) of the Kyoto protocol.

1.4. Problem statement

To address the problem of high rural poverty, government and international donors have funded on-farm plantation forestry projects as one of the tools for improving the welfare of rural communities (Kaboggoza, 2011; SPGS, 2005). For instance, government acquired a US$40 million loan from development partners to implement the Farm Income Enhancement and Forest Conservation (FIEFOC) project (OAG, 2011).

Although these projects had audit and mid-term review reports (Office of the Auditor General [OAG], 2011), their focus was on tracking indicators of progress towards achieving specific project targets. These audits and reviews provide useful information on how effectively the project was implemented and whether there are gaps between planned and realized outcomes. However, they do not reveal whether there are any changes in well-being among project participants and whether the changes in well-being are indeed due to project intervention. There is a dearth of empirical evidence regarding whether and under what conditions on-farm plantation forestry can deliver favorable livelihood outcomes. For instance, it is not clear whether the benefits are large enough to have an impact on poverty and food security. Little is also known about the factors influencing the adoption and intensity of adoption of on-farm plantation forests in Uganda.

In the wake of climate change, tree farmers can now benefit from selling carbon credits in addition to the traditional wood products (De Jong *et al.*, 2005; Perez *et al.*, 2007). However, there is ambivalence about the economic viability of forest carbon offsets (Perez *et al.*, 2007; Pfaff *et al.*, 2007). In particular, there are concerns about the possible effect of high transaction costs of small-scale AR-CDM projects, increasing timber prices and low carbon prices on the profitability of forest carbon trade (Montagnini & Nair, 2004; De Jong *et al.*, 2000).

1.5. Justification

Eradication of poverty is a key development challenge for Uganda. This is highlighted in the countries National Development Plans (I and II) and National Vision 2040 (National Planning Authority [NPA], 2010). According to the Uganda poverty status report 2014, approximately 19.7% of the Ugandan population suffered from absolute poverty by 2012/13 (Ministry of Finance, Planning and Economic Development [MFPED], 2014). The report also classified 43 percent of the population as non-poor but insecure (Figure 1.1). These households had consumption above the poverty line but remained insecure and vulnerable to falling back into absolute poverty in the occurrence of a shock such as a drought. Although there has been a reduction in absolute poverty, a large section of the population (63.0 percent) who are either poor or insecure non-poor are still vulnerable. Therefore, they still require targeted attention.

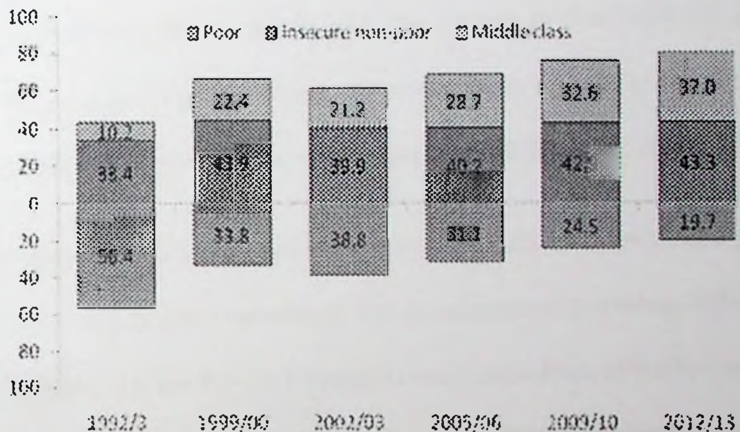

Figure 1.1 Share of the population that are poor, insecure non-poor and the middle class, 1992/3 - 2012/13

Source: MFPED (2014)

The incidence of poverty is even higher in the rural areas where the majority of Ugandans (77%) still live (MFPED, 2014). It was estimated that 22.8 percent in rural communities suffered from poverty while 47.4 percent were in the insecure non poor category. This is in contrast to urban areas where the poor were 9.3 percent and the insecure non poor were

29.2 percent. This implies that 70.2 percent of those in rural areas are not yet secure, compared to 38.5 percent in urban areas.

Given the importance of alleviating poverty among rural households in Uganda and the large amount of public funds that have been invested in promoting on-farm plantation forestry, it is important that its effectiveness in improving the welfare of small-scale farmers is understood. Policies that look good on paper may sometimes not work as well as expected. Therefore, rigorous analysis of this kind is needed to understand whether the different types of on-farm plantation forestry are generating the intended effects. This will provide policy makers with the necessary feedback for policy adjustment and thus help in informing the design of future forestry or agricultural projects which target small-scale farmers on the basis of lessons learned from the current farm forestry interventions.

At the national level, government of Uganda has developed poverty reduction strategies (PRS) as a broad framework for development planning (Oksanen *et al.*, 2003). Uganda implemented the Poverty Eradication Action Plan (PEAP) between 1997/98 and 2007/08, followed by the National Development Plan between 2010/11 and 2014/15.This study will contribute towards establishing the appropriate role of forest interventions in the national poverty reduction strategies. Establishing effective linkages between the PRS and the national forest programs will ensure that the potential of the forest sector to contribute to poverty reduction is properly assessed and tapped (FAO, 2005). An effective linkage between the forest sector programs and PRS can also help to sharpen the poverty focus in the programs. For example, by forest projects paying more attention to targeting the poor and vulnerable groups (Oksanen *et al.*, 2003).

At the international level, eradication of poverty and taking action to combat climate change are some of the global Sustainable Development Goals (SDGs). According to this declaration, the international community is committed to ending poverty in all its forms everywhere.

Secondly, the study will assess the perception and social-economic factors influencing adoption of smallholder on-farm plantation forestry. Identification of the factors determining adoption of on-farm plantation forestry is expected to improve the effectiveness of extension services and farm forestry policy. The study results can be used to develop on-farm plantation forestry adoption strategies.

Following the expiry of the Kyoto protocol in 2012 and the adoption of COP21 agreement in December 2015, the UNFCCC and voluntary carbon markets are keen to explore ways of enhancing the continent's role in climate change mitigation (Jindal *et al.*, 2008). Several countries in Africa are keen to scale-up forest carbon offset schemes (Biocarbon Fund, 2011). Therefore, it is important that the carbon sequestration potential and socio-economic impacts of forest carbon offset schemes are assessed in order to inform the design of future carbon projects, which engage small-scale farmers.

1.6. Objectives of the study

(1) To determine the factors influencing the adoption and intensity of adoption of on-farm plantation forestry.

(2) To compare the impact of eucalyptus and carbon forestry (Plan Vivo) woodlots on household poverty and food security.

(3) To analyze the benefit incidence of farm forestry projects.

(4) To determine the economic carbon sequestration potential of *Pinus caribaea and Eucalyptus grandis* plantations in Uganda.

1.7. Hypotheses of the study

1) Perception and socio-economic factors do not affect the decision to participate in on-farm plantation forestry.
2) Participation in on-farm plantation forestry does not reduce household poverty and food insecurity.
3) Poor households do not receive a significant share of the subsidies from on-farm plantation forestry projects.
4) Carbon offsets do not increase profitability of *Pinus caribaea and Eucalyptus grandis* plantation forests.

1.8. Organization of the Dissertation

The dissertation is divided into five major chapters. The second chapter reviews relevant theoretical and empirical literature on farm forestry, forest carbon offsets, poverty, food security and impact evaluation. The third chapter discusses the estimation procedures, the details of models and econometric techniques employed. The results of the study are presented and discussed in chapter four. Chapter five summarizes the results, provides conclusion and presents the major recommendations of the study.

CHAPTER TWO

LITERATURE REVIEW

2.1. Concepts of poverty, food security, impact evaluation, plantation forestry and forest carbon offsets.

2.1.1. Poverty concept and its measurement

Poverty has been defined as pronounced deprivation in well-being (World Bank, 2000). There are three main views of poverty in economics literature. The conventional view links well-being primarily to income. Accordingly, the poor are those whose income or consumption is below some minimum threshold. This view defines poverty in monetary terms (Ravallion, 2005). Typically poverty is then measured by comparing an individual's income or consumption with some defined threshold below which they are considered to be poor. Poverty may also be defined according to a specific type of consumption. In this case, someone may be considered to be house poor, food poor or health poor. These dimensions of poverty can often be measured directly, for instance by measuring malnutrition or literacy. The broadest approach to defining poverty focuses on the capability of the individual to function in society. The poor lack key capabilities, and may have inadequate income or education, be in poor health, feel powerless, or lack political freedoms (World Bank, 2000; Zeller *et al.*, 2005). This approach also views poverty as a multi-dimensional phenomenon that may be difficult to tackle.

According to Ravallion (2005), one of the purposes of measuring poverty is to guide targeting of interventions towards poorer areas. Governments need to identify the poor, and this in turn requires viable information on poverty. Information on poverty can also be used to evaluate the impacts of policies and programs designed to help the poor (Baker, 2000).

Computing poverty measures is a three step process. First, one has to choose the relevant indicator of well-being. Second, one has to select a poverty line, below which a given household or individual will be classified as poor. Finally, one has to select a poverty measure for a population subgroup (Ravallion, 2005).When estimating income poverty, one may have a choice between using income or consumption as the indicator of well-being (World Bank, 2000; Zeller *et al.*, 2005; Madden, 2000).

Measurement of poverty requires selection of a poverty line from the aggregate income data (Kassie *et al.*, 2011; Becerril & Abdulai, 2010; David& Otsuka, 1994; De Janvry & Sadoulet, 2001). Poverty lines are cutoff points separating the poor from the non-poor and they may be relative or absolute. Relative poverty lines are defined in relation to the overall income distribution in a country. For example, the poverty line could be set at the lowest 30 percent of the country's income distribution. On the other hand, absolute poverty lines are based on the cost of meeting basic needs. Normally, absolute poverty lines are based on the cost of a nutritional basket considered minimal for the health of a typical family, to which a provision is added for nonfood needs. Considering that many developing countries have high poverty rates, reliance on an absolute rather is more relevant than a relative poverty line (World Bank, 2000).

Typically, the indicator of household welfare and the chosen poverty line are converted into a poverty measure for the population sub-group (De Janvry & Sadoulet, 2001; Minten & Barrett, 2007; Moyo *et al.*, 2007). There are many poverty measures but the most commonly used include: i) Headcount index. This is the share of the population whose income is below the poverty line. ii) Poverty gap. This provides information regarding how far off households are from the poverty line. This measure estimates the total resources needed to bring all the poor to the level of the poverty line. iii) Squared poverty gap. This takes into account not only the distance of the poor from the poverty line but also the inequality among the poor. That is, a higher weight is placed on those households further away from the poverty line. The poverty gap and squared poverty gap measures are vital complements of the headcount index. It is possible for some groups to have a high poverty incidence but low poverty gap. Similarly, other groups may have a low poverty incidence but a high poverty gap for those who are poor.

Although poverty is normally measured in monetary terms, it is sometimes measured by non-monetary indicators such as health, nutrition and literacy. In some cases it is feasible to apply the procedures for measuring monetary poverty to non-monetary indicators of well-being. For example, the literacy level of a household is compared to a threshold literacy level, below which it can be said that the household is poor.

Alternative poverty lines may also be set using self-reported measures of poverty (Madden, 2000). Here, household wealth ranking is done by community members and they define what poverty means to them (Zeller *et al.*, 2005). This may involve focus group discussions, key informant interviews and participatory wealth ranking. A relative poverty index is then computed and households' socioeconomic status is ranked based on this index. Although this method is highly subjective, it is very helpful if the policy maker is to understand poverty from the community's perspective. The major weakness of this method is its subjectivity and local orientation that makes comparison across regions impossible.

Analysts have argued that measurement of poverty is necessary, but not sufficient (Ravallion, 2005). It is also important to think systematically about how poverty can be reduced (Ravallion, 2005). To this end, the Poverty Reduction Strategy Paper (PRSP) process was first introduced for Highly Indebted Poor Countries (HIPC) in 1999 (World Bank, 2005). This was supposed to be a country driven policy paper setting out a long-term strategy for poverty alleviation, based on the latest available data and analysis. The idea is that the developing countries should take the lead in developing a PRSP, so that the process is "owned" locally and not imposed from the outside (Ravallion, 2005).

2.1.1.1. Why consumption expenditure

When estimating income poverty, analysts may choose between using income or consumption expenditure as the indicator of well-being. Consumption expenditure includes all monetary expenditures on goods and services consumed plus the estimated monetary value of all consumption from income in kind (Haig & Simons, 2000).

Most analysts argue that consumption is a better poverty measure than income (Ravallion, 2005) for rural households. It is also argued that consumption is more closely related to a person's well-being than income. This is because income is only one of the elements that will allow consumption of goods. Others include questions of access and availability (Ravallion, 2005).

Secondly, measurement of household income is difficult in poor agrarian economies where incomes for rural households may fluctuate according to the harvest cycle. In-turn, the income data one collects from rural communities may fluctuate seasonally. This may present a potential difficulty for households in correctly recalling their income from the harvest season, which may result in low quality information derived from such surveys.

The life-cycle hypothesis suggests that households appear to smooth out consumption over the years. Thus information on consumption over a relatively short period such as a household survey is more likely to be representative of a household's general level of welfare than equivalent information on income, which is more volatile (Figure 2.1).

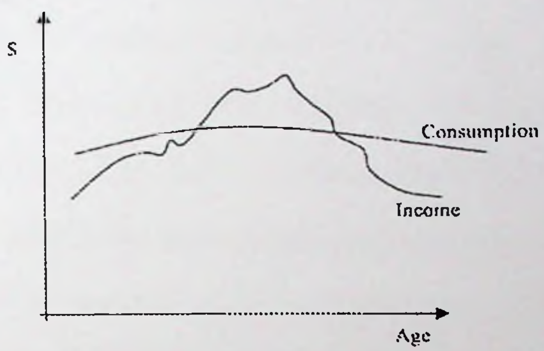

Figure 2.1 Life cycle hypothesis of income-consumption profile over time

Source: Ravallion (2005)

Estimating agrarian income presents an additional problem of excluding the inputs purchased for agricultural production from the farmer's revenues (Zeller *et al.*, 2006). Finally, large shares of rural household incomes are not monetized, especially where households consume their own production and it might be difficult to price these (Grosh & Glewwe, 2000).

A more practical case for using consumption, rather than income, is that households may be more willing to reveal what they have spent rather than what they earned (Zeller *et al.*, 2006). Households tend to under-declare what they have earned for fear of issues such as taxation.

2.1.1.2. Why use equivalence scale

Households differ in size and composition, and so a simple comparison of aggregate household consumption can be quite misleading about the welfare of individuals in the household. Most researchers recognize this problem and use some form of normalization. The most common method is to convert household consumption to individual consumption by dividing household expenditures by the number of people in the household. Then, total household expenditure per capita is the measure of welfare assigned to each member of the household. Although this is the most common measure, it is not very satisfactory, for two reasons. First, different individuals have different needs. A young child typically needs less food than an adult. Second, there are economies of scale in consumption. It costs less to house a couple than to house two single individuals.

In principle, the solution to this problem is to apply a system of weights. For a household of any given size and demographic composition, an equivalence scale measures the number of adult males to which that household is deemed to be equivalent. So each member of the household represents a fraction of an adult male. Effectively, household size is the sum of these fractions and is not measured in numbers of persons but in numbers of adult equivalents. Economies of scale can be allowed for by transforming the number of adult equivalents into "effective" adult equivalents (Osberg & Xu, 1999).

2.1.2. Food security concept and its analyses

The concept of food security has been defined in different ways by a number of organizations (United States Department of Agriculture [USDA], 2008). At the national level, a country is considered food secure when there is sufficient food to sustain food consumption and to offset fluctuations in production and prices (Smith & Subandoro, 2007). Emphasis has since shifted to the household level. According to the definition of food security adopted at the 1996 World Food Summit, food security is achieved when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (FAO, 1996; Smith & Subandoro, 2007). Others have defined a food secure household as one where all members, at all times, have access to enough food for an active, healthy life (USDA, 2008; Anderson, 1990). On the other hand, food insecurity has been defined as a situation of limited availability of nutritionally adequate and safe foods (USDA, 2008).

The 1996 International Food Summit, pledged to reduce the prevalence of hunger by at least half in the early part of the 21st century (FAO, 1996; Smith & Subandoro, 2007). Whether viewed from the national or household level, food security is an essential part of well-being. Therefore, it is important to conduct measurement of food security in order to identify groups with food insecurity. Such information is essential for policy makers to make informed decisions.

Additionally, accurate measurement and monitoring of food security can help policy makers and program managers to assess the effectiveness of existing programs. Although food insecurity is highly related to poverty, the poverty measures do not provide clear information about food security (Bickel *et al.*, 2000). Analysis of food security data shows that, in some cases, low-income households appear to be food secure, while in a few cases non-poor households appear food insecure (Bickel *et al.*, 2000). Therefore, food security measure provides more specific information on this dimension of well-being than can be inferred from poverty measures (Bickel *et al.*, 2000).

Food security has different indicators and each indicator captures just a portion of the extent of food security. They can be categorized into three as diet quantity, diet quality and current economic vulnerability (Smith & Subandoro, 2007). At the household level, diet quantity is measured by the household daily food energy availability per capita. This is the daily food energy acquired by the average household member. This indicator can be used to determine whether a household acquires sufficient food to meet their daily energy requirements (Ruel *et al.*, 2003). Energy from food is arguably the most important nutrient for physical activity and health.

The other indicator that is important for achieving food security is diet quality. Analysts have argued that it is possible for one to meet their energy requirements but be prevented from leading a healthy life due to deficiencies of other nutrients such as protein and vitamins (Welch, 2004). It has been argued that, increasingly inadequate diet quality rather than insufficient energy consumption is the main constraint facing poor households (Ruel *et al.*, 2003). For these reasons, it is important that indicators of diet quality be included in the analysis of food security. Diet quality can be measured by the number of nutritionally significant food groups acquired by a household over the reference period (Graham *et al.*, 2004). It is argued that diet diversity is a good indicator of the ability of a diet to provide nutrient requirements such as proteins, energy and vitamins (Ruel, 2002).

Diet quality has also been measured by the percentage of the energy acquired by a household that is derived from staple foods such as root tubers (Smith & Subandoro, 2007). Lastly, food security can be indicated by the percentage of total household expenditures on food. This is a measure of economic vulnerability of the household. Households that spend a large percentage of their income on food are vulnerable to food insecurity because if they experience a reduction in income it will likely be accompanied by a reduction in food consumption (Smith & Subandoro, 2007; FAO, 2013).

In Uganda, a food security survey conducted by the United Nations World Food Program showed that 6 per cent of households were food insecure (McKinney, 2009; Bridge *et al.*, 2006). According to Von-Grebmer *et al.* (2011), Uganda has a Global Hunger Index (GHI) score of 16.7 and malnutrition accounts for 40% of all child deaths.

2.1.3. Impact evaluation concept

Impact evaluations are usually interested in estimating causal effects rather than mere associations between variables (Ravallion, 2003). Impact evaluation is typically used to determine whether programs or policies had the desired effects on individuals, households, and institutions and whether those effects are attributable to the program intervention and not from other factors (Khandker *et al.*, 2010). Impact evaluations can also explore the positive and negative unintended consequences on program participants. However, impact cannot be simply measured by the outcome of a project because there may be other factors that are correlated with the outcomes but are not caused by the project (Heckman *et al.*, 1999). In order to net out the effect of one intervention from other factors, most impact evaluation methods estimate the counterfactual, that is, what would have been the outcome of interest in the absence of the intervention (Rosenbaum

& Rubin, 1983; Ravallion, 2003). The main challenge across different types of impact evaluation is to find a good counterfactual. A good counterfactual is constructed from the control group such that it resembles the treatment group in every way, the only difference between groups being program participation. Determining the counterfactual can be accomplished using either experimental or quasi-experimental designs.

It is generally agreed that experimental designs are the most robust of the evaluation methodologies (Khandker *et al.*, 2010; Ravallion, 2003; Baker, 2000). By randomly allocating the intervention among eligible beneficiaries, the assignment process itself creates comparable treatment and control groups that are statistically similar, given appropriate sample sizes (Ravallion, 2003; Baker, 2000). In theory, this implies that the control groups generated through random assignment serve as a perfect counterfactual, free from selection bias issues that exist in quasi-experimental designs. While experimental designs are considered the optimum approach in impact evaluation, they may not always be practical.

When it is not possible to construct treatment and comparison groups through experimental design, quasi-experimental methods can be used to carry out impact evaluation (Khandker *et al.*, 2010). These techniques generate the counterfactual through econometric methodologies, which include propensity score matching, double-difference, instrumental variables, and reflexive comparisons methods (Rosenbaum & Rubin, 1983; Rao & Ibanez, 2005; Baker, 2000). These techniques are usually used when the treatment and comparison groups are selected after the intervention by using non-random methods. Therefore, statistical controls must be applied to address differences between the treatment and comparison groups. Although the results of quasi-experimental designs may be less accurate compared to experimental designs, they can be performed after a program has been implemented, given sufficient existing data. Many analysts consider matched-comparison techniques a second-best alternative to experimental design (Rosenbaum & Rubin, 1985; Jalan& Ravallion, 1998). There have been significant advances in propensity score matching techniques (Rosenbaum & Rubin, 1985; Jalan& Ravallion, 1998). This technique is attractive to evaluators with time constraints given that it can be used with a single cross-section of data. However, the technique is dependent on having sufficient data of program beneficiaries for matching with the comparison group. Given the growth in the applications of National household surveys, this evaluation method seems particularly promising (Jalan& Ravallion, 1998).

Some analysts have used qualitative and participatory methods to assess impact (Kusek & Rist, 2004). Qualitative impact evaluation techniques rely on something other than the counterfactual to make a causal inference (Baker, 2000; Mohr, 1995). These techniques often provide critical insights into beneficiaries' perspectives, the processes that may have affected outcomes and a deeper interpretation of results observed in quantitative analysis. Because estimating the counterfactual is at the core of impact evaluation techniques, qualitative designs have generally been used in conjunction with quantitative impact evaluation techniques (Baker, 2000).

2.1.3.1. Benefit incidence concept

The rationale for government subsidies as part of public expenditure rests on both efficiency and equity grounds. On equity grounds, it is the role of government to improve the share of national resources that go to the poor and other disadvantaged groups (Demery, 2000). The fact that the poor may not have access to important services which would help them escape from poverty, implies that governments should seek to target the provision of these services to such groups.

Several farm forestry projects have been implemented in the study area with the common aim of improving rural household income and livelihood. The Farm Income Enhancement and Forest Conservation Project (FIEFOC) and the 'Trees for Global benefits' (TGB) project are the two major farm forestry projects that have been implemented in the study area. One of the objectives of the FIEFOC project was to improve rural household incomes and livelihood by providing an enabling environment for small-scale farming households to participate in tree planting for wood supply and environmental protection (OAG, 2011). This was achieved through provision of free tree seedlings and forestry advisory services to farming households in rural areas.

The TGB project started in 2002 and is implemented by ECOTRUST, a non-governmental organization in the same area (Schreckenberg *et al.*, 2013). The project allows smallholder farmers to plant native trees and later get paid for the carbon sequestered by the trees through the plan vivo system.

This study assessed the distribution of farm forestry subsidies from the FIEFOC (state supported project) and TGB (non-state) projects across different incomes in the study area. Benefit incidence analysis measures the distribution of the subsidies across the population. Knowledge of the distribution of benefits across different pre-intervention income levels is crucial in judging the intervention's success in targeting the poor.

2.1.4. Plantation forestry concept

Although there is no internationally agreed definition of a forest plantation, the term is widely used to refer to forests, which are established artificially. According to FAO (2005), forest plantations are stands established by planting in the process of afforestation or reforestation. They are either of introduced or indigenous species which meet a minimum area requirement of 0.5 ha; tree crown cover of at least 10 percent of the land cover; and total height of adult trees above 5 m. Categorization of plantation forests varies among countries.

Table 2.1 Scale category of plantation forests

Scale category	Number of hectares in Management Unit (FSC Definition)	Number of hectares in Management Unit (Uganda definition)
Small Scale	≤ 100 ha	Up to 1000 ha
Medium Scale	Between small scale and large scale	Between small scale and large scale
Large scale	> 80,000 ha (plantations)	> 80,000 ha (plantations)

Source: Uganda Investment Authority (2008)

It is generally accepted (Niskanen & Vayrynen, 2001) that the primary objective of most plantation projects is timber production although other products such as firewood, transmission poles and building poles may also be targeted.

2.1.4.1. On-farm plantation forestry

On-farm forest plantations are small-scale forests, which are established for subsistence or cash income in the process of afforestation or reforestation, with even age class and regular spacing (CIFOR, 2002). It has also been defined simply as forestry undertaken on farms (Niskanen & Vayrynen, 2001), which involves small scale woodlots but may include agroforestry. For this study, on-farm plantation forestry is defined as the practice of growing small-medium scale woodlots on privately owned agricultural land for the provision of wood products or/and ecosystem services such as carbon sequestration.

The development of small-scale tree farm plantations provides an additional benefit of reducing dependency on natural forest exploitation (CIFOR, 2002). Fast growing tree species including *Eucalyptus, Pinus, Grevillea, Maesopsis,* and *Tectona* among others are typically planted on marginal lands or pieces of land that farmers have difficulty managing due to labor shortage, theft or vermin constraints (Niskanen & Vayrynen, 2001). Such lands would otherwise have undergone traditional long bush fallow systems with little or no economic value. With its low management requirement, the tree woodlot system is thus an attractive economic alternative to diversify farm products. Choice of the species is normally dependent on growth rate, germplasm availability, ease of propagation and compatibility with most agricultural crops (Niskanen & Vayrynen, 2001).

In contrast to the large plantations that aim at supplying regular volumes of timber to established long term markets, small scale plantation forests are characterized by limited professional management (Niskanen & Vayrynen, 2001). These smaller plantations have not received the criticisms of large scale plantations such as causing displacement of the poor when natural forest land is converted into plantations and private land (Phuc, 2003; Sunderlin, 2005; McElwee, 2009).

A number of developing countries have begun the process of reforming forest policies that were originally put in place to support state-owned commercial forest production and are moving to privately managed plantations (Scherr, 2004). Other reforms have been geared to address growing problems of environmental degradation and wood product demands (Dhakal, 2009; Strassburg *et al.*, 2009). The reforms have intentionally promoted the establishment of small-scale plantations on-farm with the dual purpose of improving livelihoods and reducing pressure on the existing natural forests. Recent government policies designed to protect forests, have in some cases reduced rural communities' access to local forest products and further marginalized poor people (Thomas, 2008). This has led to the realization that policy reforms are essential for development of small-scale farm forestry (Scherr, 2004) without which small holder farmers will continue to be marginalized.

2.1.5. Forest carbon offsets concept

In response to concerns over the impact of climate change, the Kyoto Protocol set binding emission targets for Annex I countries for a number of potent GHGs (Intergovernmental Panel on Climate Change [IPCC], 2003). Under the Kyoto Protocol, Annex I countries were allowed to meet emissions reductions targets during the first commitment period using flexible mechanisms such as the CDM (Cacho & Wise, 2005; Biocarbon Fund, 2011; UNFCCC, 1997). The CDM allows for the purchase of Certified Emission Reductions (CERs) by Annex I countries from non-Annex I countries as a means of complying with binding emission reduction targets (Pagiola & Platais, 2007). The projects generating the carbon credits can be carried out in a number of technology sectors including, land-use change and forestry sector (LULUCF). Under the LULUCF sector, the scope of activities eligible for the CDM in the first commitment period of the Kyoto Protocol were limited to afforestation and reforestation (AR) projects. The CDM makes it possible for AR project owners in developing countries to receive payments for certified emission reductions (CERs) (Nelson & de Jong, 2003; Chomitz *et al.,* 1999; Asquith *et al.*, 2002; Nabuurs *et al.*, 2003).

The 9th Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) resolved to include small-scale forestry as an eligible activity under the Clean Development Mechanism (CDM) of the Kyoto Protocol. The small-scale AR-CDM category offers a better opportunity for small-scale tree farmers to participate in the CDM carbon market (Biocarbon Fund, 2011). The aim of the small-scale AR category is to reduce transaction costs per unit in order to promote small-scale projects (UNFCCC, 2006). There are two eligibility requirements AR projects have to fulfill to be considered small scale: (i) they must be developed or implemented by low-income communities and individuals; and (ii) they must result in greenhouse gas removals of less than 16,000 tCO_2e per year (UNFCCC, 2008). In addition, the UNFCCC allows project developers to bundle small-scale projects as a way to further reduce transaction costs. The Tree farmers are paid for certified emission reductions (CERs) over a 20 year contract period (UNFCCC, 2007).

The Uganda Nile Basin Reforestation Project developed by the National Forest Authority is the first ARCDM project in Africa that was successfully validated against the UNFCCC standard. The project applied the small-scale AR CDM methodology and a portfolio of five projects has been established. The potential of forest carbon trade in Uganda is largely a consequence of the excellent conditions for tree growth (Kaboggoza, 2011). Substantial land areas could be used for carbon sequestration, through plantation forestry (MWLE, 2002).

Following the expiry of the Kyoto protocol in 2012, the international community adopted the Doha amendment to the Kyoto protocol followed by the COP21 agreement in December 2015. The COP21 agreement established a new mechanism, which will succeed the CDM in 2020. However, the rules for the new mechanism have not yet been adopted. Therefore, it is important that the economic viability of forest carbon offsets is assessed in order to inform the design of future carbon projects.

Forests have been cited as cheap and relatively long term carbon sinks (Nabuurs *et al.*, 2003). The potential of forests to sequester carbon to mitigate climate change has encouraged growth of the forest carbon markets. Carbon offsets can be bought from anywhere in the Annex II countries because the effect on the atmosphere is the same regardless of where carbon sequestration takes place. The rationale of payment for carbon sequestration is to compensate land owners for providing an ecosystem service. It is also seen as a proactive approach to encouraging forest carbon sequestration (Engel *et al.*, 2008). Because most ecosystem services have no market value, there is no economic incentive for their sustainable management. It was expected that paying for forest carbon credits would encourage carbon sequestration through plantation forestry and agroforestry activities (Pagiola & Platais, 2007; Pagiola *et al.*, 2002; Bayon, 2004).

Recent technical innovations allow for accurate measurement of the amount of CO_2 sequestered by a given stand of trees or unit of land. The carbon sequestration potential of a forest plantation depends on the growth characteristics of the tree species, the conditions for growth where the tree is planted, and the density of the tree's wood (Albretch & Kandgi, 2009). The most accurate way to estimate stored carbon and subsequently CO_2 equivalents is to directly measure the trees on a specific site. This involves developing and implementing a sampling inventory (Albretch & Kandgi, 2009).

2.2. Review of empirical evidence

2.2.1. Effect of farm forestry on household poverty

There is a growing recognition that forests and trees can make a significant contribution to rural livelihood (Sunderlin *et al.*, 2002; World Bank, 2001; Oksanen *et al.*, 2002; FAO, 2005; World Bank, 2001a). Hence governments and non-state actors are increasingly looking to the forestry sector for solutions to reduce poverty (Arnold, 2001). Small-scale farm forestry provides an opportunity for rural households to integrate into the wood products supply chain thus increasing their potentials for income improvements.

Available studies show that forest-related income contributes between 6% and 45% of the total household income in many rural areas (Appiah *et al.*, 2009; Babulo *et al.*, 2008; Hogarth *et al.*, 2013; Illukpitiya & Yanagida, 2008; Mamo *et al.*, 2007; McElwee, 2008; Shackleton *et al.*, 2007; Tieguhong & Nkamgnia, 2012; Vedeld *et al.*, 2004). They point out that forests provide wood and non-wood forest products for sale on the local, national and in some cases the international market. They also indicate that forests form important safety nets during the dry seasons when the previous seasons yields are low (Oksanen, 2002; Yemiru *et al.*, 2010; Angelsen & Wunder, 2003).

At the macro level, the contribution of forests to Uganda's GDP is estimated to be 6%. Although as noted by Kaboggoza (2011), it could be higher when the non-monetary contribution from ecosystem services and woody biomass as the main energy source for the country is considered.

In the case of farm forestry, there are widely differing views about its socio-economic impacts. On the one hand, plantation forest investments have been associated with potential benefits from increasing farm income, diversification of income sources and gaining access to credit services (Barlow & Cocklin, 2003; Higman *et al.*, 1999; Curtis & Race, 1998). In his study, Nsiah (2010) analyzed the financial contribution of on–farm plantation forests to household's income and livelihood strategies. The results from this study indicated that cash income from selling farm forest products contributed an average of $273.6 to total household's income in one agricultural season. This amount accounted for 17.6% of total household's income and represented the second highest source of income after agricultural crop production. In Tabora region of Tanzania, rotational woodlots were found to offer substantial benefits to farmers, in terms of income generation and higher returns on labor than maize fallow (FAO, 2000). Similarly, Stewart *et al.* (2011) reported that, blue gum farm forestry in Australia, was found to have a net value of $1236/ ha to the farmer compared to $768/ha for livestock grazing during 1993 – 2007.

Sun and Chen (2003) reported that small-scale forest enterprises are often among the few available sources of income generation in remote areas. They noted that, in China forestry enterprises are among the main sources of local livelihoods in 496 of the 592 state designated poverty counties. However, they contend that while small-scale forest enterprises (SMFEs) have the potential to be highly pro-poor, there is no guarantee that

SMFEs will reduce poverty. The crucial determinant is the policy, institutional and market environment (Sun & Chen, 2003).

On the other hand, some analysts contend that the role of forest plantations in poverty alleviation, is ambiguous and it contains risks which are likely to affect the poorest strata. For example, Sandewall *et al.* (2010) examined the pre-requisites for farm-based plantation forestry and its impact on rural people's livelihood strategies, socio-economic status, income and security. The findings indicated that although on-farm plantation forestry was considered a safe type of income it was not accessible to the poorest households. They contend that the poorest households may need access to a credit system, which enables them to go through a cycle of plantation growth. Other reports indicated that the poor risk losing access to natural forest land when it is being converted into plantations and private land (Phuc, 2003).

In the wake of climate change, farm forestry has evolved to include carbon forestry where farmers grow trees primarily to benefit from selling carbon credits (BioCarbon Fund, 2011). In their study, Shuifa *et al.* (2010) concluded that farm forestry interventions that include sale of carbon credits have the potential to alleviate poverty and increase job opportunities in China. In contrast, Glomsrod *et al.* (2011) reported that such projects provided significant environmental benefits in terms of carbon sequestration but limited socio economic benefits to rural households. Concerns have also been raised about the opportunity cost associated with displacement of other land uses (Pagiola *et al.*, 2005; Corbera *et al.*, 2007) and poorer carbon sellers getting trapped in long-term land-use deals with negative livelihood outcomes (Landell mills & Porras, 2002).

Studies on the poverty alleviation and distributional effects of other agro-industrial investments have shown similar ambivalence (Rui, 2006; Heltberg & Tarp, 2002). In some cases, the poor farmers were excluded from participation due to lack of access to productive assets such as land thus increasing the inequality (Heltberg & Tarp, 2002). Other studies did not find exclusion of the poor farmers (Glover, 1984).

Criticism has also been leveled against commercial plantation forestry for not improving the welfare of communities where they are located (FAO, 2001; Williams *et al.*, 2003). It has also been proposed that on-farm plantation forestry may have greater potential to improve the welfare of rural communities than commercial plantation forestry. However, no hard evidence has been provided in Uganda.

As outlined above, most studies reveal the benefits and threats associated with farm forestry enterprises. However, they donot reveal whether there are any changes in well-being among project participants and whether the changes in well-being are indeed due to project intervention. There is distinct lack of rigorous empirical evidence of the impact of farm forestry enterprises on household poverty and food security in Uganda.

2.2. 2. Empirical studies on farm forestry and food security

Concerns have also been raised about the effect of using agricultural land for tree farming on household food security and vulnerability (Arnold, 1997; Petheran *et al.*, 2000; FAO, 2001; Williams *et al.*, 2003; Pickworth, 2005). In his study, Molua (2005) observed that eucalyptus woodlots were the most desired and planted tree genus in some parts of Ethiopia because of its profitability. He argued that high adoption of eucalyptus may threaten food crop cultivation.

Similar concerns have also been raised about the effect of using agricultural land for growing cash crops (Arnold, 1997; Petheran *et al.*, 2000; Mulugetta, 2009). They point out the potential dangers associated with the emergence of agricultural cash crops on food crop production. This comes at a time when there is increasing demand for food due to the fast rising population in sub-Saharan Africa. This concern over food security is one which is very sensitive in Sub-Saharan Africa given the large number of food deficit countries (Mulugetta, 2009).

In his review, Longhurst (1987) observed that there is mixed evidence on the impact of tree cash crops on food security. On the one hand, increased income is expected to increase the household's access to food. On the other hand, it has been suggested that shifts from subsistence food production to cash cropping has a negative impact on household food security and nutrition. Concerns have also been raised about the effect of long-term carbon contracts on food production because land that is locked in multi-year carbon plantations will not be available for food production.

2.2.3. Empirical studies on carbon sequestration potential of plantation forestry

Several studies have demonstrated the substantial amount of carbon that can be stored by plantation forestry projects (De Jong *et al.*, 2005; Aune *et al.*, 2004; Shiufa *et al.*, 2010; De Jong *et al.*, 2005, Glomsrod *et al.*, 2011, Wong *et al.*, 2005, Vonada *et al.*, 2011). Other studies have also investigated the economic viability of including payments for carbon offsets (Palmer & Silber, 2009; Soto-pinto *et al.*, 2009; Schmitt-Harsh *et al.*, 2012). However, most profitability studies assume equal rotation for plantations with and without carbon credits (Palmer & Silber, 2009; Olschewski *et al.*, 2005; Wise & Cacho, 2004), yet in reality plantations without carbon credits may be harvested before the crediting period of 20 years under CDM. Few studies have compared the profitability of forest carbon payments under alternative rotation length (Kothke & Dieter, 2010). Additionally, previous studies have provided mixed results thus perpetuating the ambivalence about the economic viability of forest carbon offsets (Perez *et al.*, 2007; Pfaff *et al.*, 2007). In particular, there are concerns about the possible effect of high transaction costs of small-scale AR-CDM projects, increasing timber prices and low carbon prices on the profitability of forest carbon trade (Montagnini & Nair, 2004; De Jong *et al.*, 2000).

2.2.4. Empirical studies on the adoption of agricultural technologies

Assessments of the factors influencing adoption of agricultural technologies tend to focus on the socio-economic and institutional factors (Sall *et al.*, 2002; Shiyani *et al.*, 2002; Wabbi *et al.*, 2012). Several studies have reported that farmer's age, farm size, land value, erosion rate, education level, tenure system, resource endowment, site description factors, and market incentives as factors that influenced adoption of agricultural technologies (Valdivia & Paulos, 2009; Arbuckle *et al.*, 2009; Moser *et al.*, 2009; Oeba *et al.*, 2012). The main factors that have been found to influence adoption of agricultural technologies include; farmer characteristics, attributes of the farm, location and policy (Feder *et al.*, 1985; Doss, 2006). Other studies have shown that the production and consumption attributes are important in explaining the adoption of modern varieties (Hintze *et al.*, 2003; Smale *et al.*, 2001). In their study of the factors influencing the adoption of maize varieties in Malawi, Lunduka *et al.* (2012), used a set of dummy variables measuring maize variety attributes related to production and processing/consumption. The results of their study showed that production characteristics and consumption characteristics of the varieties were influential to farmers' growing decision. Several studies indicated that resource endowment, age, education, land size, agricultural extension, positive technology attributes and off-farm income positively influenced agricultural technology adoption (Lunduka *et al.*, 2012; Idrisa *et al.*, 2012; Ojiako *et al.*, 2007; Freeman & Omiti, 2003; Jagger & Pender, 2003). On the contrary, Itana (1985) reported that age negatively influenced the adoption decision while Freud *et al.* (1996) reported no relationship between age and adoption. Whereas, it is evident from the above literature that there is lack of consistence in their findings, the studies provide empirical evidence of the factors which influence adoption.

Few studies have specifically analyzed the factors influencing adoption of on-farm plantation forestry in Uganda. However, to my knowledge, none of the studies has analyzed the factors influencing the intensity of adoption after the adoption decision has been made. The few studies also did not assess how farmers' perceptions of technology attributes influence the adoption decision. The paucity of empirical evidence on the factors influencing adoption of on-farm plantation forestry in general and the role of farmers' perceptions in particular, justify further investigation. Therefore this study identified the perception, socioeconomic and institutional factors that influence the adoption and intensity of on-farm plantation forestry in south western Uganda.

2.4. On-farm plantation forestry interventions in Uganda

The plantation forestry sector in Uganda has a long history, although the rapid expansion of the plantation forest acreage has been recorded more recently (Kabogozza, 2011). The Ugandan government has promoted plantation forestry in response to the triple challenges of poverty, high deforestation and climate change in Uganda (Obua *et al.*, 2010). The high deforestation rate has been caused by the explosive population growth (3.2% p.a) and high demand for timber, which has placed increasing demands on the limited forest resources (Barret & Aboud, 2002; Collier, 2007). According to NFA (2012), it is estimated that the annual demand for sawn timber will be about 879, 500 m^3 by 2030 (Kaboggoza, 2011).

One consequence of the increasing demand for wood products is that the forestry sector is gradually shifting to fast-growing plantations of mainly *E.grandis* and *P.caribaea* species in commercial, medium and small-scale farm plantations. Involvement by small-scale growers in farm forestry presents an opportunity to increase long-term wood supply while contributing significant social, economic and environmental benefits (FAO, 2011). In Uganda, investment in tree planting is hypothesized to be a potential development pathway out of poverty and food insecurity (FAO, 2003; Bukenya & Nyombi, 2013). Smallholder plantations or woodlots are an increasingly important source of timber, poles and firewood, as well as a critical soil and water conservation investments as deforestation and land degradation escalate.

Although there are few records pertaining to such tree growers in Uganda, it is acknowledged by Kaboggoza (2011) that the number of farmers growing trees has increased in the recent past due to the publicity of tree growing as an income generator through the supply of timber and other wood products to the market. Plantation forest expansion in Uganda has been attributed to the improvement in private financing and country wide campaigns for private forestry. Plantation forest expansion has also been boosted by global grants and carbon sequestration campaigns in Uganda (Kabogozza, 2011; Lyons & Westoby, 2014). As indicated by Kaboggoza (2011), the Payment for Environmental Services (PES) derived from the forestry sector has also grown in importance. Uganda's plantation forest estate is dominated by *P.caribaea* and*E.grandis*. In specific areas, other species such as *Maesopsis eminii*, *Pinus patula, P. oocarpa, Cupressus lusitanica, Auraucaria spp., Terminalia spp.* and Teak (*Tectona grandis)*have been planted but the total area of these species is relatively small.*Eucalyptus* is the most widely planted species by small-scale farmers in Uganda. The species has been widely adopted because it is silviculturally robust, and adaptable within a range of sites (Alder *et al.*, 2003). It is also highly adopted due to its fast growth, which allows it to provide a variety of wood products after short rotations of 3-7 years (Bukenya & Nyombi, 2013). Eucalyptus woodlots can provide a variety of products including firewood, transmission poles, construction poles, fencing posts and timber. Recent efforts to promote on-farm plantation forestry have been through government supported projects such as FIEFOC and SPGS, as outlined below.

2.4.1. Farm Income Enhancement and Forest Conservation Project (FIEFOC)

The FIEFOC Project was conceived in February 1995 to improve incomes, rural livelihoods and food security, through sustainable natural resources management and agricultural enterprise development (OAG, 2011). The project was implemented under Uganda's plan for modernization of agriculture (PMA) and poverty eradication action plan (PEAP) frameworks and was funded by Government of Uganda (GoU) and its development partners. The Ministry of Water and Environment (MWE) and the Ministry of Agriculture Animal Industry and Fisheries (MAAIF) being coordinated by the

National Project Coordination Unit (NPCU) were responsible for the implementation of the Farm Income Enhancement and Forest Conservation (FIEFOC) project.

The tree planting sub-component of the project aimed at providing an enabling environment for small-scale households to participate in tree planting for wood supply. In accordance with global trends and the forestry sector policy, the project used a community based development approach. The districts and sub-counties were the focus of the management plans and the private sector as the main provider of the required technical services. FIEFOC was originally meant to operate in 37 districts but was increased to 55 following the creation of more districts. The project was designed to utilize the existing staff at the ministry, districts and sub-counties in order to harness synergies and reduce on costs. The project beneficiaries received tree seedlings and advisory services from technical personnel.

2.4.2. Sawlog Production Grant Scheme (SPGS)

The SPGS is a joint European Union, Government of Norway and Government of Uganda project that started in 2004. It gives tree planting grants and technical support to private tree growers to establish plantations ranging from 25 to 500 ha. The SPGS provides technical knowledge and financial assistance of up to US$ 340 per hectare of planted trees. Pines and eucalyptus are most common species under this project. The SPGS grants plus the availability of land in CFRs for rent on a 50-year long permit are very good incentives which have been critical to the success of the project (SPGS, 2014).

By 2013, the project had supported over 400 investors to establish over 37,000 hectares of timber plantations to acceptable standards (SPGS, 2014). SPGS also supports small-scale tree planting on farms by the rural poor through its Community Tree Planting Initiative. Rural farmers with a minimum individual area of ½ an acre are provided with technical advice, practical training and quality tree seedlings to plant. Approximately 1,721,053 seedlings were supplied to 3,120 farmers in 103 community groups under this initiative (SPGS, 2014).

2.5. Carbon forest projects in Uganda

In addition to the government supported plantation forestry projects, a number of carbon projects have also promoted on-farm plantation forestry. The potential of forest carbon trade in Uganda is largely a consequence of the availability of land for tree growing and the fact that tree growth is relatively faster (NFA, 2010). Substantial land areas could be used for carbon sequestration, through plantation forestry and agroforestry (NFA, 2008). Some of the carbon forest projects implemented in Uganda include the TGB and the Uganda Nile Basin Reforestation Project.

2.5.1. Trees for Global Benefit (TGB)

The TGB project is a community Payments for Ecosystem Services (PES) scheme linking small-scale landholder farmers to the voluntary carbon market (Schreckenberg *et al.*, 2013). The project which started in 2002 contracts farmers to plant a variety of indigenous tree species in order to sell voluntary emissions reductions on the voluntary carbon market. Farmers are paid in installments over 10 years and unlike many carbon offset projects, carbon credits in the TGB project are sold up-front (Schreckenberg *et al.*, 2013). The project is implemented by an environmental NGO, Environmental Conservation Trust of Uganda (ECOTRUST) with sites in Mitooma, Rubirizi, Bushenyi, Hoima, Kasese and Masindi Districts, in south western Uganda. The project has explicit objectives of poverty reduction and environmental protection (Schreckenberg *et al.*, 2013). The project has more than 1500 registered participants.

The project uses the Plan Vivo land use system, which is now operational in four other projects worldwide. The Plan Vivo (PV) is a system for managing the supply of Voluntary Emissions Reductions (VERs) from community based land-use projects (Schreckenberg *et al.*, 2013). Eligible land use activities for generating VERs under the Plan Vivo system currently include afforestation and reforestation, agroforestry, forest restoration and forest conservation. The Plan Vivo foundation is responsible for issuing VER certificates for projects which operate using the Plan Vivo standards.

2.5.2. Clean development mechanism (CDM) projects

In the recent past, more funding has come through the CDM to contribute to international initiatives on climate change adaptation and mitigation (Biocarbon Fund, 2011). For example, the World Bank has funded three carbon projects in Uganda at Rwoho, Rwenzori and Kasagala central forest reserves. There are few forestry projects participating in CDM due to the high transaction costs under the CDM (Biocarbon Fund, 2011). This is exacerbated by the long approval process associated with carbon certification. Due to the high transaction costs, the community groups participating in CDM in Rwoho carbon project are not paying the CDM transaction costs. The costs are paid by the National Forestry Authority (NFA) as part of the community development program.

The Uganda Nile Basin Reforestation Project developed by the National Forest Authority is the first ARCDM project in Africa that was successfully validated against the UNFCCC standard (NFA, 2010). The project applied the small-scale AR CDM methodology.

CHAPTER THREE

METHODOLOGY

3.1. Description of Study Area

3.1.1. Location, Topography and Land Cover Type in Study Area

The districts of Rubirizi and Mitooma are located in southwestern Uganda, lying approximately between 671003 M East and 324000 M North. The topography is characterized by broad ridge tops, small valleys and steep slopes in some areas. The altitude ranges from 910 to 1950 meters above sea level. The main land use systems are farmland (80%), woodland (12%), and grassland (5%) (National Environment Management Authority [NEMA], 2004).

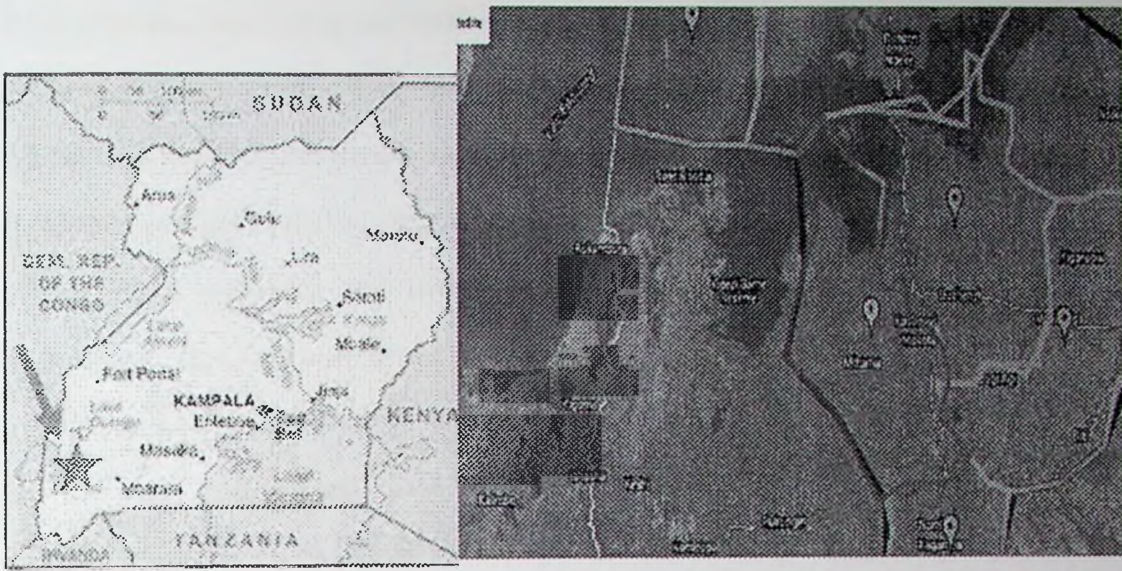

Figure 3.1 Map of Mitooma and Rubirizi districts in South Western Uganda

Source: Google maps

3.1.2. Soils, farming systems, and productivity

The predominant soil types are yellowish brown sandy clay loams developed from phyllite, schists, and gneisses rocks. Black sandy loams developed from volcanic ash and rift valley sediments are a common occurrence towards the North and Northwestern part of the region (NEMA, 2004). The FAO classification characterizes these soils as predominantly ferasols and acrisols. Soil productivity is largely characterized as medium, owing to good soil depth, structure and inherent soil fertility. Banana production dominates the use of the cropped land (81%), followed by bean (4%), maize (4%), sweet potato (4%), finger millet (3%) and sorghum (2%) as the main food crops. Tea, coffee (robusta) as well as cotton and Irish potato are the dominant cash crops (NEMA, 2004). Dairy livestock is also a dominant farming system.

3.1.3. Climate, population and biodiversity

The region has a climate characterized by mean annual rainfall of 1200 mm, which occurs in a bimodal pattern allowing for two planting seasons in a year. This region experiences moderate temperatures with a long term mean temperature of 21^{0}C (NEMA, 2004). Mean minimum and mean maximum temperatures are 14^{0}C and 26°C, respectively. This favorable climate and the fertile soils coupled with historical factors led to high population densities in the area. The population density stands at 220 people per km^2 with a growth rate of 3.1%. The geography of the region includes highly populated highlands with mid-elevation high-intensity mixed farming systems. There is barely an area located on flat terrain. Although some areas have slopes ranging from 20 - 50°, most areas are located on steep slopes of between 20° and 70°. The area is highly susceptible to erosion due to steep slopes that are devoid of vegetation. The districts are a biodiversity hotspot (NEMA, 2004). Due to their biodiversity conservation importance, the districts are home to several protected areas including national parks, wildlife reserves, forest reserves, Ramsar sites, and UNESCO World Heritage sites.

3.2 Sampling

The study was conducted in the districts of Rubirizi and Mitooma in south western Uganda. The districts were purposively sampled because they have a higher adoption rate of on-farm plantation forestry compared to other districts. The criterion for selecting carbon forestry farmers was that the respondent must have been a participant in the plan vivo carbon forestry scheme for at least 6 years. This is because at 6 years the participating farmer is expected to have received at least 90% of carbon payments in the contract. Secondly, there were very few farmers who had participated in this scheme for more than 6 years. Similarly, the criterion for selecting eucalyptus woodlot farmers was that the respondent must have been practicing woodlot farming for at least 10 years and has harvested before. The idea behind including only farmers who have participated for a specified minimum period and have harvested before was to include sufficient time frame to allow for program impacts (Baker, 2000). Tree growing is a long term investment hence the need to allow for sufficient time for impact.

Stratified cluster random sampling was used to select respondents from carbon forestry, eucalyptus and control group farmers. A list of farmers in each treatment group (eucalyptus woodlots and carbon forestry) who fitted the criteria was compiled from three randomly selected sub-counties in each district with the assistance of the respective district forest officers, local leaders and NGO representatives. Respondents were randomly selected from each list according to their population proportions by district.

A control group of farmers who are not practicing on-farm plantation forestry (non-participants) but have land was randomly selected from villages with low incidence of tree farming within each district. The idea behind including eligible non-participants (farmers with land) was to increase the precision of propensity score matching. Four villages were then randomly selected from a list of villages with low incidence of tree farming in each district. The sampling frame for the non-adopters in the village was provided by the village local councils. The non-adopters were also sampled proportionally by district.

3.2.1. Sample size

The sample size for primary data collection was determined by the following formula (Edriss, 2013):

$$n = \frac{Z^2 (1 - P) P}{e^2} \tag{1}$$

Where: z = 1.96 (2 tailed test), e = 0.05 (margin of error) and p = estimated proportion of farmers having eucalyptus (0.25) and carbon woodlots (0.17). After adding 10% for non-respondents and 2% for design effects[1], 242 carbon forestry famers in the plan vivo scheme and 322 eucalyptus woodlot farmers were sampled. Analysts have argued that in order to ensure matching when using PSM, the sample size of the control group should be larger, if possible double that of the participants (Khandker *et al.*, 2010). Therefore, 396 respondents were sampled in the control group.

3.2.2. Data collection

To evaluate impact, a cross-sectional household questionnaire survey was used to collect data on socio-demographic characteristics, consumption expenditure and food acquisition, durable assets, farm and non-farm income (Appendix 1). Questionnaire survey data was supplemented by qualitative data collected through ten key informant interviews and 12 focus group discussions. Focus group discussions were conducted with tree farmers to collect economic data on the quantity, price and flow of other farm outputs (timber production, firewood) and transaction costs associated with on-farm plantation forestry. They also provided information about the typical management regimes, carbon payments received by individual farmers and perceptions of on-farm

[1] A default value of 1.5 to 2.0 for design effect is typically used

plantation forestry. Key informant interviews provided information about technical specifications such as tree species, tree spacing and number per hectare, expected sequestered carbon, carbon payment schedules of the carbon forestry schemes. They also provided information on institutional arrangements in the government supported forestry projects as well as carbon forestry schemes implemented by NGOs.

3.2.3. Biomass estimation data

Tree inventory data was collected from tree farmers in Rubirizi and Mitooma districts in South Western Uganda. Inventory data included tree height (metres), diameter at breast height, dbh (cm), plantation area (hectares), species and age of trees (Appendix 2). The data was collected from 94 and 106 plots of *P.caribaea* and *E.grandis* respectively. Plot size was 20 x 20 m. The number of plots established on each farm depended on the farm size. The data was collected from plantations of 5, 10, 15 and 20 years of age. District forest department staff, NGO staff and farmers in the study area provided information about the location of plantations.

3.3 Conceptual Framework

The figure 3.2, shows that on-farm plantation forestry can directly contribute to improvement of social welfare through provision of products for domestic consumption and cash income for small-medium scale tree farmers. Participation in on-farm plantation forestry is expected to integrate rural communities into the national wood products supply chain thus contributing to poverty alleviation. Woodlots can provide timber, carbon credits, transmission poles, building poles and firewood, depending on the species and rotation adopted by the farmer. The common rotations adopted by farmers include: short rotations of 3 - 4 years for firewood and building poles; medium-long rotation of 8-20 years for transmission poles and timber production. The impact of farm forestry on poverty alleviation could be seen in two dimensions: as poverty mitigation, where forestry provides a safety net during tough times such as out of crop season, or as poverty elimination, where forestry can be used as a career out of poverty (Angelsen & Wunder, 2003). This model is based on a number of assumptions. First, the model assumes that there is a ready market for the wood products and services from the forest plantations and that the farmers will be linked up to markets. The model further assumes that diverting some of the limited farm resources such as labour, land and capital to tree farming will not negatively affect food production. If this assumption does not hold then tree farming can instead increase food insecurity and poverty.

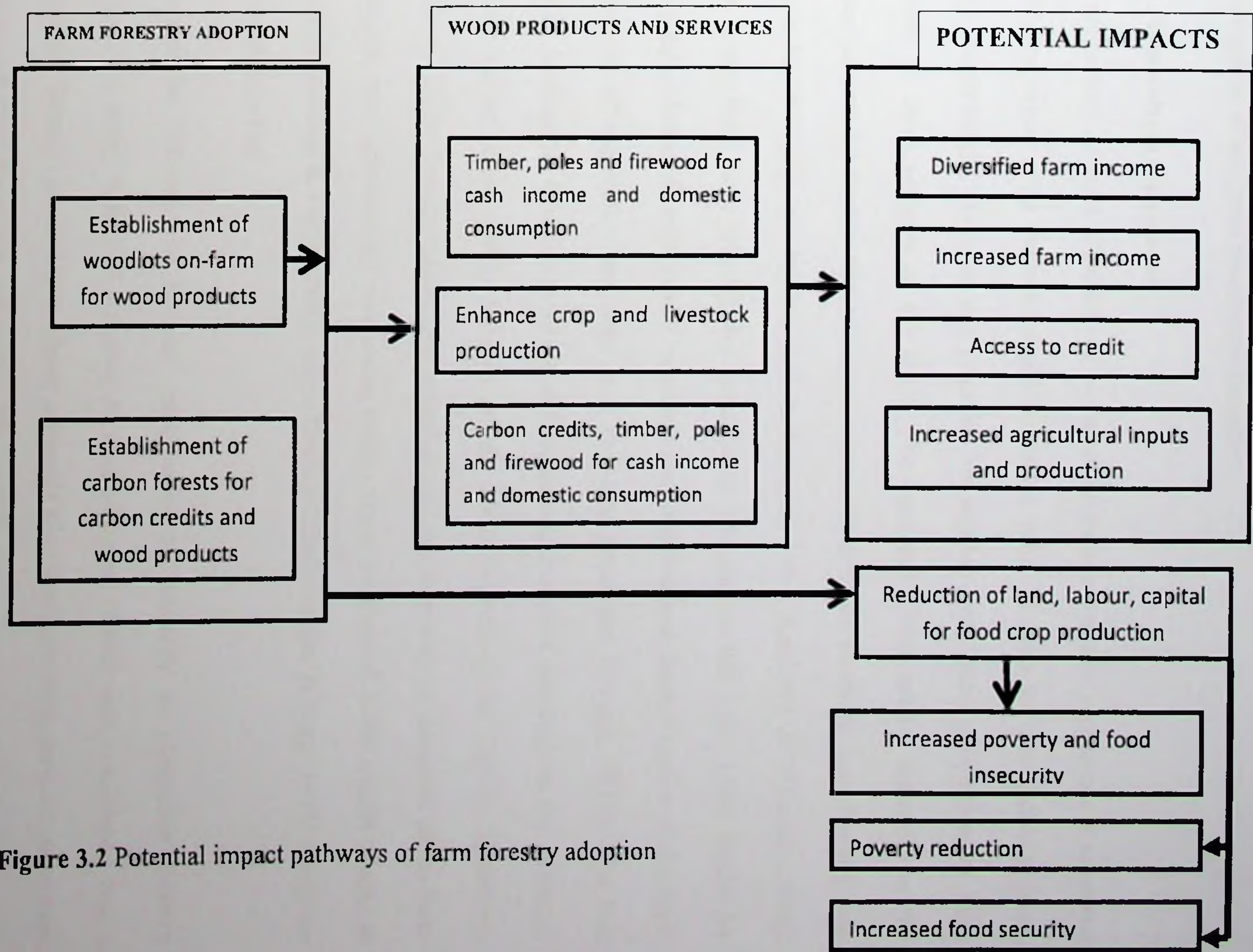

Figure 3.2 Potential impact pathways of farm forestry adoption

3.4. Objective 1. To determine the factors influencing the adoption and intensity of adoption of on-farm plantation forestry

3.4.1. Theoretical framework

The proportion of land allocated to on-farm plantation forestry represents a censored distribution since some farmers would assume a value of zero for not adopting (non-users). Accordingly, there is a cluster of households with zero proportion of land allocated to farm forestry at the limit. The censored Tobit model depends on the assumption that the factors that influence a farmer's decision to adopt farm forestry also increase the intensity of adoption (Lin & Schmidt, 1984; Kachova & Miranda, 2004). Other researchers have relaxed the assumption inherent in the joint Tobit model by specifying a Double-Hurdle model in which the adoption and determination of the level of intensity of application are seen as a two-step procedure (Cragg, 1971). The first involves making the decision to adopt and the second involves deciding on the extent of adoption (Staal *et al.*, 2002; Shiyani *et al.*, 2002; Wabbi *et al.*, 2012). Therefore, assessment of the factors influencing adoption and the intensity of adoption of on-farm plantations was estimated by comparing results from a censored Tobit model (Feder *et al.*, 1985; Freeman & Omiti, 2003) and a Double-Hurdle model (Cragg, 1971) using the likelihood ratio test.

To model the influence of farmers' perceptions on intensity of plantation forestry adoption, the study followed Adesina & Baidu-Forson (1995) and considered that a smallholder farmer i perceives to obtain a benefit $\pi(c)$ from adopting on-farm plantation forestry and $Z(t)$ from not adopting. The smallholder farmer is assumed to have perceptions of on-farm plantation forestry characteristics and let the perceptions be represented by M_{ic} and P_{it} for adoption and non-adoption respectively. Let socio-economic and demographic factors be represented by R. Let $\pi_{ci} = f(M_{ic}, P_{it}; R_i)$ and $Z_{ti} = g(M_{ic}, P_{it}; R_i)$. Let the difference between the perceived benefit from adoption $\pi_i(c)$ and non-adoption $Z_i(t)$ of farm forestry be denoted as S_h^* and represented as:

$$S_h^* = \pi_i(c) - Z_i(t) \tag{2}$$

If the participation decision J =1 for participants and 0 otherwise, the link between the binary decision variable and the latent variable S_h^* will be expressed as.

$$J = \begin{cases} 1 \ \ if\ S_h^* \geq 0 \\ 0 \ \ if\ S_h^* < 0 \end{cases} \tag{3}$$

The above equation implies that households will only participate in farm forestry if the perceived benefit from participation is positive.

A Tobit model was used to estimate the determinants of adoption and intensity of adoption of farm forestry (Tobin, 1958), represented as

$$A_i^* = \beta x_i + \varepsilon_i \tag{4}$$

$$A_i = 0\ if\ A_i^* \leq 0 \tag{5}$$

$$A_i = A_i^*\ if\ A_i^* > 0 \tag{6}$$

Where A_i represents the proportion of land allocated to on-farm plantation forestry (observable variable); A_i^* is the latent variable that indexes the adoption of on-farm plantation forestry intervention; x is a vector of perception and socio-economic variables;

β is a vector of parameters to be estimated (Tobit maximum likelihood estimates); and ε is the independently and normally distributed error term assumed to be normal with mean zero and constant variance σ.

The Tobit model is estimated by maximum likelihood estimation (Tobin, 1958). The likelihood function consists of two parts. For the adopters, $A_i = A_i^*$, this part is given by the density function as

$$\frac{1}{\sigma}\phi\left[\frac{A_i-\beta x_i}{\sigma}\right] \tag{7}$$

For the non-adopters, $A^* \leq 0$, the likelihood contribution is given by

$$1-\Phi\left(\frac{\beta x_i}{\sigma}\right) \tag{8}$$

Where, $\phi(.)$ and $\Phi(.)$ are the probability density and standard normal cumulative distribution functions, respectively. The likelihood function is represented as

$$L = \prod_{A_i=0}\left[1-\Phi\left(\frac{\beta x_i}{\sigma}\right)\right]\prod_{A_i>0}\frac{1}{\sigma}\phi\left(\frac{A_i-\beta x_i}{\sigma}\right) \tag{9}$$

The Tobit estimators of the parameters are the $\beta \; and \; \sigma$ values which maximize the likelihood function (L). The marginal effect of an explanatory variable on the expected value of A is:

$$\frac{\partial E(A|x)}{\partial x_k} = \beta_k\Phi\left(\frac{\beta x}{\sigma}\right) \tag{10}$$

The marginal effect of an explanatory variable on A for the adopters is:

$$\frac{\partial E(A|x,A>0)}{\partial x_k} = \beta\left\{1-\lambda\left(\frac{\beta x}{\sigma}\right)\left[\frac{\beta x}{\sigma}+\lambda\left(\frac{\beta x}{\sigma}\right)\right]\right\} \tag{11}$$

Where $\lambda(c) \equiv \frac{\phi(c)}{\Phi(c)}$ is the inverse mills ratio.

3.4.2. Double-hurdle model

It has been observed that the decision to adopt might in fact precede that on intensity of adoption. Following Cragg (1971) and Moffat (2003), the Double-Hurdle model contains two equations. The first stage of Cragg's model is a probit model to analyze determinants of adoption, and the second stage is a truncated regression model for determinants of the level of adoption (Cragg, 1971).

$$d_i^* = \alpha z_i + \mu_i \tag{12}$$

$$y_i^* = \beta x_i + \varepsilon_i \tag{13}$$

Where

$$d_i = \begin{cases} 1, & if\ d_i^* > 0 \\ 0, & if\ d_i^* \leq 0 \end{cases} \quad \text{and} \quad y_i = \begin{Bmatrix} y_i^*, & if\ y_i^* > 0\ and\ d_i^* > 0 \\ 0\ if\ otherwise & \end{Bmatrix} \tag{14}$$

Where, d_i^* is the latent variable describing a farm's decision to adopt on-farm plantation forestry, taking on value of 1 if the farmer adopts or 0 if farmer does not adopt. y_i^* is the latent variable describing its decision on the proportion of land to allocate to on-farm plantation forestry, and d_i and y_i are their observed counterparts, respectively. z_i is the vector of variables explaining whether a farmer adopts farm forestry, x_i is a vector of variables explaining level of adoption, and μ_i and ε_i are the error terms. Equations 12 and 13 are assumed to be independent, and therefore the error terms are randomly and independently distributed, $\varepsilon_i \sim N(0,1)$ and $\mu_i \sim N(0,\sigma_\varepsilon^2)$ (Caroll *et al.*, 2005). Under this assumption, the likelihood function is the sum of the truncated regression and the Probit models and is given as:

$$L = \prod_{y_i=0}\left[1 - \Phi(z_i\alpha)\Phi\left(\frac{x_i\beta}{\sigma}\right)\right] + \prod_{y_i>0}\left(\Phi(z_i\alpha)\frac{1}{\sigma}\emptyset\left(\frac{y_i-x_i\beta}{\sigma}\right)\right) \quad (15)$$

where Φ and ϕ are the standard normal cumulative distribution function and density function, respectively. The log-likelihood function is estimated using the maximum likelihood estimation (MLE) technique.

The two models can be compared using the likelihood ratio test when the determinants in both hurdles are the same (Greene, 2000). The LR statistics can be computed using the following formula:

$$\Gamma = -2[lnL_T - (lnL_P + lnL_{TR})] \sim x_k^2 \quad (16)$$

Where L_T, L_P, and L_{TR} are log-likelihoods of the Tobit, Probit, and truncated regression models, respectively, and k is the number of independent variables in both equations. The likelihood ratio test involves testing the hypothesis that $\lambda = \frac{\beta}{\sigma}$. The null hypothesis will be rejected if ($\Gamma > \chi^2_k$). Rejection of the null hypothesis indicates the superiority of the double-hurdle model over the Tobit model and establishes that the decisions about adoption and level of adoption are made in two different stages.

3.4.3. Empirical model

The dependent variable in the first stage of the double-hurdle model is the farmer's adoption decision. This variable is binary in nature, taking numeric value 1 for adopters, and 0 for non-adopters. In the second stage, the dependent variable is the proportion of farm land allocated to on-farm plantation forestry. As the variables explaining adoption can also explain level of adoption, the same set of independent variables were used in both stages. The dependent variable for the Tobit model is also the proportion of farm land allocated to on-farm plantation forestry.

The proportion of farm land allocated to on-farm plantation forestry or adoption decision (Y) is specified as a function of perception, socio-economic and institutional factors as follows:

$$Y_i = \beta_0 + \beta_j X_{ij} + \mu_i \qquad (17)$$

The key variables investigated in this study include a set of perception variables (Perceived compatibility with agricultural crop production, labour requirements, expected returns, initial investment, time to accrue benefits, ability to provide income during hunger periods), socio-economic (age of household head, education, gender, farming experience, non-farm employment, non-farm income, distance to market) and institutional variables (extension services, forestry skills training, security of tenure). Variable selection was based on variables used in other plantation forestry adoption studies.

Perceptions were measured by asking farmers to rate the attributes of on-farm plantation forestry. Each dummy variable for perceptions of on-farm plantation forestry attributes was coded as 1 if the respondent stated that the given characteristic was a positive characteristic of on-farm plantation forestry, and 0 otherwise.

Table 3.1 Description of variables specified in the model

Variable	Variable description	Variable measurement	Expected sign
Woodlot	Woodlot adoption	Dummy (1=adopt, 0 otherwise)	
Intensity	Intensity of adoption	Proportion of farm land allocated to on-farm plantation forestry	
Agricultural crops	Perceived compatibility of on-farm plantation forestry with agricultural crop production.	Dummy (1=positive, 0 otherwise)	+
Perceived returns	Perceived returns from farm forestry	Dummy (1=positive, 0 otherwise)	+
income	Perceived ability to provide out of crop season income	Dummy (1=positive, 0 otherwise)	+
Landsize	Household landholding	Acres	+
Age	Age of household head	Years	-
Security of tenure	Security of land tenure	Dummy(1=secure, 0 otherwise)	+
Female headed	Female headed household	Dummy(1=female, 0 otherwise)	-
Secondary	Dummy for secondary education by household head	Dummy(1=secondary, 0 otherwise)	+
Tertiary	Dummy for tertiary education by household head	Dummy(1=Tertiary, 0 otherwise)	+
Forestry skills	Received formal forestry skills training	Dummy(1=trained, 0 otherwise)	+

Table 3.1 Contd

Variable	Variable description	Variable measurement	Expected sign
Experience	Years of farming experience	Years	+
One extension	Dummy for atleast one extension visit in last year	Dummy(1=received, 0 otherwise)	-
Two extension	Dummy for atleast two extension visits in last year	Dummy(1=received, 0 otherwise)	+
Employment	Formal employment by household head	Dummy(1=employed, 0 otherwise)	-
Non-farm	Non-farm income by household	Dummy(1=income, 0 otherwise)	+
Distance	Distance to main market	Kilometres	-

3.5. Objective 2. To compare the impact of eucalyptus and carbon forestry (Plan Vivo) woodlots on household poverty and food security

In this study, the impact of adopting eucalyptus woodlots and carbon forestry woodlots under the Plan Vivo system on poverty and food security was assessed. The adoption decision in this study is modeled in the random utility framework. To model the impact of participation in farm forestry on household poverty and food security, the study followed Becerril & Abdulai (2010), Bokosi (2008) and Kassie *et al.* (2011). The model assumes that households decide whether or not to participate in farm forestry in order to maximize utility. Let U_{jh} be the utility associated with the participation decision, j for household, h. Where j = 1 for participants and 0, otherwise. Since these utilities are unobservable, they can be expressed as a function of observable elements in a latent variable model. We assume that total utility is a function of an outcome variable of interest associated with each participation alternative such that total utility is represented as.

$$U_{jh} = \beta y_{jh} + \delta z_h + e_{jh} \qquad (18)$$

where y_{jh} represents the outcome variable of interest, z_h represents all other background factors that relate observed factors to total utility. e_{jh} is a random component which captures other unobserved factors that affect total utility, β and δ are unknown parameters. We assume that a utility-maximizing farm household, h, will choose to adopt farm forestry if the utility gained from adopting is greater than the utility of not adopting. Let the difference between the utility from adoption (U_{1h}) and non-adoption (U_{0h}) of farm forestry be denoted as S_h^*. The utility model can be expressed as:

$$S_h^* = U_{1h} - U_{0h} = \beta(y_{1h} - y_{0h}) - \delta z_h - e_h \tag{19}$$

Where $e_h = e_{1h} - e_{oh}$ and $\delta = \delta_1 - \delta_0$. The link between the binary decision variable and the latent S_h^* will be expressed as.

$$J = \begin{cases} 1 \ \ if\ S_h^* > 0 \\ 0 \ \ if\ S_h^* \leq 0 \end{cases} \tag{20}$$

The above equation implies that households will only participate in farm forestry if the utility from participation is greater than non-participation. This also implies that the difference between the outcome variable of participants and non-participants is key in influencing household participation decisions. Assuming that the outcome variable varies among households depending on whether or not they participate and differences in observable characteristics, $x_h = x_h \in z_h$, equations associated with each alternative can be written as:

$$y_{1h} = \beta_1 x_h + \sigma_1 \varepsilon_{1h} \quad if\ j = 1 \tag{21}$$

$$y_{0h} = \beta_0 x_h + \sigma_0 \varepsilon_{0h} \quad if\ \ j = 0 \tag{22}$$

Where y_{1h} and y_{0h} denote the outcome variable associated with participation and non-participation, respectively. β_1 *and* β_0 are unknown parameters, σ_1 and σ_0 are standard deviations. ε_{1h} and ε_{0h} are the error terms with $E(\varepsilon_{jh}|x_h) = 0$.

The impact of farm forestry could be estimated by:

$$Impact = y_{1h} - y_{0h} \tag{23}$$

However, household participation in farm forestry is voluntary and it may lead to self-selection. It could be that observed and unobserved characteristics which determine the decision to participate in farm forestry also determine the outcome variable of interest. Farmers that adopt farm forestry may be systematically different from the farmers that did not adopt. In other words, the outcomes of participants and non-participants would differ even in the absence of treatment leading to selection bias. In addition, farmers may also have decided to adopt based on expected benefits. This means that adoption of farm forestry is potentially endogenous and therefore this approach might lead to biased estimates (Kassie *et al.*, 2007; Gilligan & Hoddinott, 2007), represented as.

$$E(y_{1h}|J = 1) - E(y_{oh}|J = 0) \tag{24}$$

Leads to bias

$$E(y_{1h}|J = 1) - E(y_{oh}|J = 1) + [(y_{oh}|\ J = 1) - (E(y_{oh}|J = 0) \tag{25}$$

This bias would be eliminated if

$$E(y_{0h}|J = 1) - (E(y_{0h}|J = 0) = 0 \tag{26}$$

i.e. if the outcomes of individuals from the treatment and comparison groups would not differ in the absence of treatment.

This can be achieved were households are randomly assigned to participant and non-participant groups in an experimental setting. Randomization ensures that the distribution of the observed and unobserved characteristics is the same for both the participants and the control group. Hence comparing average outcomes between the two groups,$y_{1h} - y_{0h}$, yields an unbiased estimate of impact.

Since participation in farm forestry is not random, the standard approaches for dealing with the problem of self-selection including propensity score matching (PSM) and endogenous switching regression were used. The counterfactual can be constructed econometrically, using the propensity score matching technique (PSM). Two proxies were used to measure household welfare in this study. Household consumption expenditure per adult equivalent was used as a proxy for present household poverty status and daily calorie acquisition per adult equivalent as a proxy for food security.

3.5.1. Propensity score matching

PSM is a technique that is used to control for as many observable characteristics as might be affecting participation in farm forestry (Khandker *et al.*, 2010).

In this study, cross-sectional propensity score matching (PSM) is used to estimate the impact of farm forestry on poverty and food security. Using PSM, the impact of participation is the average treatment effect on the treated (Rosenbaum & Rubin, 1983). This is the difference between the outcome in the participants and the counterfactual. Average Treatment effect on the treated (ATT) can be represented as:

$$ATT = E(Y_1 - Y_0 | J = 1, X) = E(Y_1 | J = 1, X) - E(Y_0 | J = 1, X) \quad (27)$$

Where participation is denoted by J, and J = 1 for participation and J = 0 for non-participation. Xis a set of observable household characteristics that explain participation in farm forestry. Y_1 represents outcomes for participants and Y_0 outcomes for non-participants. Since the counterfactual, $E(Y_0|J = 1,X)$, is not observable in the data, the average outcome in the control group, $E(Y_0|J = 0, X)$, will be used to estimate it. PSM is based on a number of assumptions. The first is the conditional independence assumption

$$(Y_1,Y_0)\perp J|X \quad (28)$$

which states that given a set of observable covariates X that are not affected by treatment, potential outcomes Y are independent of treatment assignment J (Rosenbaum & Rubin, 1983). This assumption implies that farm forestry participation is determined entirely on observed characteristics (Khandker *et al.*, 2010). This assumption also implies that the counterfactual is equal to observed outcome from the non-participants.

$$E(Y_0|J =1,X) = E(Y_0|J = 0,X) \quad (29)$$

Because PSM controls for selection bias on the basis of observed covariates, we conduct Rosenbaum bounds tests to gauge the sensitivity of the estimated treatment effects to hidden bias (Rosenbaum, 2002).

Propensity score matching is used to identify households in the control group that have similar observable characteristics with the participants. In practice, it may be difficult to ensure that the matched control for each participant has exactly the same covariates X. Instead, Rosenbaum & Rubin (1983) suggested matching along P(X), a single index variable that summarizes covariates. It is the probability of participation in farm forestry given covariates,

$$P(X) = pr(J = 1)|X \quad (30)$$

This index is known as propensity score. The conditional independence assumption can then be expressed as

$$E(Y_0|J = 1, P(X)) = E(Y_0|J = 0, P(X)) \qquad (31)$$

Therefore equation (1), ATT, can be expressed as

$$TT(X) = E(Y_1\text{-}Y_0|J = 1, P(X)) = E(Y_1|J = 1, P(X)) - E(Y_0|J = 1, P(X)) \qquad (32)$$

This is the difference between the outcome of the participants and the counterfactual. The generated propensity score will be used to measure effect of participation on outcome (poverty, food security) within the common support (Rosenbaum & Rubin, 1985).

The second assumption is the common support condition; $0 < P(J = 1|X) < 1$. This condition ensures that treatment observations have matching observations in the propensity score distribution. Among other methods, the common support condition can be checked by the visual inspection of the density distribution and by comparing the minima and maxima (Caliendo & Kopeining, 2005).

Given the fact that propensity score is a continuous variable, exact matches will rarely be achieved. Therefore, matching estimators will accept a certain distance between treated and untreated households. In this study, nearest neighbor, radius and kernel matching estimators were used.

The third assumption is the balancing condition. It means that the matching procedure is able to balance the distribution of the explanatory variables for both the participants and non-participants (Caliendo & Kopeinig, 2005). The balancing test may include T-test, comparing Pseudo-R^2 and comparing standard bias (before and after matching).

3.5.2. Switching regression

PSM is a useful approach for impact evaluation when only observed characteristics are believed to affect program participation. If unobserved characteristics determine both program participation and the welfare outcome, conditional independence assumption will be violated and PSM will not be an appropriate method (Rosenbaum, 2002). For example, if the most skilled farmers adopted farm forestry and we fail to control for skills, then we will get biased impact estimates. We checked the sensitivity of the (ATT) estimates from PSM to hidden bias, using the Rosenbaum bounds test (Rosenbaum, 2002). This test shows the effect unobservables should have in order to reverse the findings based on matching on observables. Therefore, to check the robustness of our results under different assumptions, we also used an endogenous switching regression. Endogenous switching regression can be used to correct for selection bias due to unobservable characteristics. Following Maddala & Nelson (1975) and Ravallion (2003), the switching regression can be defined by the following equations

$$S_i^* = Z_i\gamma + u_i \tag{33}$$

$$J = \begin{cases} 1 & if\ S_h^* > 0 \\ 0 & if\ S_h^* \leq 0 \end{cases} \tag{34}$$

$$Y_{1i} = X_{1i}\beta_1 + \varepsilon_{1i}\ \ if\ J_i = 1 \tag{36}$$

$$Y_{0i} = X_{0i}\beta_0 + \varepsilon_{0i}\ \ if\ J_i = 0 \tag{37}$$

Where:

Y_{1i} is household outcome measure (daily calorie acquisition per adult equivalent, consumption expenditure per adult equivalent) for participant in farm forestry and Y_{0i} for non-participant, X_{1i} and X_{0i} are vectors of exogenous explanatory variables relevant to each group. The explanatory variables included in the Logit model should be closely related to participation in farm forestry, but they should not be affected by the intervention (Barraud, 2009). β_1, β_0 and γ are parameter vectors. Let S_i^* be a latent variable determining which group applies, z_i is a vector of explanatory variables assumed to explain the probability of participation in farm forestry. Equation (33) is a selection equation determining which regime applies while Equations (36) and (37) describe the conditional expectation of the outcome variables in each of two regimes.

Finally, the error terms u_i, ε_{1i} and ε_{0i} are assumed to have a trivariate normal distribution, with zero mean and non-singular covariance matrix expressed as:

$$COV(u_i, \varepsilon_{1i}, \varepsilon_{0i}) = \begin{pmatrix} \sigma_{\varepsilon 0}^2 & \cdot & \sigma_{\varepsilon 0u} \\ \cdot & \sigma_{\varepsilon 1}^2 & \sigma_{\varepsilon 1u} \\ \cdot & \cdot & \sigma_u^2 \end{pmatrix} \tag{38}$$

where σ_u^2 is the variance of the error term in the selection equation (33), which can be assumed to be equal to 1 since the coefficients are estimable only up to a scale factor. $\sigma_{\varepsilon 0}^2$ *and* $\sigma_{\varepsilon 1}^2$ are the variances of the error terms in the welfare outcome functions (36) and (37). $\sigma_{\varepsilon 0u}$ *and* $\sigma_{\varepsilon 1u}$ represent the covariance of $(u_i, \varepsilon_{1i}, \varepsilon_{0i})$. Since individuals are observed either in state $J_i = 1$, or in state $J_i = 0$, but never in both, the covariance of equation 36 and 37 is equal to zero (Maddala, 1983). An important implication of the error structure is that because the error term of the selection equation (33) u_i is correlated with the error terms of the welfare outcome functions (36) and (37) (ε_{1i} *and* ε_{0i}), the expected values of ε_{1i} *and* ε_{0i} conditional on the sample selection are nonzero. Based on this assumption, the conditional expectation of the error terms are given by

$$E(\varepsilon_{1i}|J = 1) = \sigma_{\varepsilon 1u}\frac{\phi(Z_i\gamma)}{\Phi(Z_i\gamma)} = \sigma_{\varepsilon 1u}\lambda_{1i} \tag{39}$$

$$E(\varepsilon_{0i}|J = 0) = \sigma_{\varepsilon 0u}\frac{\phi(Z_i\gamma)}{\Phi(Z_i\gamma)} = \sigma_{\varepsilon 0u}\lambda_{0i} \tag{40}$$

where λ(.), is the inverse mill's ratio defined as$\lambda_1 = \frac{\phi(Z_i\gamma)}{\Phi(Z_i\gamma)}$ for positive observations (J_i = 1) and $\lambda_0 = -\frac{\phi(Z_i\gamma)}{1-\Phi(Z_i\gamma)}$ for the zero observations (J_i = 0) where ϕ and Φ are the normal density distribution function and cumulative normal distribution functions(cdf) respectively. Outcome variables equations (36 & 37) can be written as

$$Y_1 = x_1\beta_1 + \sigma_{\varepsilon 1u}\lambda_1 + v_1 \text{if } J=1 \tag{41}$$

$$Y_0 = x_0\beta_0 + \sigma_{\varepsilon 0u}\lambda_0 + v_0 \text{if } J=0 \tag{42}$$

Following (Lokshin & Sajaia, 2004) endogenous switching regression models can be efficiently estimated by full information maximum likelihood (FIML) method. The FIML method simultaneously estimates the selection equation and the outcome equations to yield consistent standard errors. Conditional on the trivariate normal distribution assumption for the error terms, the logarithmic likelihood function for the system of equations (33) and (36&37) can be given as

$$lnL = \sum_{i=1}^{N} J_i \left[ln\emptyset \langle \frac{\varepsilon_{1i}}{\sigma_{\varepsilon 1}} \rangle - ln\sigma_{\varepsilon i} + ln\Phi(\varphi_{1i}) \right] + (1 - J_i) \left[ln\emptyset \langle \frac{\varepsilon_{0i}}{\sigma_{\varepsilon 0}} \rangle - ln\sigma_{\varepsilon 0} + ln(1 - \Phi(\varphi_{0i})) \right] \quad (43)$$

Where $\varphi_{ji} = \frac{(\gamma z_i + \rho_j \varepsilon_{ij}/\sigma_j)}{\sqrt{1-\rho_j^2}}$, $j_i = 1,0.\rho_1$is the correlation coefficient between the error term ε_1 and μ and ρ_0 is the correlation coefficient between the error term ε_0 and μ respectively. The parameter estimates using FIML method can be obtained using the movestay command in STATA (Lokshin & Sajaia, 2004).

If the estimated covariances $\sigma_{\varepsilon 1u}$ and $\sigma_{\varepsilon 0u}$ are statistically significant, then the adoption decision and the outcome variables are correlated. This indicates the validity of switching regression model with endogenous switching and rejects the null hypothesis of absence of sample selectivity bias (Maddala & Nelson, 1975).

After estimating the parameters by FIML, the conditional and unconditional expectations of outcome variables for participants and counterfactual are calculated as follows.

$$E(Y_{1i}|J = 1) = X_{1i}\beta_1 + \sigma_{\varepsilon 1u}\lambda_{1i} \quad (44)$$

$$E(Y_{0i}|J = 1) = X_{1i}\beta_0 + \sigma_{\varepsilon 0u}\lambda_{1i} \quad (45)$$

The ATT is calculated as:

$$E(Y_{1i}|x_i, J_i = 1) - E(Y_{0i}|x_i, J_i = 1) = X_{1i}(\beta_1 - \beta_0) + (\sigma_{\varepsilon 1u} - \sigma_{\varepsilon 0u})\lambda_{1i} \quad (46)$$

3.5.3. Outcome measures

3.5.3.1. Poverty

Household consumption expenditure per adult equivalent was used as a proxy for present household poverty status. A poverty line of US$365 per year was adopted for this study, in line with comparable studies and the Uganda poverty status report (Kassie *et al.*, 2011; MFPED, 2014).

In this study household consumption expenditure included i) the value of food consumed (includes food bought from the market and that provided from one's own production), ii) value of frequently purchased goods and services such as transport services, toiletries, telephone bills, house rent. iii) rental value of owner-occupied housing iv) consumption of major durable goods during the year. Consumption of the durable goods during the year was measured from the change in the value of the asset during the year. This was estimated by asking the respondents the purchase price of the good, when it was purchased and the estimated current value.

In this study, an adult equivalence scale that adjusts for age and sex differences between households was used (Smith & Subandoro, 2007). Each person in the household was assigned an adult equivalence conversion factor that compares his or her energy needs with those of a 30-60 year old male (2,900 kilocalories) according to the energy requirements for moderate activity (Smith & Subandoro, 2007). The number of adult equivalents was summed up to obtain total number of adult equivalents for each household.

Foster–Greer–Thorbecke poverty measures (headcount index, the poverty gap index, and the poverty severity index) were used to compare poverty levels of adopters and non-adopters in the descriptive statistics. The FGT measure is presented as:

$$P_a = \frac{1}{N}\sum_{i=1}^{q}\left[\frac{z-y_i}{z}\right]^{\alpha} \tag{47}$$

Where,

Z = the poverty line; Y = the annual per capita expenditure; q = the number of poor households in the population of size n; α = the degree of poverty aversion; $\alpha = 0$ is the Headcount index measuring the incidence of poverty (proportion of the total population of a given group that is poor, based on poverty line); $\alpha = 1$ is the poverty gap index measuring the depth of poverty that is on average how far the poor is from the poverty line; $\alpha = 2$ is the squared poverty gap measuring the severity of poverty and inequality among the poor.

3.5.3.2. Measurement of Food Security

The data on household consumption expenditure on food in the last 7 days was used to estimate calorie acquisition, which is a measure of food security. The food quantities acquired by the household were expressed in terms of their caloric content, using the factors that convert quantities of edible portions into calories. First, the edible portions of the acquired foods were converted into a common unit, kilograms. Then the calories available in a type of food were computed by taking the converted standard quantity and multiplying it by the number of calories available in one kilogram of the food type (Smith & Subandoro, 2007; Kennedy *et al.*, 2011). The weekly household calorie acquisition was divided by seven day to get the household daily calorie intake. The family size of each household was converted into adult equivalents, which adjusts for differences in age and sex of members in the household. The daily net calorie consumption of the household was divided by the adult equivalents of the households to obtain the daily calorie acquisition per adult equivalent of the household.

3.6. Objective 3. To determine the benefit incidence of farm forestry projects

The study assessed the distribution of farm forestry subsidies conditional on the pre-intervention income categories. Following Jalan & Ravallion (2003), pre-intervention income is represented as: $pre = pst - gn$

Where: pre is the pre-intervention consumption expenditure per adult equivalent, pst is the observed post-intervention consumption expenditure per adult equivalent, gn is the average gain in consumption expenditure per adult equivalent estimated by PSM for participants in farm forestry intervention.

Using the pre-intervention incomes, the households are assigned to quantiles using the same bounds calibrated from the Uganda National Household Survey (MFPED, 2012). Households are assigned on the basis of the consumption expenditure per adult equivalent to which they belong. Following Demery (2000), the value of the subsidy going to income/gender group j is estimated as.

$$X_j = \sum_{i=1}^{N} N_{ij}(S_i * P_i) \tag{48}$$

Where: X_j is the value of subsidy imputed to group j, S_i is the quantity of the subsidy of type i received by household, P_i is the unit price of the subsidy of type i, and N_{ij} is the number of households in group j receiving subsidy type I, N is the number of subsidy types received in group j.

3.7. Objective 4: To determine the economic carbon sequestration potential of *Pinus caribaea* and *Eucalyptus grandis* plantations

This study assessed the effect of including carbon offsets on the profitability of two common plantation forestry species. The study assessed the economic carbon sequestration potential of *Pinus caribaea* and *Eucalyptus grandis* plantations under the small-scale CDM. The study also tests the effect of variations in transaction costs, timber prices and rotation length on relative profitability of the carbon offsets. *Pinus caribaea and Eucalyptus grandis* are two of the most widely planted exotic plantation species in S.W. Uganda (NFA, 2010). Both have been widely adopted by tree farmers because they are silviculturally robust, and adaptable within a range of sites.

3.7.1. Estimation of carbon stocks in woodlots

In order to estimate the temporal sequence of benefits received by farmers from the sale of carbon credits, we estimated carbon accumulation over the 20 year crediting period. The carbon stocks in *P.caribaea* and *E.grandis* plantations at 5, 10, 15, and 20 years were estimated using Uganda and species specific volume equations (Alder *et al.*, 2003). The volume equations predict overbark volumes to 5 cm top diameter and underbark volumes up to 10 cm top diameter. Overback volume to a 5 cm top diameter normally approximates stem volume (Alders *et al.*, 2003), while underbark volumes up to 10 cm top diameter approximates merchantable volume. The stem volume is converted to above-ground tree biomass using the respective basic wood density and biomass expansion factor, represented as

$$B_{uh.t} = V_{h,t} * D * BEF \quad (49)$$

Expanding to total tree biomass using the root-shoot ratio

$$B_{h,t} = V_{h,t} * D * BEF * (1 + R) \quad (50)$$

Where, $B_{h,t}$ is the total tree biomass per hectare in year t, tons of dry matter per hectare ($t.d.m.ha^{-1}$); $B_{uh,t}$ is the above ground biomass per hectare in year t, tons of dry matter per hectare ($t.d.m.ha^{-1}$); $V_{h,t}$ represents stem volume per hectare (over bark to 5 cm top) in year t, m^3ha^{-1}; D is the basic wood density of species, tons of dry matter per m^3 ($t.d.m.m^{-3}$); BEF is the biomass expansion factor for conversion of stem biomass to above-ground tree biomass and R is the root-shoot ratio for species.

Carbon stock (CO_2 equivalent) in tree biomass per hectare in year t is estimated as;

$$C_{ht} = \frac{44}{12} * B_{ht} * CF \quad (51)$$

Where C_{ht} represents carbon stock in tree biomass per hectare in year t, (tCO_2e), $B_{h,t}$ is the total tree biomass per hectare in year t, $t.d.m.ha^{-1}$ and CF is the carbon fraction of tree biomass, a default value of 0.5 is used (IPCC, 2003; Brown, 1997; McGroddy *et al.*, 2004).

Table 3.2 Regression equations used to estimate stem volume and biomass

Species	Volume equation	n	R^2	References
P.caribaea	$V=(0.5046 Ln(\sqrt{[10000/N]}). exp[-7.2328+2.1619 ln(Hd) + ln(N)]$	867	90.9	(Alders *et al.*, 2003)
P.caribaea	$V_{10ub} = 0.23232 D_g^{0.30142} . V^{1.02238}$	867	99.8	(Alders *et al.*, 2003)
E.grandis	$V= 0.008429(H_d - 2.5)^{2.148} N^{0.4933}$	346	95.9	(Alders *et al.*, 2003)
E.grandis	$V_{10ub}/V = 1 - exp(-0.4327(D_{g1} - 9.5)^{0.762})$	346	99.5	(Alders *et al.*, 2003, Shiver & Brister's (1992))

Where: Hd is dominant height in m, N is stocking in trees/ha, V is total stem volume (overbark to 5 cm top, in m^3/ha), V_{10ub} is volume underbark to a 10 cm top diameter (merchantable volume), in m^3/ha, D_g is the stand mean basal area diameter, in cm (PINE); D_{g1} is the stand mean diameter (eucalyptus).

3.7.3. The economic model

In the base-case model, the net benefits of the woodlots with and without carbon credits over the crediting period of 20 years were estimated using the Net Present Value (NPV). To make the alternatives comparable over time, the costs and benefits were discounted into a present value using a real discount rate of 10% and 2015 constant prices (Gittinger, 1982; Graves, 2007).

This study adopted the "ideal" carbon payment method proposed by Cacho & Wise (2005), for evaluating certified emission reductions under CDM. Under this method, payments for the amount of carbon sequestered are made at the end of the year (Cacho *et* *al.*, 2003b). The profit function faced by the tree farmer over the project period of T years is

$$NPV(T,X,S) = \sum_{t=0}^{T}[(H_t(S).P_h + A_t(S).P_a) - C_t^h(S)].\delta^{-t} - C_E + CER(T,S) \quad (52)$$

Where NPV is the net present value of the stream of net revenues US\$ ha^{-1} obtained from merchantable volume/stumpage volume (H_t), firewood, A_t and carbon payments, (CER_t) sales from the woodlot, using the discount factor δ for the discount rate r. S represents the particular species and T the time. In this study, wood harvested included stumpage volume at the end of the rotation and firewood (from thinnings and tree tops after harvesting). P_h is the stumpage, P_a is price of firewood harvested and C_t^h represents the variable costs over the rotation. C_E represents the establishment costs per hectare (land preparation, planting and establishing carbon contract). The last term in equation (52) is the present value of the stream of net revenues obtained from the sale of carbon payments, Certified emission reductions (CERs), for CDM. It is defined as

$$CER(T,X,S) = \sum_{t=0}^{T}[(\Delta C_t(S)).P_c - C_m].\delta^{-t} \quad (53)$$

Where ΔC_t represents annual changes in carbon stock in tree biomass per hectare in year t, tCO_{2-e}; P_c is the price of carbon and C_m is the annual cost of measuring carbon.

The annual change in carbon stock in tree biomass was calculated by dividing carbon stock accumulated in any 5 year interval (5, 10, 15, 20 years) by 5.

$$\Delta C_t = (C_{t+1} - C_t)/5 \quad (54)$$

Similarly, the annual change in merchantable wood volume was assumed to be uniform in any 5 year interval. The value of the merchantable wood volume was estimated from underbark volumes up to 10 cm top diameter, using the long run stumpage value approach. The volume of tree tops after final harvest was estimated as the difference between volume overbark up to 5cm top diameter (total tree volume) and underbark volumes up to 10 cm top diameter (merchantable volume).

3.7.4. Costs

Carbon transaction costs under the small scale AR CDM include contract establishment costs and carbon monitoring costs. CDM contract establishment is a fixed cost. This implies that the CDM contract establishment cost per hectare will reduce with increasing acreage due to economies of scale. Due to absence of reliable data on transaction costs, estimates from similar carbon projects were used. In this study, CDM contract establishment cost for 100 hectares of plantation forest of \$100 ha^{-1} was adopted in the base case model (Cacho *et al.*, 2003b). The annual carbon monitoring cost adopted for this study was \$5 ha^{-1} yr^{-1} (Cacho *et al.*, 2004; Biocarbon Fund, 2011). Other costs are outlined in Table 3.3.

Table 3.3 Base-case assumptions and parameter values for *P.caribaea, E.grandis*

Description	Eucalyptus grandis		Pinus caribaea		
	Value	Units	Value	Units	source
CDM carbon price	4.15	US$/t$CO_2$e	4.15	US$/ t$CO_2$e	A
Stumpage price	30	US$/$M^3$	50	US$/$M^3$	F
Price of firewood	5	US$/$M^3$	5	US$/$M^3$	F
Discount rate	10	%	10	%	g,h
Baseline carbon	9	tCO_2e /ha	9	tCO_2e/ha	I
Establishment costs	356	US$/ha	467	US$/ha	F
Maintenance costs					
Slashing cost	40	US$/ha	40	US$/ha	F
1st thinning cost	33	US$/ha	33	US$/ha	F
2nd thinning cost	40	US$/ha	40	US$/ha	F
CDM annual monitoring costs	5	US$/ha	5	US$/ha	J,n
CDM contract establishment cost	100	US$	100	US$	N
Wood density	0.52	t.d.m/m^3	0.48	t.d.m/m^3	k,l,m
Wood carbon content	0.5	-	0.5	-	K
Root-shoot ratio	0.45-0.2	-	0.46- 0.23	-	K
Biomass expansion factor	1.39	-	1.3	-	k,b

Sources: a: (Tennigkeit & Windhorst, 2007), f: field data collection, g: (Gittinger, 1982), h: (Wise & Cacho, 2005),i: (Ecotrust,2009), j: (Cacho *et al.*, 2004), n: (Biocarbon Fund, 2011), k: (IPCC, 2003), l: (Santos *et al.*, 2004), m: (Orwa *et al.*,2009), b:(Rawat *et al.*, 2015).

3.7.5. Varying rotation approach

In the second approach, we assessed the profitability of plantations with and without carbon offsets under varying rotations. Whereas, the base-case model assumed equal rotation for plantations with and without carbon credits, in reality plantations without carbon credits may be harvested before the crediting period of 20 years under CDM. This implies that the non-carbon farmers do not need to wait for the crediting period because they are not under any contract. Instead they can harvest at the optimal economic rotation, which may be different from the crediting period for CDM. Therefore, the economic profitability of plantations without carbon credits at shorter rotations including, the economically optimal rotation of each species was estimated and compared with carbon offsets. Apart from varying the rotations, the other base-case assumptions remained the same.

The optimal economic rotation age of the forest stand is reached when the land expectation value (LEV) reaches its maximum (Kothke & Dieter, 2010). The maximum value of LEV for a sequence of rotations is defined by Faustmann formula as.

$$LEV = \frac{Rh_T + \sum_{a=0}^{T}(R_{sa} \cdot (1+i)^{T-a}) - K \cdot (1+i)^T}{(1+i)^T - 1} \rightarrow Max! \qquad (55)$$

Where LEV is the land expectation value ($\$ \ ha^{-1}$), T is the rotation age (years), a is the year of revenue or cost (years), Rh is the stumpage value ($\$ \ ha^{-1}$), Rs is the net revenue from thinning ($\$ \ ha^{-1}$), K is the replanting cost ($\$ \ ha^{-1}$), i is the interest rate.

Given the difference in the rotations, annual equivalent value was derived from the NPV and used to compare profitability. It was adopted because NPV is not appropriate for

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Given the difference in the rotations, annual equivalent value was derived from the NPV and used to compare profitability. It was adopted because NPV is not appropriate for comparisons of economic feasibility of projects with different lifetimes (Jiing-Shyang & Joseph, 1997; Gutierrez *et al.*, 2006; Gittinger, 1982). The annual equivalent value (AEV) approach calculates the constant annual cash flow generated by an investment over its lifespan as an annuity. The present value of the constant annual cash flows is exactly equal to the project's net present value (NPV). AEV is defined as

$$AEV = \frac{NPV \cdot i}{1-(1+i)^{-n}} \tag{56}$$

where n is the lifetime of the project and i is the discount rate.

3.7.6. Sensitivity analysis

The base-case results are affected by stumpage price, discount rate, carbon price and carbon transaction costs (Cacho *et al.*, 2005). Therefore, these variables were subjected to sensitivity analysis. Sensitivity analysis was conducted by changing the variable of interest while keeping all other variables at their base-case values. The base-case assumed a carbon price of US$4.15/t$CO_2$e under CDM, which was reported in the Uganda Nile Basin Reforestation Project. Other studies have reported the carbon price to range between US$5 to US$25/tCO_2e (Cacho *et al.*, 2005). Therefore, we tested this range within the sensitivity analysis.

The base-case stumpage price was US$50 m^{-3} for *P.caribaea* and US$30 m^{-3} for *E.grandis*. However, stumpage prices have been steadily rising throughout the last decade due to the increased demand for timber and they are expected to continue rising (Kaboggoza, 2011). Annual price increments of up to 20% have been reported in Uganda. Stumpage prices ranging from US$50 to US$70 m^{-3} were evaluated for *P.caribaea* and

US$30 to US$50 m^{-3} for *E.grandis*. Carbon contract establishment costs ranging from \$100 to \$2000 ha^{-1} are included in the sensitivity analysis. Comparable studies showed a wide range of discount rates, ranging from 5 to 25% (De Jong *et al.*, 2000; Tomich *et al.*, 2002; Aune *et al.*, 2004; Cacho *et al.*, 2003a). Therefore, we tested this range within the sensitivity analysis.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. Descriptive statistics

Descriptive statistics including the means, Pearson's chi-square test of association (X^2) and ANOVA F-test of differences in means (F-value) for selected variables are presented by adoption status (Table 4.1) for 919 households included in the survey. Pearson's chi-square test of association (X^2) is used for comparison of means of categorical variables while ANOVA F-test of differences in means (F-value) is used for comparison of means of continuous variables. Some of these variables are used in the estimated models we present further on.

Table 4.1 Descriptive summary of variables used in estimations

Variable	Eucalyptus woodlots	Carbon forests	Non-adopters of farm forestry	All sample	Pearson's chi-square (X^2) or ANOVA (F-value)
Outcome Variables					
Consumption expenditure per adult	848_a	738	612_b	729	9.9***
equivalent (U S $)	(844)	(670)	(522)	(697)	
Daily calorie intake per adult equivalent	2768_a	2329	2090_b	2396	4.4**
(KCal)	(3925)	(2657)	(2046)	(3009)	
Household characteristics					
Age of household head(years)	41.8_a	45.5_b (13.8)	40.4_{ac}	42	8.4***
	(14.2)		(14.0)	(14.1)	
Family size (number)	5.5_a	6.1_b	5.2_{ac}	5.5	9.8***
	(2.4)	(2.6)	(2.3)	(2.5)	
Adults in household (number)	2.7_a	3.1_b	2.6_{ac}	2.8	5.8***
	(1.8)	(1.8)	(1.6)	(1.7)	

Table 4.1 Contd

Variable	Eucalyptus woodlots	Carbon forests	Non-adopters of farm forestry	All sample	Pearson's chi-square (X^2) or ANOVA (F-value)
Household members employed (number)	2.1	1.9	2.0	2	0.87
	(2.1)	(1.1)	(1.6)	(1.7)	
Landsize (hectares)	4.3_a	5.4_b	2.7_c	3.9	18.1***
	(5.7)	(7.9)	(1.9)	(5.4)	
Distance to market (Kilometers)	4.7_a	3.2_b	3.4_{bc}	3.8	12.1***
	(5.1)	(2.9)	(3.2)	(4.0)	
Non-farm income (U Sh)	115140.2	124985	119827	119346	0.03
	(347582)	(767499)	(414114)	(501443)	
Marital status					
Married	35.4%	24.8%	39.7%	84.4%	4.5
Not married	42.9%	17.6%	39.4%	15.5%	
Education of household head					
None or primary	35.9%	22.0%	42.0%	77.7%	11.9*
Secondary	39.0%	27.4%	33.5%	16.6%	

Table 4.1 Contd

Variable	Eucalyptus woodlots	Carbon forests	Non-adopters of farm forestry	All sample	Pearson's chi-square (X^2) or ANOVA (F-value)
Tertiary	42.0%	36.0%	22.0%	5.5%	
Forestry training					
Received training	47.1%	41.7%	11.1%	49.3%	340***
No training	26.6%	5.0%	68.2%	50.6%	
Extension visits					
None in last month	30.4%	6.3%	63.2%	41.1%	209.4***
Once in last month	47.7%	23.5%	28.6%	30.2%	
Twice in last month	33.2%	47.4%	19.3%	28.6%	
Land tenure					
Freehold	34.0%	20.6%	45.2%	30.6%	15.9*
Leasehold	58.8%	11.7%	29.4%	1.9%	
Mailo	50%	28.5%	21.4%	1.5%	
Customary	36%	25%	37.7%	65.5%	
Other	100%	0%	0%	0.3%	
Security of land tenure					

Table 4.1 Contd

Variable	Eucalyptus woodlots	Carbon forests	Non-adopters of farm forestry	All sample	Pearson's chi-square (X^2) or ANOVA (F-value)
Feel secure	34.9%	24.4%	40.5%	96.1%	22.8***
Insecure	74.2%	5.7%	20.0%	3.8%	
Gender of household head					
Male	37.8%	26.0%	36.3%	69.1%	10.8***
Female	34.7%	18.2%	46.9%	30.8%	

Note. Pearson's chi-square test of association (X^2) for categorical variables and ANOVA F-test of differences in means (F-value) for continuous variables. Astericks represent level of significances, * = p < .05, *** = p < .001. Standard deviations appear in parentheses below means. Means with differing subscripts within rows are significantly different at the p < .05 based on a Tukey post hoc test.

The results (Table 4.1) show that there were statistically significant differences in socio-economic characteristics between the adopters of eucalyptus woodlots, plan vivo carbon forestry and non-adopters. Variables such as age of household head, family size, number of adults in household, land size and distance to market were significantly different by adoption status. There was also a significant association between adoption status and variables such as education of household head, forestry training, number of extension visits received, land tenure, security of land tenure and gender of household head. However, non-farm income and number of household members employed were not significantly different between the three groups. There was also no association between marital status and adoption status.

The average age of sampled household heads was about 42 years. The age of household heads was 45.5, 41.8 and 40.4 for adopters of carbon forestry, eucalyptus woodlots and non-adopters respectively and the difference was significant. The adopters of carbon forestry, eucalyptus woodlots and non-adopters had a mean landholding of 5.4, 4.3 and 2.7 hectares respectively and the difference was significant. The adopters of farm forestry had higher percentage of male headed households, household heads who achieved tertiary education, and households that received forestry training.

Table 4.2 Poverty status in study area

Poverty measures	Eucalyptus woodlots	Carbon forestry	Non-adopters
Poverty measures			
Head count index	0.23	0.21	0.39
Poverty gap index	0.09	0.06	0.14
Poverty severity gap index	0.05	0.03	0.06

The headcount index, the poverty gap index, and the poverty severity index of adopters and non-adopters of farm forestry are computed using the Foster–Greer– Thorbecke (FGT) poverty measures (Table 4.2). The head count index indicates that the poverty level in the study area is within range of the national average for rural areas. The higher poverty levels in the rural areas have been a target of various poverty alleviation initiatives.

4.2. Empirical results

4.3. Assessing the factors influencing adoption of on-farm plantation forestry

Comparison of the two models using the likelihood ratio test indicated the superiority of the double-hurdle model over the Tobit model. The likelihood ratio statistic (Γ= 284.72) exceeded the critical chi-square value ($\chi2(16)$= 26.29) at the 5% level of significance. This implies that the decisions about adoption and proportion of land allocated to farm forestry were made in two different stages. Consequently, the discussion focuses on the results of the double-hurdle model.

Literature indicates that violation of the assumptions of homoscedastic and normally-distributed errors leads to inconsistent maximum likelihood parameter estimates (Fennema & sinning, 2007; Martinez-Espineira, 2006). Thus, the regressions were estimated using robust standard errors to correct for heteroscedasticity. To get a normally distributed error term, the dependent variable was transformed to the square root of the proportion of land allocated to farm forestry. The VIF was less than 10 indicating the absence of problems of multicollinearity.

The Wald test of joint significance of the joint Tobit and double-hurdle models is highly significant at 1% level indicating that the chosen independent variables fit the data reasonably well (Table 4.3). The results for both the joint Tobit and Double-Hurdle model are presented in Table 4.3.

Table 4.3 Maximum likelihood estimates for joint Tobit and Hurdle models

Variable	Joint Tobit estimates	Double-hurdle estimates			
		Probit		Truncated regression	
	Coefficients (Robust std error)	Coefficients (Robust std. errors)	Average marginal effects	Coefficient (Robust std.error)	Average marginal effects
Agricultural crops	0.099 (0.041)**	1.371 (0.732)*	0.134	0.033 (0.028)	0.033
Perceived returns	0.534 (0.068)***	2.881 (0.480)***	0.411	-0.005 (0.068)	-0.005

Table 4.3 Contd

Variable	Joint Tobit estimates	Double-hurdle estimates			
		Probit		Truncated regression	
	Coefficients (Robust std error)	Coefficients (Robust std. errors)	Average marginal effects	Coefficients (Robust std error)	Average marginal effects
Income	0.364	2.568	0.347	0.035	0.035
	(0.076)***	(0.515)***		(0.044)	
Landsize	-0.005	0.085	0.004	-0.007	-0.007
	(0.001)***	(0.035)**		(0.002)***	
Age	-0.002	0.003	0.002	-0.001	-0.001
	(0.001)*	(0.005)		(0.001)	
Security of tenure	-0.146	-0.545	-0.036	-0.034	-0.034
	(0.091)	(0.431)		(0.074)	
Female headed	0.023	-0.210	-0.011	0.060	0.060
	(0.038)	(0.228)		(0.036)*	
Secondary	0.067	0.572	0.035	-0.011	-0.011
	(0.045)	(0.220)***		(0.037)	
Tertiary	0.041	0.298	0.016	0.002	0.002
	(0.070)	(0.353)		(0.052)	
Forestry skills	0.132	0.580	0.038	-0.002	-0.002
	(0.048)***	(0.185)***		(0.040)	
Experience	0.003	-0.007	-0.000	-0.000	0.000
	(0.001)*	(0.005)		(0.001)	
Extension	0.117	0.526	0.030	0.060	0.060
	(0.043)***	(0.251)**		(0.043)	

Table 4.3 Contd

Variable	Joint Tobit estimates	Double-hurdle estimates			
		Probit		Truncated regression	
	Coefficients (Robust std error)	Coefficients (Robust std. errors)	Average marginal effects	Coefficients (Robust std error)	Average marginal effects
Employment	0.038	0.085	0.004	0.021	0.021
	(0.079)	(0.355)		(0.062)	
Log non-farm	-0.001	0.002	0.001	-0.000	0.000
	(0.006)	(0.026)		(0.005)	
Distance	0.020	0.011	0.000	0.019	0.019
	(0.012)*	(0.021)		(0.012)	
Constant	-0.371	-2.058		0.555	
	(0.145)	(0.575)***		(0.109)***	
Number of observations	839	839		486	
Log likelihood	-351	-76.6		-132	
Chi-square	37.45***				
Wald chi-square		107***		27.93**	
Mean VIF		1.99		1.65	

Note: ***(P-value<0.01); **(P-value<0.05); *(P-value <0.1)

Results from the double-hurdle model (Table 4.3) show that the perceived compatibility of on-farm plantation forestry with agricultural crop production, the perceived returns from farm forestry investments and the perceived ability to provide out of crop season income significantly influenced the probability of adoption but did not influence the intensity decision once the adoption decision had been made. Farmers who rated the perceived compatibility with agricultural crop production, the perceived returns from investment and perceived ability to provide out of crop season income as positive attributes of on-farm plantation, on average, had a higher predicted probability of 0.13, 0.41 and 0.35 respectively, for adopting farm forestry than those who rated them negatively.

The results also indicate that land size, secondary school education, forestry skills training and extension significantly explain the variation in the decision to invest in on-farm plantation forestry. On average, farmers who received forestry skills training and those who had received atleast one extension visit in the last year were 3.8 and 3.0 percentage points respectively, more likely to adopt on-farm plantation forestry than those who did not receive these services. Similarly, farmers with secondary school education were, on average, 3.5 percentage points more likely to adopt than those with primary education.

The results from the truncated regression indicate that landholding and gender of household head influenced the proportion of land allocated to farm forestry. The marginal effects show that for an additional acre of land, the proportion of farm land allocated to farm forestry reduces by 0.007. Female headed households had a higher proportion of farm land allocated to farm forestry by 0.06 compared to male headed households.

The influence of education on adoption has been reported in other study findings. Attaining secondary education may enhance the ability to process technical information about new technologies and thereby facilitate adoption (Freeman & Omiti, 2003; Jagger & Pender, 2003; Adesina, 1996; Adesina *et al.*, 2000).

The household landholding is also an important variable because having adequate land enables the household to diversify its cropping patterns into cash crops such as plantation forestry. Other studies have shown that, household endowments such as land holding are positively related to the probability of adopting new technologies (Doss, 2006; Freeman & Omiti, 2003; Lunduka *et al.*, 2012). This is because adoption of new technologies entails subjective risk, which smallholder farmers may not be willing to undertake since they have fewer resources to fall back on (Doss, 2006; Feder *et al.*, 1985). However, land holding has a negative and significant influence on the intensity of adoption. This implies that the proportion of land allocated to farm forestry decreases with increase in landholding. This is in agreement with the findings of Feder *et al.* (1985), which suggest that land size is negatively correlated with management intensity.

The positive and significant influence of extension services on adoption of farm forestry agrees with findings of earlier studies (Alene *et al.*, 2000; Idrisa *et al.*, 2012; Staal *et al.*, 2002). Access to extension services and formal skills training, provide farmers with information about plantation forestry technologies before they make a decision on adoption (Alene *et al.*, 2000). Public extension service agents, NGO agents and mass media have been the main pathways for introducing on-farm plantation forestry to small-scale farmers in Uganda (NFA, 2010).

The significance of the perception variables indicates that farmers are concerned about the returns, out of crop season income and compatibility of tree farming with agricultural crop production. This suggests that extension service agents should consider these attributes of farm forestry when designing adoption strategies. This also implies that forestry research should focus on enhancing these attributes of farm forestry to increase adoption.

4.4. Comparing the impact of eucalyptus and carbon forestry (Plan Vivo) woodlots on household poverty and food security

The average treatment effect was estimated using propensity score matching (PSM) and endogenous switching regression.

4.4.1. Propensity Score Matching

Probit models were used to estimate the propensity to adopt the different types of on-farm plantation forestry (Table 4.4).

Table 4.4 Probit estimates of the propensity to adopt on-farm plantation forestry enterprises

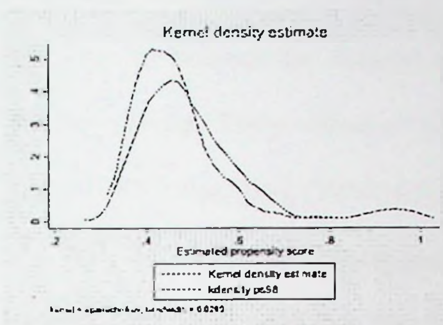
variable	Carbon forestry	Long rotation eucalyptus	Short rotation eucalyptus	All eucalyptus
Age of household head	0.008(0.004)*	0.003(0.003)	0.012(0.025)	-0.002(0.003)
Gender of household head	-0.204(0.126)	-0.14(0.118)	-0.071(0.154)	-0.123(0.108)
Family size	0.045(0.024)*	0.012(0.023)	0.035(0.031)	0.023(0.021)
Education	0.251(0.106)**	0.106(0.103)	0.315(0.128)**	0.189(0.096)*
Land size	0.132(0.024)***	0.044(0.018)**	-0.118(0.095)	0.072(0.018)***
Non-farm income	-1.15e-07(0.00)	-5.6e-08(0.00)	-2.9e-07(0.00)	-0.000(0.00)
Non-farm (sqrt)			0.0001(0.000)	
Age(sqr)			-0.000(0.000)	
Landsize(sqrt)			1.34(0.367)***	
Ageland			-0.0009(0.001)	
constant	-1.45(0.32)	-0.58(0.305)	-3.41(0.732)	-0.588(0.290)
Pseudo R^2	0.114	0.02	0.11	0.039
Model chi-square	87	15.5	56.6	37.6
Log likelihood ratio	-336	-378	-228	-457

Statistical significance at the 99% (***), 95% (**) and 90% (*) confidence levels. Figures in parentheses are standard errors

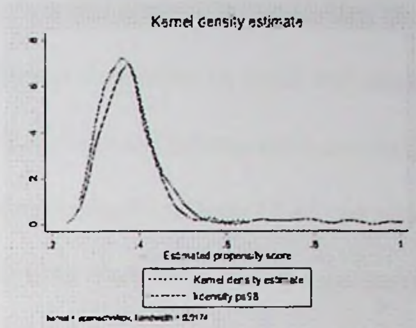
4.4.1.1. Propensity score distribution and common support

A visual inspection of the density distributions (Figure 4.1) of the estimated propensity scores in the four matches indicates that there is considerable overlap in common support. This indicates that the common support condition is satisfied.

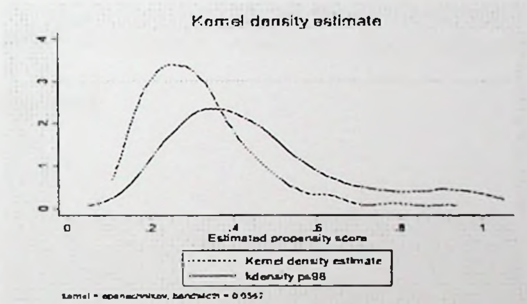
Common support graph for eucalyptus woodlot farmers vs control group



Common support for Long rotation eucalyptus vs control group



Common support graph for carbon forestry vs control group



Common support short rotation eucalyptus vs control group

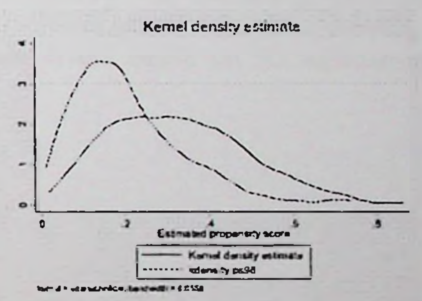


Figure 4.1 Region of common support

4.4.1.2. Balancing test

Table 4.5 presents results of the balancing test for each covariate before and after matching. We used the standardized bias and t-test to check if the matching procedure was able to balance the distribution of the relevant variables in both the control and treatment group. The p-values of t-tests indicated that the covariates were not statistically different after matching (Table 4.5). Similarly, the standardized bias of all covariates was less than 20%. The low mean standardized bias after matching and the insignificant p-values of the t-test indicates that both groups have the same distribution in covariates after matching. These results show that the matching procedure is able to balance the covariates in the treated and control groups. Therefore, all results presented in the following pages are based on specifications that passed the balancing tests and the common support condition. Bootstrapped standard errors based on 50 replications are reported.

Table 4.5 Matching quality indicators before and after matching based on kernel matching

Variable	Carbon forestry			Short rotation eucalyptus			Long rotation eucalyptus			All eucalyptus		
	%bias after	%bias reduction	P>|t|	%bias after	%bias reduction	P>|t|	%bias after	%bias reduction	P>|t|	%bias after	%bias reduction	P>|t|
Age	-1.3	96.2	0.89	-4.1	50.5	0.75	2.1	76.6	0.83	-1.6	81.9	0.84
Education	-3.1	88.1	0.78	0.6	98.2	0.96	4.9	61.4	0.55	0.7	96.5	0.92
Land size	5.1	89.4	0.41	5.1	90.1	0.72	0.1	99.5	0.98	3.1	91.2	0.51
Non-farm income	1.7	-537.4	0.86	-6.7	-113.8	0.54	-0.2	88.6	0.98	-0.7	69.5	0.92
Family size	3.7	90.4	0.71	0.9	95.8	0.94	7.3	46.9	0.46	1.7	89.2	0.83
Gender	9.2	64.7	0.31	4.3	76.6	0.74	-0.9	92	0.92	2.4	82.9	0.76
Nfincomesqrt	Na	na	na	-7.9	-2241	0.56	na	na	na	na	na	na
Agesqr	Na	na	na	-2.3	68.4	0.86	na	na	na	na	na	na
Landsizesqrt	Na	na	na	4.2	97.5	0.94	na	na	na	na	na	na
Ageland	Na	na	na	1.0	97.5	0.94	na	na	na	na	na	na

Note: The Pstest is based on Kernel matching method because it will be the focus of interpreting ATT results. Similar results were obtained from pstests based on radius and nearest neighbor matching.

4.4.1.3. Estimation of average treatment effect on the treated (ATT): matching algorithms

The study assessed the impact of eucalyptus and carbon forestry woodlots on poverty and food security using consumption expenditure per adult equivalent and daily calorie acquisition per adult equivalent (Kcal) as the outcome variables. Table 4.6 reports the average treatment effects using the nearest neighbor, radius and Kernel matching estimators. The three matching estimators were used to check the robustness of the PSM results. However, interpretation of ATT results will be based on the kernel matching estimator.

4.4.1.4. Impact on poverty

The results (Table 4.6) indicate that adoption of eucalyptus woodlots increases consumption expenditure per adult equivalent by US$ 201. This represents an average increase of 32% compared to non-adopters. On the other hand, adoption of carbon forestry (planvivo) had no significant impact on consumption expenditure. Further differential impact analysis of eucalyptus woodlot farming indicated that adoption of long rotation eucalyptus woodlots leads to higher increases in consumption expenditure per adult equivalent (US$ 247) than short rotation eucalyptus (US$ 148). This represents an average increase of 40% and 22% compared to non-adopters, for long rotation eucalyptus and short rotation eucalyptus farmers respectively.

Table 4.6 Average treatment effects for farm forestry participants using PSM

Treatment	Nearest neighbor	Kernel	Radius
Consumption expenditure per adult equivalent (US$)			
Carbon forestry (n=217)	72.5(106)	69(64.9)	84(78)
ALL Eucalyptus woodlots (n= 336)	236(79.8)***	201(51.8)***	238(57)***
Long rotation eucalyptus woodlots (n=219)	317(97)***	247(66)***	248(68)***
Short rotation eucalyptus woodlots (n=117)	132(103)	148(66)**	166(62.5)***
Daily calorie acquisition per adult equivalent (Kcal)			
Carbon forestry (n=217)	469(236)**	421(183)**	390(174)**
ALL Eucalyptus woodlots (n=336)	837(247)***	744(266)***	750(257)***
Long rotation eucalyptus woodlots (n=219)	1052(379)***	1030(361)***	991(357)***
Short rotation eucalyptus woodlots (n=117)	50.6(297)	139(256)	155(191)

Asterisks represent level of significance at the 99% (***), 95% (**) and 90% (*) confidence levels. The number in brackets shows bootstrapped standard errors with 50 replication samples.

4.4.1.5. Impact on food security

The results (Table 4.6) indicate that adoption of eucalyptus woodlot farming provides a bigger increase in daily calorie acquisition per adult equivalent (744 Kcal) than carbon forestry (421 Kcal). This represents an average increase of 22% and 36% compared to non-adopters, for carbon forestry and eucalyptus woodlot farmers respectively.

Differential impact assessment indicated that adoption of long rotation eucalyptus woodlots increases daily calorie acquisition per adult equivalent by 1030 (Kcal) as opposed to short rotation eucalyptus woodlot farming that had positive but insignificant ATT on calorie acquisition.

4.4.1.6. Differential impact of adoption by marginalized groups

We also examined the differential impact of adoption on sub-groups using kernel matching estimator (Table 4.7). As observed in Table 4.7, adoption of eucalyptus woodlot farming by marginalized households including female headed, youth headed and those with small landholding (<= 2.5 acres) increased household welfare ranging from US$ 152 to US$ 292. However, households with larger landholding (>= 2.5) had a bigger increase in welfare (US$ 247.6) than those with smaller landholding (US$ 152).

Table 4.7 Differential impact of adoption by sub-groups on consumption expenditure

Variable	ATT Carbon forestry	ATT All eucalyptus
Landholding(<= 2.5 acre)	76(74.6)	152(64.9)**
Landholding(>= 2.5 acre)	81(78)	247.6(82)***
Female headed households	259.1(105)**	292(108)***
Youth headed households	38(120.8)	154(92.8)*

Statistical significance at the 99% (***), 95% (**) and 90% (*) confidence levels. Figures in parentheses are standard errors

4.4.1.7. Rosenbaum sensitivity analysis

Table 4.8 presents results of the Rosenbaum bounds sensitivity analysis for the PSM results. The Rosenbaum sensitivity analysis is used to assess if our estimates based on matching are robust to the possible presence of hidden bias. The sensitivity of ATT estimates to hidden bias for the three matching estimators was different. ATT estimates from Kernel matching and Radius caliper matching were not robust to hidden bias. The critical values of gamma were 1.1, which implies that the results are insensitive to a bias that would make individuals with the same covariates differ in their odds of adoption by a factor of 10%. This suggests that even a small unobserved difference in a covariate would change our inference. This does not mean that hidden bias exists and that there is no effect of treatment on the outcome variable. This simply means that our estimates based on these matching estimators are not robust to the possible presence of hidden bias. Therefore, we cannot state whether the conditional independence assumption holds.

Table 4.8 Rosenbaum sensitivity analysis

Matching estimator	outcome	Critical level of hidden bias (Γ)			
		Carbon forestry	All Eucalyptus woodlots	Short rotation woodlots	Long rotation woodlots
NNM	Poverty	1.1	1.6	1.4	1.6
	Food security	1.5	1.3	1.2	1.1
KBM	Poverty	1.1	1.1	1.1	1.1
	Food security	1.1	1.1	1.1	1.1
Radius	Poverty	1.1	1.1	1.1	1.1
	Food security	1.1	1.1	1.1	1.1

Note:Gamma (Γ) close to 1 indicates that the impact estimate is highly sensitive to hidden bias while a larger value of Γ indicates less sensitivity of the estimate to hidden bias.

However, the critical values of gamma for estimating the effect of long rotation woodlots on poverty and carbon forestry on food security using the nearest neighbor matching estimator (NNM) are 1.6 and 1.5 respectively. This implies that the ATT estimates from NNM are insensitive to a bias that would make individuals with the same covariates differ in their odds of adoption by a factor of 50–60%. This implies that these two ATT estimates using the NNM are fairly robust to hidden bias. Given that the results from kernel based matching, which is the focus for interpreting our results, are sensitive to hidden bias, we check the robustness of our results by estimating the ATTS using an endogenous switching regression.

4.4.2. Endogenous switching regression results

Estimating the endogenous switching regression model requires that an exclusion restriction be imposed for the model to be identified. This was done by including in the participation equation two variables that influence participation decision but have no effect on the outcome variable (Wooldridge, 2010). Tests of the validity of these instrumental variables indicated that the variables are significant in the participation equation but are insignificant in the outcome equation for non-participants (Di Falco *et al.*, 2013). Results from the endogenous switching regression model showed that the correlation coefficient (ρ) between the respective outcome equations and the selection equations were significantly different from zero thus indicating presence of selection bias.

Results from full information maximum likelihood endogenous switching regressions (Table 4.9) indicate that Plan Vivo carbon forestry and eucalyptus woodlot farming have a significant and positive impact on consumption expenditure per adult equivalent and calorie acquisition per adult equivalent. The average treatment effect on the treated (ATT) on consumption expenditure per adult equivalent for adopters of carbon forestry and eucalyptus woodlots was 24.1% and 28.3% respectively. Similarly, the average treatment effect on the treated (ATT) on calorie acquisition per adult equivalent for adopters of carbon forestry and eucalyptus was 26.9% and 13.1% respectively. Differential impact analysis of short and long rotation woodlots indicated that both categories have a significant and positive impact on consumption expenditure per adult equivalent and calorie acquisition per adult equivalent.

Table 4.9 Summary of ATT from switching regression

Variable	Carbon forestry	Long rotation eucalyptus	short rotation eucalyptus	All eucalyptus
ATT, Log consumption expenditure per adult equivalent	0.241(0.032)***	0.245(0.033)***	0.349(0.043)***	0.283(0.021)***
σ_0	0.65(0.028)	0.632(0.04)	0.644(0.04)	0.635(0.041)
σ_1	0.607(0.05)	0.813(0.053)	0.468(0.04)	0.712(0.038)
ρ_0	-0.512(0.156)**	-0.524(0.179)**	-0.633(0.168)**	-0.507(0.17)**
ρ_1	-0.219(0.139)	0.19(0.214)	0.17(0.409)	0.143(0.208)
ATT, Log caloric acquisition per adult equivalent	0.269(0.022)***	0.079(0.029)***	0.228(0.031)***	0.131(0.028)***
σ_0	0.891(0.12)	0.715(0.048)	0.732(0.046)	0.718(0.052)
σ_1	0.473(0.063)	1.24(0.19)	0.362(0.087)	0.999(0.081)
ρ_0	-0.171(0.087)	-0.308(0.295)	-0.49(0.205)**	-0.319(0.296)
ρ_1	-0.233(0.126)	0.60(0.115)**	0.028(0.307)	0.49(0.10)**

Statistical significance at the 99% (***), 95% (**) and 90% (*) confidence levels. Figures in parentheses are standard errors. ρ_i is the correlation coefficient between the outcome and selection equationsand σ is the standard deviation of the error term of the equation. A statistically significant correlation coefficient implies presence of selection bias.

In conclusion, PSM and switching regression results consistently indicated that overall, adoption of eucalyptus woodlot farming (all eucalyptus) increases consumption expenditure and calorie acquisition per adult equivalent. Differential impact assessment of long and short rotations woodlots indicated that both increase consumption expenditure per adult equivalent for the adopters. The results also consistently indicated that adoption of long rotation eucalyptus woodlots had a positive and significant impact on calorie acquisition per adult equivalent while the impact of short rotations was mixed. Focus group discussions revealed that farmers usually set up eucalyptus woodlots on marginal lands, which have low substitutability for agricultural crop production. In other cases, the farmers had spare land after crop production to use for tree farming.

Further investigation indicated that adoption of carbon forestry increases calorie acquisition per adult equivalent although the impact on consumption expenditure per adult equivalent is mixed. The insignificant increase in consumption expenditure under PSM for adopters of carbon forestry could be due to presence of hidden bias.

The results suggest that overall; adoption of eucalyptus woodlots has potential for poverty alleviation and reducing food insecurity. However, adoption of long rotation eucalyptus woodlots showed more consistency in alleviating food insecurity compared to short rotation woodlots. The study also indicated that adoption of carbon forestry under the plan vivo system increases food security. On the other hand, the study did not provide strong evidence that payments for carbon sequestration through the plan vivo system can alleviate poverty.

These findings are consistent with recent studies on the impact of farm-based plantation forestry on household welfare. Sandewall *et al.* (2010) in Vietnam showed that the adoption of farm-based plantation forestry improved household income and alleviated poverty. Focus group discussions and farm visits indicated that most farmers who participated in the carbon forestry project under the Plan Vivo system, interplant indigenous trees with food crops in an agroforestry system. This may explain the improvement in food security. The important elements of agroforestry systems that have been reported to contribute to food security include changes in the microclimate, protection through provision of permanent cover, reduced soil erosion, improving water use efficiency and contribution to soil fertility improvement (Mulugeta, 2014; Sanchez, 2002; Kwesiga & Chisumpa, 1992). Additionally, TGB project has deliberately included farmers with a minimum land area of 1 ha to ensure that tree farming does not threaten food crop production.

The ability of carbon forestry woodlots under the Plan Vivo system to contribute to poverty alleviation may be constrained by the low carbon credits raised by the farmers. The carbon credits are low because the projects are planting only slow-growing native species. In addition, the price of carbon credits paid to tree farmers is still low.

However, it should be noted that our sample included farmers who had participated in the Plan Vivo carbon forestry scheme for at least 6 years. After 6 years of participation, carbon farmers are expected to have received 90% of the carbon payments. Therefore, our results only provide evidence of the impact of payments for carbon sequestration through the plan vivo system on poverty. Understanding the full potential of carbon forestry woodlots under the plan vivo system will require conducting the impact analysis after 25 years when the farmer have harvested timber, the main benefit from carbon forestry woodlots. Understanding the full potential of adopting the on-farm plantation forestry enterprises will also require measurement and quantifying other effects on soil condition, crop productivity and environmental effects.

Results also indicated that households with larger landholding had a bigger increase in welfare than those with smaller landholdings. This can be explained by information from qualitative interviews, which indicated that households with small land holdings are less likely to adopt on-farm plantation forestry and those that adopt are likely to use a smaller proportion of their land for on-farm plantation forestry. This is because households with small land holding tended to prioritize food crop production before cash crops. Sandwall *et al.* (2010) also indicated that the wealthier farmers tend to invest in long rotation plantation forestry, whilst the poorer farmers tend to invest in short rotation plantation forestry because they require a more continuous cash flow. This may in return lead to differential impacts since long rotation plantation forestry was reported to have greater poverty alleviation potential compared short rotation forestry.

4.5. Benefit incidence analysis of the projects

The poor households were well represented in the FIEFOC and TGB projects in terms of numbers. About 39% of the project participants were poor (Table 4.10), which was above the national average of 24.5% in 2014 (UNHS, 2010). Inspite of the good representation by the poor in terms of numbers, the results (Table 4.10) indicate that the poor gained just 13.7% and 18.1% of the total subsidy in the FIEFOC and TGB projects respectively. This is in contrast to 53% and 36.3% for the richest quantile in the FIEFOC and TGB projects respectively. This implies that the farm forestry subsidies in both projects were not well targeted to the poor in the population. In both cases, the poor gained significantly less than their share in the population (Table 4.10). In the case of the FIEFOC project, the richest quantile (middle class) gained a bigger share of the total subsidy due to the much higher average subsidy received per household (Table 4.10). In other words, the richer households got bigger subsidies. In the TGB project, this was due to the low participation of the poor households in the project. This suggests that the farm forestry projects need to be re-designed to increase targeting of the poor households. Focus group discussions indicated that smallholder farmers preferred trees that can be integrated with agricultural crop production and those with short term benefits because they need a more continuous cash flow.

The distribution of the subsidy in the TGB project was progressive in relation to expenditure. The subsidy received as a share of household expenditure was 23.8% and 8.9% for the poor and middle class respectively. In contrast, the subsidy distribution in the FIEFOC project was regressive. The middle class gained more than the poor in relation to their expenditure.

Although the subsidy per household for female headed households was approximately similar with the male headed households, the male headed households received 65% and 76% of the total subsidy from FIEFOC and TGB projects respectively. However, there is no gender imbalance in the distribution of the subsidies since the share of total subsidies is closely similar to the share of male and female headed households in the population (UNHS, 2010).

Table 4.10 Benefit incidence of farm forestry projects in South Western Uganda

	National income distribution (2014)	FIEFOC PROJECT			TGB PROJECT		
		Per household subsidy(US$)	Share of total subsidy, %	Share of household expenditure, %	Per household subsidy,(US$)	Share of total subsidy, %	Share of household expenditure, %
Population quantile							
Poor	24.5	181	13.7	8.5	410	18.1	23.8
Insecure	42.9	546	33.2	14.4	402	45.4	11.8
Middle class	32.6	928	53	13.1	409	36.3	8.9
Gender							
Male		483	65		404	76.1	
Female		592	34		413	23.8	

4.6. Determining the economic carbon sequestration potential of *Pinus caribaea* and *Eucalyptus grandis* woodlots in Uganda

The results (Figure 4.2) indicate that *P.caribaea and E.grandis* plantations sequestered 418 and 638 (tCO_2e/ha) respectively over a 20 year rotation. The average merchantable wood volume accumulated in *P.caribaea and E.grandis* plantations over the same period was 279 and 448 (m^3/ha) respectively. In this study, the merchantable wood volume refers to tree volume underbark up to 10 cm top diameter, in m^3 ha^{-1} (Alders *et al.*, 2003).

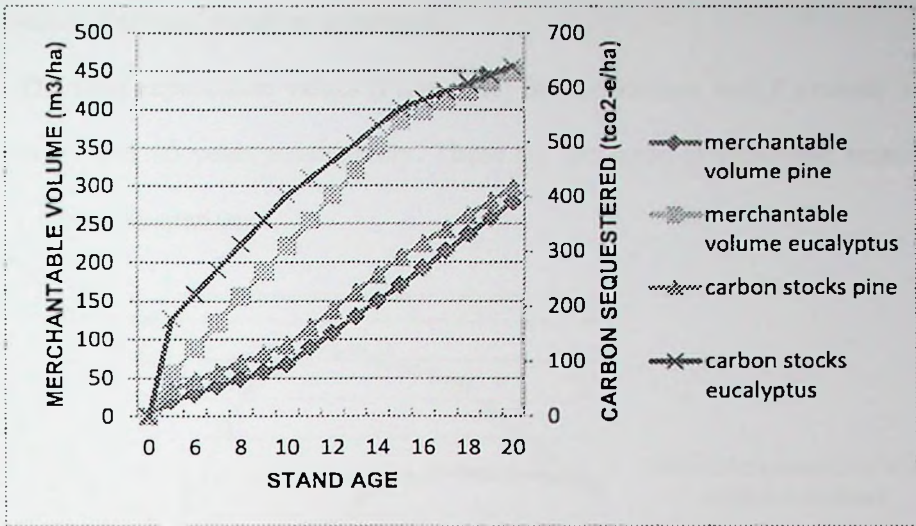


Figure 4.2 Time trajectory of merchantable wood volume (m^3/ha) and carbon stocks in standing tree biomass (tCO_2e/ha) for thinned *P.caribaea* and *E.grandis* plantations

4.6.1. Base-case results under equal rotation assumption

The results indicated that the NPV of *E.grandis* woodlots with CDM carbon credits of US\$2540 ha^{-1} was positive and higher than without carbon credits of US\$1543 ha^{-1}, assuming an equal rotation of 20 years. Similarly, the NPV for *P.caribaea* with carbon credits of US\$1814 ha^{-1} was higher than without carbon credits of US\$1390 ha^{-1}. This implies that it is worth investing in carbon forestry under CDM assuming that woodlots with and without carbon credits have equal rotations of 20 years and given the other base-case assumptions. Under these assumptions, carbon payments under CDM increased NPV of *E.grandis* and *P.caribaea* by 65% and 31% respectively.

4.6.2. Varying rotation approach

The land expectation values (Figure 4.3) for *P.caribaea* and *E.grandis* were maximized at 16 and 10 years respectively. These are the optimal economic rotations for the two types of plantations.

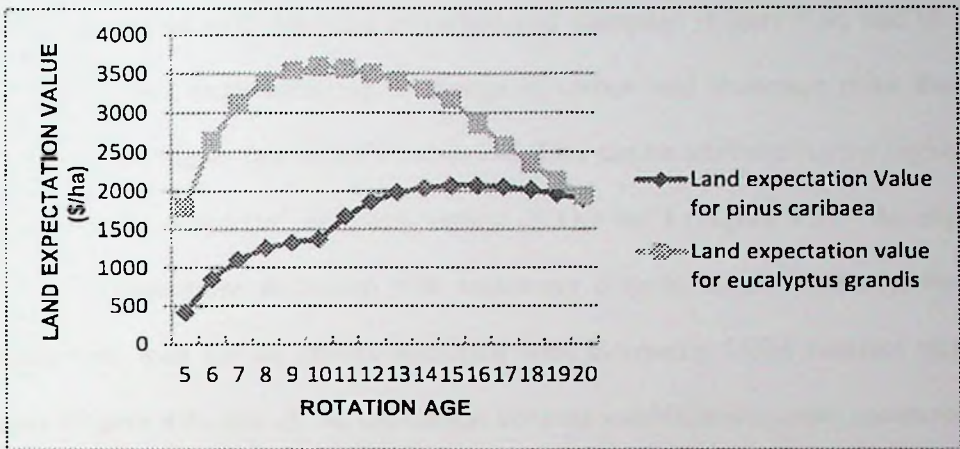


Figure 4.3 Time trajectory of the land expectation value for *P.caribaea* and *E.grandis*

The results indicated that the annual equivalent value (AEV) of *E.grandis* when harvested at its optimal economic rotation of 10 years, without carbon credits, is US\$316 ha^{-1}. This is slightly higher than the AEV of *E.grandis* with carbon credits under base-case assumptions of US\$298 ha^{-1}. This implies that *E.grandis* stand harvested at 10 years rotation without carbon credits is more profitable than one that receives payments for carbon credits under CDM but has to observe the 20 year credit period. In contrast, the AEV of *P.caribaea* with carbon credits under CDM was US\$213 ha^{-1} and higher than US\$169 ha^{-1} for P.caribaea harvested at its optimal economic rotation of 16 years, without carbon credits. These results suggest that *E.grandis* may are not be economically viable for participation in the CDM carbon offset scheme at the current carbon prices. In contrast, it is economically viable to include *P.caribaea* woodlots in CDM, even at the current carbon prices.

4.6.3. Sensitivity analysis under equal rotation assumption

The results of the sensitivity analysis indicated that the NPVs of plantations with carbon credits increased with the price of carbon and stumpage (Figure 4.4d and b). However, eucalyptus was more sensitive to change in carbon and stumpage price than pine, as shown by the higher rate of NPV increment. This can be attributed to the higher stocks of merchantable wood (m^3 ha^{-1}) and carbon (tCO_2e ha^{-1}) (Figure 4.2). As expected, the NPVs of plantations decreased with increasing discount rates. Similarly, the NPVs of plantations with carbon credits decreased with increasing CDM contract establishment costs (Figure 4.4a and c). As the carbon contract establishment costs increased the NPV of woodlots with carbon credits fell below that without carbon credits at US\$500 ha^{-1} and US\$1000 ha^{-1} for *P.caribaea* and *E.grandis* respectively. This suggests that if the average contract establishment costs exceed US\$500 ha^{-1} and US\$1000 ha^{-1} for *P.caribaea* and *E.grandis* plantations respectively, then it is not economically viable for one to participate in CDM forest carbon offsets.

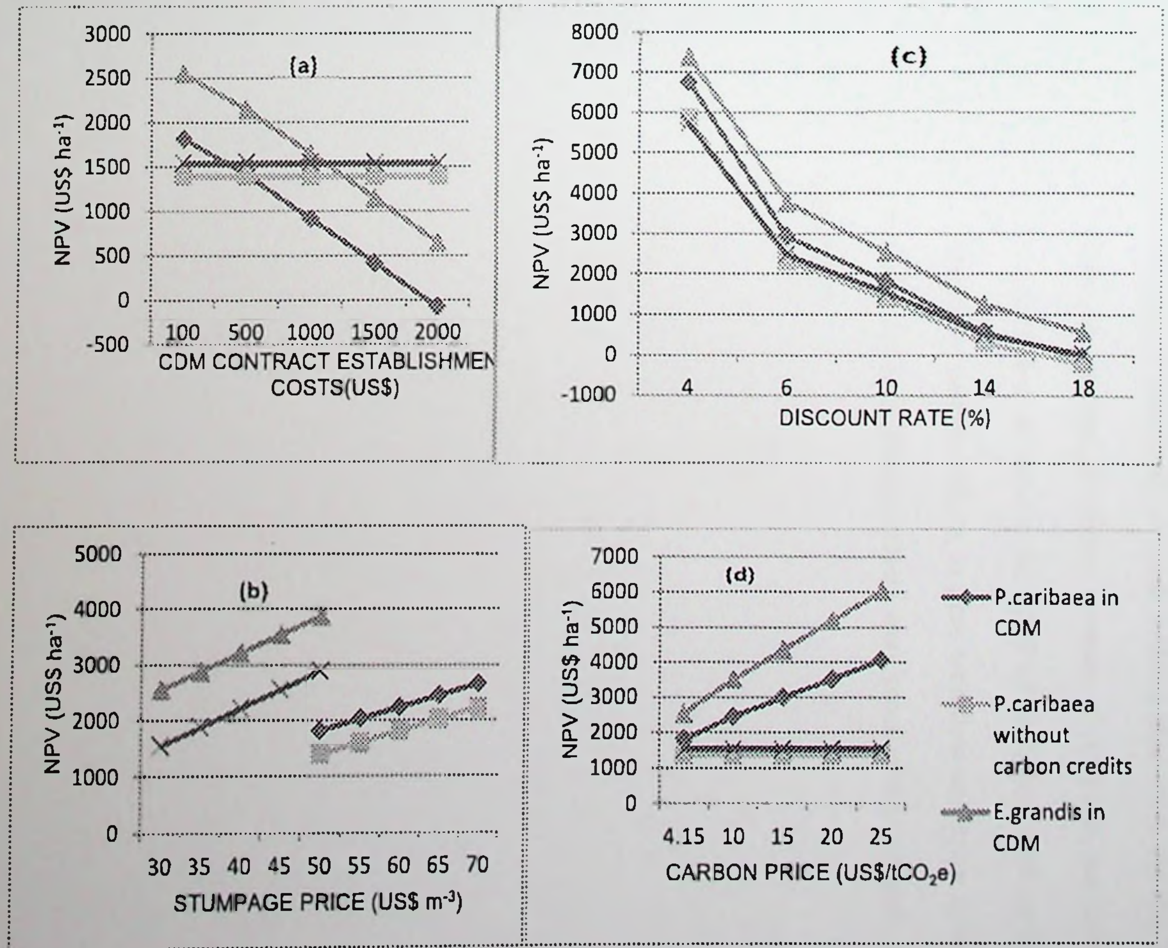


Figure 4.4 Sensitivity of NPV under CDM to contract establishment costs (a), stumpage price (b), discount rate (c) and carbon price

4.6.4. Sensitivity analysis using equivalent annual annuity approach

In general, the AEVs of the plantations increased with stumpage price (Figure 4.5b). However, the AEVs of the shorter rotation plantations increased at a faster rate than the longer rotations. This implies that at high stumpage price of eucalyptus, it would pay to adopt shorter rotations without carbon credits rather than wait for the 20 year crediting period under CDM. In contrast, the faster increase of AEVs in the shorter rotation pine woodlots was not sufficient to exceed the AEV of woodlots with carbon credits in the range tested. Therefore, carbon offsets in pine woodlots are more robust to increase in stumpage price. As expected, carbon offsets were more profitable with increasing carbon prices (Figure 4.5c).

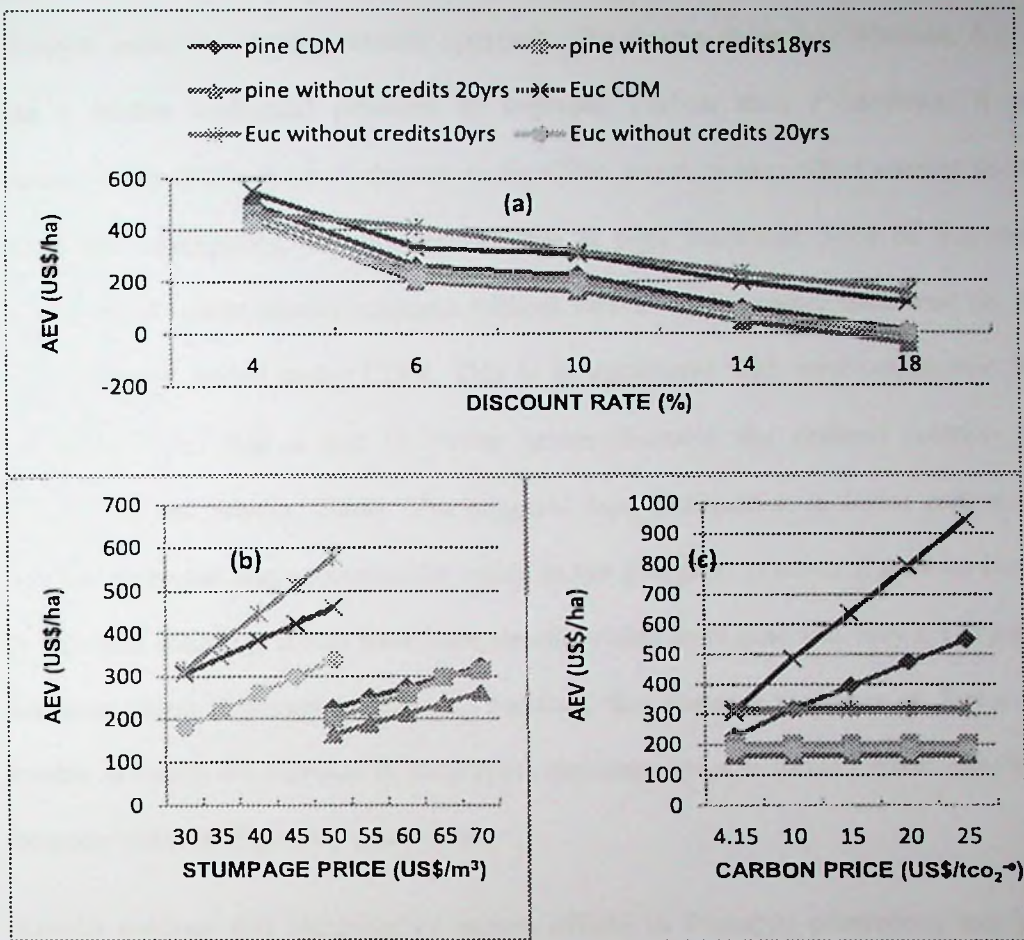


Figure 4.5 Sensitivity analysis using equivalent annual annuity approach, under different rotations

The findings show that *E.grandis* and *P.caribaea* plantations accumulated substantial amounts of carbon over a 20 year rotation. This suggests that the plantation forestry sector has the potential to significantly contribute to carbon sequestration and climate change mitigation. The potential of carbon trade in Uganda's plantation forests has been attributed to the relatively fast tree growth. The results also indicated that it is worth investing in carbon forestry under CDM in the equal rotation scenario. However, this changes under the varying rotation approach. The results show that whereas, *E.grandis* has a higher biological potential to sequester carbon than *P.caribaea,* it is not economically viable for participation in the CDM forest carbon offset scheme under the base-case assumptions. Results indicate that at high stumpage price of *E.grandis*, it would pay to adopt shorter rotations without carbon credits rather than wait for the 20 year crediting period under CDM. This is in agreement with micro-economic theory, which indicates that a rise in timber prices shortens the optimal rotation period (Nicholson and Snyder, 2008). This suggests that participation in forest carbon offsets will become even less economically viable as the stumpage price of *E.grandis* increases. In Uganda, stumpage prices have been steadily rising over time and they are expected to continue rising (Kaboggoza, 2011). Therefore, this requires the price of forest carbon credits to match the increase in eucalyptus stumpage price if forest carbon offsets are to become viable in *E.grandis* plantations.

Results indicate that inclusion of carbon offsets in *Eucalypt* plantations can become viable if the carbon price is raised from the current US$4.15/t$CO_2$e. Therefore, the price of forest carbon should be increased beyond US$4.15/t$CO_2$ein order to make carbon offsets under CDM economically attractive to *Eucalypt* tree farmers. This is justified by the higher potential of eucalypt to sequester carbon thus contributing to mitigation of global warming.

In contrast, it is economically viable to include *P.caribaea* plantations in CDM, even at the current carbon prices. Due to its slower growth rate, the optimal economic rotation of

16 years is close to the 20 year crediting period under CDM. Therefore, sale of carbon credits may be considered an additional benefit to *P.caribaea* plantation owners.

Results show that when the average CDM contract establishment costs exceed US$500 ha^{-1} and US$1000 ha^{-1} for *P.caribaea* and *E.grandis* woodlots respectively, it is not economically viable for one to participate in the CDM forest carbon offsets programme.However, such costs are still unaffordable to the average small scale forest plantation owners and may continue to be a major hindrance to small holder farmer participation in CDM under LULUCF. Therefore, modalities for small-scale AR category need to be simplified further, in order to reduce the transaction costs and promote the participation of small-scale projects in CDM under LULUCF. Because carbon contract establishment costs are fixed, participation in CDM under LULUCF can be made profitable either by having large acreage, such that the average cost per hectare is lowered or by bundling many farmers together to share the costs (Biocarbon Fund, 2011). At the national level, government and NGOs should facilitate the process of bundling tree farmers together in sizable groups in order to reduce costs per project.

The soil carbon stock was not accounted for under the assumptions of this paper because the net change in soil carbon is expected to be positive but small. The consensus is that soil carbon should be measured under LULUCF if a decrease is expected or if the financial benefit exceeds the cost of measuring and certifying the soil carbon (Brown, 2001; Cacho *et al.*, 2003b).

Benefit incidence analysis indicated that the poor households were well represented in the FIEFOC and TGB projects in terms of numbers. Inspite of the good representation by the poor in terms of numbers, the results indicate that the poor gained just 13.7% and 18.1% of the total subsidy in the FIEFOC and TGB projects respectively. Results also indicated that there was no gender imbalance in the distribution of the subsidies since the share of total subsidies is closely similar to the share of male and female headed households in the population.

Assessment of the factors influencing adoption of on-farm plantation forestry was done by comparing results of a joint Tobit and double-hurdle model using a likelihood ratio test. The results of the double-hurdle model indicated that farmers who rated the perceived compatibility with agricultural crop production, the perceived returns from investment and perceived ability to provide out of crop season income as positive attributes of on-farm plantation, on average, had a higher predicted probability of 0.13, 0.14 and 0.35 respectively, for adopting farm forestry than those who rated them negatively.

The results also indicate that land size, secondary school education, forestry skills training and extension significantly explain the variation in the decision to invest in on-farm plantation forestry. On average, farmers who received forestry skills training and extension services were 3.8 and 3.0 percentage points respectively, more likely to adopt on-farm plantation forestry than those who didn't receive these services.

The thesis indicated that on average *E.grandis* and *P.caribaea* woodlots sequestered 638 and 418 (tCO_2e/ha) respectively, over a 20 year rotation. Analysis indicated that whereas

E.grandis has a higher biological potential to sequester carbon than *P.caribaea,* it is not economically viable for participation in the CDM forest carbon offset scheme under the base-case assumptions. In contrast, it is economically viable to include *P.caribaea* woodlots in CDM, even at the current carbon prices.

5.2. Conclusions and Recommendations

The findings of this thesis provide empirical evidence that adoption of on-farm eucalyptus woodlots is an important pathway for smallholder farmers to escape poverty and improve food security. The findings suggest that adoption of long rotation Eucalyptus woodlot farming is more consistent in improving food security than short rotation woodlots. Findings of the thesis indicated that adoption of carbon forestry woodlots under the Plan Vivo system had a positive impact on food security but the impact of carbon payments on poverty was mixed. Given the above evidence, eucalyptus woodlot farming should be promoted as one of the interventions for alleviating poverty and food insecurity in the suitable agro-ecological zones. However, smallholder farmers should be guided to ensure it doesn't compete with food crop production.

Similarly, carbon forestry projects under the Plan Vivo system should be replicated in other areas as one of the avenues for enhancing food security among smallholder farmers. TGB project should liaise with agroforestry organizations such as ICRAF to identify tree-crop-livestock interactions that are suitable for different sites.

The study indicated that farm forestry subsidies in two projects in the study area were not well targeted to the poor in the population. Therefore, farm forestry projects should be re-designed to increase targeting of the poor households. The projects should consider including trees that can be integrated with agricultural crop production and those with short term benefits because they are preferred by smallholder farmers.

Thesis findings indicate that whereas *E.grandis* has a higher biological potential to sequester carbon than *P.caribaea,* it is currently not economically viable for participation in the CDM forest carbon offset scheme. In contrast, it is economically viable for *P.caribaea* plantations to participate in the CDM, if the CDM contract establishment costs are low. First, this implies that eucalyptus woodlot farmers should be advised not to participate in CDM at the current carbon prices. Second, the carbon price under CDM should be increased in order to make it economically viable for participation of fast growing species such as *E.grandis.*

The study findings indicate that the high transaction costs are a major hindrance to smallholder participation in CDM. In order to overcome the obstacle of high transaction costs, Uganda's forest agencies and NGOs in liaison with tree farmer organizations should develop a system of collective contracting. In this system, smallholder tree farmers can join CDM in large groups, thus spreading transaction costs over a large group. Secondly, the A/R CDM modalities should be further simplified in order to lower the transaction costs and allow smallholder participation.

This thesis identifies the factors influencing adoption and intensity of adoption of on-farm plantation forestry. The study confirmed the importance of farmers' access to extension services, landholding, non-farm income, education, forestry skills training and farmers' perceptions in adopting on-farm plantation forestry. This highlights some of the areas that should be considered in developing adoption strategies for on-farm plantation forestry. The study suggests that policy makers need to strengthen the capacity of forestry agencies to deliver extension services and formal forestry skills training in order to improve the adoption rate. The study also highlights the importance of farmers' perceptions in influencing adoption of farm forestry. This suggests that extension service providers should seek and consider farmers' perceptions of farm forestry technologies when developing their adoption strategies.

Second, the paper shows that the double-hurdle model is a better specification of the factors influencing adoption and intensity of adoption of farm forestry technologies than the standard Tobit. This implies that decision on whether to participate in farm forestry and the intensity of participation are made separately. Given that the factors influencing adoption and intensity of farm forestry adoption are different, it is important that both stages are considered in developing adoption strategies for farm forestry.

5.3. Future Research

Understanding the full potential of carbon forestry woodlots under the Plan Vivo system will require conducting the impact analysis after 25 years when the farmer have harvested timber, the main benefit from carbon forestry woodlots. Understanding the full potential of adopting the on-farm plantation forestry enterprises will also require measurement and quantifying other effects on soil condition, crop productivity and environmental effects.

Plantation forests can sequester substantial amounts of carbon in the soil as organic matter. Therefore, future studies of the economic viability of carbon offsets should include the carbon sequestered in the soil.

Currently, it is difficult to get adequate primary data on CDM carbon contract establishment costs and carbon monitoring costs. Future studies should focus on this aspect of carbon forestry in African countries.

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APPENDICES

Appendix 1: Questionnaire for Household Interview

ON-FARM PLANTATION FORESTRY IN UGANDA

Notes to the interviewer:

- This interview is entirely for planning and design purposes. Information gathered will be treated as confidential and will not be used for any purpose other than the aims of this assignment.
- This interview is anticipated to last 40 minutes. Please inform the respondent of this estimated duration before beginning the interview. Try to keep within this limit, but if more time is needed, request for the respondent consent to continue for a few more minutes.
- Nonetheless, try to be patient with the respondents and show appreciation for their time and information at the end of the interview.

SECTION A: Household identification information

Please provide the following information below

I. District	
II. Sub-county	
III. Village	

IV.	Interviewer	
V.	Date of interview	
VI.	Name of respondent	
VII.	Household code	

Section B: Socio-demographic information

B1	Gender of the household head	1=Male 2=Female					
B2	Marital status	1=married; 2=single					
B3	Age of household head	(in complete years)					
B4	Highest education level of household head	1=None or Primary; 2 =Secondary; 3=Tertiary					
B6	Number of people in the household	Males		Females		AGE	

B7	How many people in the household are gainfully employed?						
B8	How many people in the household are involved in agricultural activities?						
B9	What is the total land holding of						

	the household?(acres)		
B10	How much of this landholding is arable?(acres)		
B11	Has anybody in the household received forestry skills training?	1= yes; 2= No	
B12	How long have you practiced agriculture, (years)?		
	Institutional factors		
B13	How many times have you got access to agricultural extension services in the last one year?	1= none; 2 = once; 3 = atleast twice	
B14	What is the tenure of your parcels of land?	01 | 02 | 03 | 04 | 05 | 06 1=freehold; 2=leasehold; 3=mailo; 4=Customary;5=other(specify)	
B15	Do you feel the land tenure is secure?	01 | 02 | 03 | 04 | 05 | 06 1= yes; 2= No	
B16	What is the distance to the main market? (km)		

Section C: Household consumption expenditure and food acquisition (Sections C to F should be answered by household head)

C1) I am going to ask you about the food brought into your home in the last week for your family to eat. This includes foods that you bought with money or collected from your farm or garden. Please tell me about a food even if you haven't eaten it yet.

			C1	**C2**	**C3**	**C4**	**C5**	**C6**
Since last (day of week) did you or anybody in your household acquire any (name of food item)			**How much did you buy?**		**How much money did you**	**How much did you eat from your own production?**		**How much money would you spend if you bought it?**
Item description	**Y 1 N 2**	**Item code**	**quantity**	**Unit**	**(SHS)**	**Quantity**	**UNIT**	**(SHS)**
Food and beverages acquired in last 7 days								
Cereals and grains,								

sugar								
Maize flour		**01**						
rice		**02**						
sorghum		**03**						
millet		**04**						
bread		**05**						
wheat		**06**						
sugar		**07**						
Starchy roots, tubers, nuts, bananas								
Cassava		**09**						
Sweet potatoes		**10**						
Irish potatoes		**11**						
matooke		**12**						
Yams		**13**						
Ground nuts		**14**						
Grain Legumes		**15**						
Beans		**16**						
Cow peas		**17**						
Milk, Meat, poultry and eggs								
Fish		**19**						

Beef		**20**						
Eggs		**21**						
Poultry		**22**						
Other foods								
	23							
	24							
	25							
Fruits and vegetables								
Oranges	**26**							
bananas	**27**							
Others (specify)	**28**							
	29							
	30							
Bevearges								
Beer	**31**							
Soda	**32**							
Other alcoholic drink	**33**							
Expenditure on food consumption outside home in last 7 days								

Unit codes 1=kilograms; 2=gram; 3= litter; 4=packet; 5=loaf; 6= soda bottle; 7=beer bottle; 8= heap; 9=bunch; 10=bucket; 11= sack; others, specify

D) Please provide information about the following frequently purchased goods and services in the last 30 days

	D1	D2	D3	D4	D5	D6	D7	D8
Frequently purchased goods and services in last 30 days			**How much did you buy?**		**How much money did you spend?**	**How much did you obtain from your**		**How much money would you spend if**
Item description	**Y 1 N 2**	**Item code**	**quantity**	**Unit**	**(SHS)**	**Quantity**	**UNIT**	**(SHS)**
Electricity (bill for last month)		01						
Water (bill for last month)		02						
Telephone(airtime)		03						
Medical bills		04						
Taxi fares		05						
Boda boda fares		06						

Petrol/diesel		07						
Clothing		08						
cosmetics		09						
charcoal		10						
fuelwood		11						
kerosene		12						
Rent (home)		13						
Washing soap		14						
Bathing soap		15						
Tooth paste		16						
Other expenses (specify)		17						
		18						
		19						
		20						
		21						
School fees per term		22						
		23						

E. Durable goods

What type of assets do you have? Please tell me their monetary value

	E1	E2	E3	E4	E5
Durable good	Code	Quantity (number)	Purchase price	Year of purchase	Estimated current value
House	01				
Car	02				
Motor cycle	03				
Bicycle	04				
Television	05				
Spray pump	06				
Others (specify)	07				
	08				
	09				
	10				
	11				

Section F: Aggregate agricultural productivity

Please provide information about crops harvested from your land in the last cropping season

	Outputs						
F1	F2	F3	F4	F5	F6	F7	F8
Crop name	Total area of crop planted	Land parcel id	Total crop yield	unit	Crop yield sold	Market price (USh)	Total revenue

G. Please provide information about inputs used in last cropping season

	Inputs		
G1	G2	G3	G4
Input	CODE	Quantity used	Price
Fertilizer		(kg)	
Pesticide			
Certified seed			
Oxen			

Tractor			
Labour from household (number of persons in household participating)			
Others (specify)			

H. Please provide information about livestock holding and sales within the last year

			How many did you sell within last year?			
H1		**H2**	**H3**	**H4**	**H5**	**H6**
Type of	**CODE**	**How**	**Period of sale**	**Quantity**	**Average**	**Total**

livestock reared		many do you have now?	(month/year/season)	sold	unit price	revenue

livestock reared		many do you have now?	(month/year/season)	sold	unit price	revenue

Section J: Non-farm income

J1) Did you generate non-farm income in the last cropping season? 1= Yes, 2= No

J2) If yes, identify the source of the income and the amount in the following table.

	J3	J4	J5	J6
Source of non-farm income	**Code**	**Frequency of income generation (1= daily, 2= weekly, 3=monthly, 4=bi-annual, 5=yearly)**	**Amount generated per period**	**Total amount generated in year**
Daily labour				
Trade				
Salary				
Remittance/gift				
Other (specify)				

SECTION K: Farm forestry enterprise selection

K1) Are you participating in any farm forestry enterprise? 1= yes, 2= No

K2) If yes, please provide the following information about your farm forestry enterprise (s).

Farm forestry enterprise	Land parcel id (01 - 06)	Area planted	In general what is the topography of this parcel 1=hilly;2=flat 3=gentle slope 4=steep slope	What soil quality is this parcel 1=Fertile soils; 2=Fairly productive; 3=Unproductive soils	Perceptions of on-farm plantation forestry attributes (using codes 1-5, yes=1; 0 otherwise) 1=Can be inter-planted with agricultural food crops; 2=Has low labour requirements; 3=Has high Expected returns; 4= Has low initial investment; 5=Time to accrue benefits is not very long; 6= Can provide income during hunger season							
K3	K3i	K4	K5	K6	Codes							
					1	2	3	4	5	6		
2= Short rotation												

Eucalypts												
3= Long rotation eucalyptus												
4= carbon forestry woodlot												
5= carbon agroforestry												
6= other species, specify												

K8) Did you get any assistance in establishing the farm forestry enterprise? 1= yes; 2= No

K9) If yes, what is the type, quantity and source of the aid?

K10	K11	K12	K13
Source of aid; 1= Fiefoc 2= NGO 3= NFA 4= Other,	Type of aid; 1=tree seedlings, 2=land; 3=skills training;	Quantity	Unit price

specify	4=financial subsidy;5= other,specify		

L) Please provide information about outputs from your farm forestry enterprise (s).

Farm forestry enterprise	unit	Amount	Frequency of harvest 1= seasonal 2= specify rotation,……..	Unit price	Average annual income		
L1	L2	L3	L4	L5	L6		
Woodlots							
2= Eucalypts							

3= carbon forestry							

Appendix 2: Biomass Assessment Tool (20x20m plot)

2.3. Name of farmer..

2.3.1. a) Age of plot...................... b) Species........................... c)

Spacing........................

d) Mgt system................................ e) Estimated area of

woodlot..

2.3.2. Tree measurements

Tree no	Dorminant height	Tree Height	Dbh	Crown width
