ECONOMICS OF PAYMENTS FOR ENVIRONMENTAL SERVICES: THREE ESSAYS ON KENYA, TANZANIA, AND MOZAMBIQUE

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ABSTRACT

ECONOMICS OF PAYMENTS FOR ENVIRONMENTAL SERVICES:
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The present study reviews important aspects of payments for environmental services (PES). In particular, it focuses on three important questions around application of the PES approach in developing countries: (i) how to assess the feasibility of PES projects on the ground, (ii) how to estimate payments when markets for environmental services are missing, and (iii) what kinds of local impacts can we realistically expect after PES projects have been functional in the field? These questions are answered through field work on actual PES sites in Kenya, Tanzania, and Mozambique by combining theory from environmental and resource economics, information economics and microeconomics with econometric methods. Research methods include field transects, exploratory interviews, focus groups, household survey, and field experiments in the form of auctions to allocate tree planting contracts. The total sample size of the study is more than 1,000 households in three different countries. The overall study consists of three separate papers, each focusing on a specific question. Together, they present a comprehensive review of PES in developing countries, including its entire project cycle.

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Centre (ICRAF) blossomed, he gave me generous funding to do action research under ICRAF's PES project in Tanzania. Dr. Grace first served as a supervisor for my master's thesis. He was instrumental in introducing me to climate change mitigation work and chose me as the lead researcher to do the impact evaluation of the University of Edinburgh's carbon forestry project in Mozambique.

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PREFACE

Payments for Environmental Services (PES) have become an important area for scholarly work. Under PES, land stewards receive payments for adopting environment friendly practices on their farms. After the failure of top down regulatory approaches in many parts of the world, and the limited impact of both unconditional subsidies for conservation and integrated conservation development project (ICDP) approaches, researchers, policy makers, and field practitioners have started to focus their attention on PES as a way to secure and conserve valuable landscapes. Hundreds of articles have appeared in prestigious journals and several new projects are announced every month. PES has also become the main approach for climate change mitigation and adaptation work on forested lands, with international financial commitments of more than $4 billion to date to help reduce emissions from deforestation and degradation in the tropics.

Amidst all this attention, however, literature on actual experience with PES on the ground remains sketchy. While a good number of studies have started to appear on national level PES programs in countries such as China, Mexico, and Costa Rica, a particular concern in this regard is the relative absence of scholarly work on field experience with small community-based PES projects in other developing countries. Important questions remain unanswered. What is the actual scope of PES on the ground? What payments systems are in place or even how to estimate payment levels that will result in effective provision of an environmental service? How to address information asymmetry between service providers or sellers and people who want to buy these services? Similarly, a lot has been written about the potential of PES approach in reducing poverty among local communities. Again, detailed empirical studies on this subject remain scarce.

The present study attempts to address some of these research gaps. In particular, it focuses on three important questions around application of the PES approach in developing countries: (i) how to assess the feasibility of PES projects on the ground, (ii) how to estimate payments when markets for environmental services are missing, and (iii) what kinds of local impacts can we realistically expect after PES projects have been functional in the field?

These questions are answered through field work on actual PES sites in Kenya, Tanzania, and Mozambique by combining theory from environmental and resource economics, information economics and microeconomics with econometric methods. Research methods included field transects, exploratory interviews, focus groups, household survey, and field experiments in the form of auctions to allocate tree planting contracts. In all, I surveyed more than 1,000 households through three different surveys that I designed and carried out in three different countries. The overall study consists of three separate papers, each focusing on a specific question. Together, the three papers present a comprehensive review of PES in developing countries, including its entire project cycle.

The first paper, "*Exploring demand for forestry in Lake Victoria Basin, Kenya: an econometric approach,*" explores feasibility of the PES approach by estimating the local demand for a tree planting program amongst rural households in western Kenya. It is based on a field survey with 277 households, using a stratified random sampling approach. The study follows an attribute-based method to elicit farmers' preferences. Local demand for tree planting is explored in terms of the number of trees that a household would like to plant under different incentive levels, and the choice of tree species that it makes. The mean willingness to plant new trees per household increases from 44 trees when farmers have to pay 10ksh/seedling, to 244 trees when farmers receive 10ksh/seedling, while a majority of local households prefer at least one timber species amongst the trees they propose to plant. The paper uses fixed effects, random effects and random effects tobit, and random effects logit models to estimate relevant parameters. In addition, the two demand equations are jointly estimated using the seemingly unrelated regression technique. A unique contribution of the study is the combination of conventional literature on determinants of agroforestry adoption in the tropics with PES literature on potential impacts of conditional payments. The study finds that introduction of an incentive of KSH 1 per tree seedling results in an increased demand for 18 seedlings per household. It therefore shows that introduction of economic incentives can create demand for PES activities among local communities in developing countries such as Kenya. It also identifies additional socio-economic variables that affect this demand: availability of timber species (positive effect), gender of the respondent (men likely to plant more trees than women), availability of agricultural labor at the household (positive), and secure title to the land (positive) have a significant effect on mean willingness to plant trees. Furthermore, farmers in the Yala River basin are likely to plant more trees than those in the Nyando River basin with important lessons for the Western Kenya Ecosystem Integrated Project being implemented in the area.

The second paper, "*Estimating 'payment' in payments for environmental services: Results from field auctions in the Uluguru Mountains, Tanzania,*" looks at how to estimate payment level in a PES project that can adequately compensate the opportunity cost of participating farmers. It uses a set of field auctions to estimate an equilibrium price and allocate conservation contracts under a PES project in Tanzania. 251 randomly selected local farmers in the Uluguru Mountains submitted sealed bids for agroforestry contracts requiring them to plant and protect 80 trees of selected species on a 0.5 acre plot in return for an upfront payment. Winning bids were decided using the Vickrey Auction uniform pricing format, with the last rejected bid setting up the equilibrium payment. This ensures incentive compatibility for participating farmers to reveal their estimated opportunity costs in the form of their bids. Results show that bids across the two auction rounds were fairly similar. The mean bid for an agroforestry contract was TSH 143,840 (USD 113.30), while the median bid is TSH 130,000 (USD 102.40). In all, 32 winners received a total of 2,560 tree seedlings to plant on their farms. There is no evidence of collusion or cooperative bidding. Ordered bids can thus be used to estimate a landscape level supply curve. Auction bids and analysis of socio-economic data collected through a household survey show that many poor households are able to participate, but not all.Regression of bids on household demographics revealed that male-headed households, households located in either of the two main villages, smaller households with fewer members, and households with less livestock assets faced higher opportunity costs. The model is also used to predict budget requirements for alternate targeting of PES contracts in the area based on a mix of socio-economic and environmental criteria. The paper thus demonstrates the feasibility of using auctions in developing country setting as one of the ways to estimate payments and allocate PES contracts. However, in contrast to some previous studies, it shows that alternate targeting of contracts, though easy to conceptualize, is difficult to operationalize in the field.

The third paper, "*Reducing poverty through carbon forestry? Exploring impacts of the N'hambita Community Carbon Project in Mozambique,*" uses a mix of household surveys and focus groups to analyze environmental and livelihood impacts of the N'hambita carbon project in Mozambique. The project makes payments for carbon sequestration and avoided deforestation activities, generating 236,513 tCO_2 of carbon offsets. Farmers receive US$433-808/ha over seven years. The project has achieved an impressive diffusion rate with 852 households representing 80% of all households in the area participating in the project. Econometric analysis shows that poor households are able to access the project. In addition, larger households, residents who have been in the area longer, and households with off-farm income are also more likely to participate in the project. A unique contribution of this study is the use of the difference-in-difference method to differentiate the impact of carbon payments from the impact of other development activities introduced by the project in the area. Although there has been a lot of discussion in the environmental literature on potential poverty impacts of PES projects, the paper shows that on their own, conservation payments are not enough to move households out of poverty. Comparison between 2001 and 2008 shows that while carbon payments do supplement incomes, the amount is small. In contrast, households employed in project-related microenterprises are much better off. Further, permanence of carbon sequestration is an issue as payments end after seven years.

By focusing on small community based projects in developing countries, the three papers together add to the current discourse on PES. But they also show that field research is messy and it is difficult to come up with conclusive answers. For instance, it is difficult to say whether or not local farmers in Tanzania understood the auction process or its implications completely, though absence of collusion and presence of normally distributed bids indicate that they did understand the process to a large extent. At the same time, it is difficult to know to what extent the auction findings can guide the design of follow-up PES projects. Similarly, measuring the impacts of carbon payments in Mozambique required the use of several different analytical techniques to try to distinguish between the effects of carbon payments from those of other project activities and from wider scale economic progress in the area. The research neither says that the carbon project is harmful, nor that the project has completely revitalized the local economy. Instead, it offers more subtle and nuanced answers that help in linking PES theory with field application. While payments increase the likelihood of conservation, they alone are unable to move people out of poverty. The study thus points out the limitation of the win-win strategy that has been repeatedly highlighted in the environmental literature.

Such a lack of unambiguous, clear-cut answers is likely to be the norm in research on PES, especially in developing countries, due to the complexity of PES and the methodological challenges associated with the absence of environmental service markets and the confounding effects of other economic activities.

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CHAPTER 1: EXPLORING DEMAND FOR FORESTRY IN LAKE VICTORIA BASIN, KENYA: AN ECONOMETRIC APPROACH

1.1 INTRODUCTION

This paper estimates the impact of economic incentives and farmer characteristics on demand for a forestry program in the Lake Victoria basin in Western Kenya. Demand is quantified as the additional number of trees and the kinds of tree species (exotic or indigenous) that a farmer is willing to plant on her farm, while economic incentives are explored in terms of a hypothetical subsidy that farmers would receive for planting each additional tree. The results presented in the paper are based on a survey with local households in the Yala and Nyando river basins, which contribute a significant proportion of water flow into Lake Victoria.
It was conducted under the Western Kenya Integrated Ecosystem Management (WKIEM) project, funded by the Global Environment Facility, which aims to conserve these river basins through forestry activities with local farmers.

Sediment flow into Lake Victoria due to large scale soil erosion in its catchment is a major concern for ecologists and environmentalists. Recent studies uniformly indicate the occurrence of severe land degradation in important catchment areas such as the Nyando River basin, which contributes to the growing silt inflow into Lake Victoria. Land degradation of this magnitude has significant negative impacts on soil fertility and water quality in the surrounding area, resulting in rapid colonization of the lake by water hyacinth and decreased fish and aquatic plant diversity. The economic impact includes reduced fish catch from the lake and escalation in maintenance costs for operating hydroelectric turbines in Uganda downstream from the lake (ICRAF and KARI, 2004). Consequently, initiatives such as the WKIEM project focus on reducing silt inflow into the lake by taking up afforestation and reforestation activities in the upper catchment areas. The present study originated from the need to estimate the feasibility of such a forestry program in the area. It had two main objectives: (i) to prepare a socio-economic baseline of the area, and (ii) to assess the feasibility of a forestry program in the area by estimating the effects of economic incentives and relevant demographic characteristics of farmers on their willingness to plant new trees on their farms. It was conducted in collaboration with the World Agroforestry Center (ICRAF), one of the implementing organizations for the WKIEM project.

The study builds on existing research pertaining to adoption of agroforestry and farm forestry by smallholders in developing countries. These research studies usually analyze whether or not a household will adopt agroforestry practices and factors that determine this choice (Mercer, 2004). For instance, Nkamleu and Manyong (2005) look at socio-economic factors that affect adoption of agroforestry practices in Cameroon. They find that men are more likely to adopt new agroforestry practices such as live fencing. Other significant factors include family size (positive impact on adoption), security of land tenure (positive), and agroecological zone (probability of adoption being low in forest margins). Similarly, Franzel (1999) point out a strong association between wealth and adoption of agricultural fallows across Kenya and Zambia. Other important factors included in this paper are gender of the farmer and significance of off-farm income for the family. Marenya and Barrett (2007) use panel data to show that resources available with a household (farm size, livestock, off-farm income, and family labor supply) had a significant effect on likelihood of improved soil fertility management practices in Kenya.

A valuable contribution to this literature is by Pattanayak et al. (2003), who reviewed 120 papers on adoption of agricultural and forestry technology by smallholders. They report five categories of factors that are most significant – preferences, resource endowments, market incentives, biophysical characteristics, and risk and uncertainty. The authors find that although market incentives are important, only a handful of studies consider all of these factors. Furthermore, only nine percent of the studies analyzed the explicit impact of prices on adoption rates.

This gap in the literature on the potential role of economic incentives in forestry adoption assumes significance amidst the recent emergence of payments for environmental services (PES). PES pertains to a system of payments or other economic rewards to land stewards in return for providing valuable environmental services such as carbon sequestration and watershed conservation (Wunder, 2005). In Africa such payments have been used to encourage farmers to invest in farm forestry and in protection of existing forests (Jindal *et al.*, 2008). However, an objective estimate of the impact of such payments on actual adoption rates in the field or on demand from farmers for new forestry practices is still unknown in most cases. Therefore, a study on the effect of direct economic incentives on farmers' willingness to adopt new forestry practices can tie these two different strands of research together. The present paper makes an attempt in this direction by exploring the impact of prices of tree seedlings on farmers' willingness to plant additional trees on their farms. Using this strategy, the paper is able to show a direct relationship between environmental payments (in the form of a per seedling subsidy) and the supply of conservation (in the form of additional trees that can be planted) in the Lake Victoria basin. The paper also looks at the differential impacts of relevant socio-economic characteristics. The methodology adopted is based on attribute-based survey methods.

1.2. CHOICE OF SURVEY METHODS

Since the objective of this study was to assess farmers' preferences regarding ex ante adoption of new agroforestry practices (say in terms of additional trees to be planted), it could typically take two forms, i.e. either a contingent valuation type study or an attribute based study. Contingent Valuation Method (CVM) is a survey-based methodology for eliciting values people place on goods, services and amenities (Boyle, 2003). In a CVM survey, respondents are asked to state their willingness to pay (WTP) for a good, or their willingness to accept (WTA) compensation to voluntarily give up a good. Both of these are Hicksian consumer surplus measures and the specific context determines which one is used – WTP is used if the respondent does not have the property right over the good in the status quo while WTA is used if the respondent has a legal entitlement over the good and is being asked to give up that entitlement (Carson, 2000). For the present purpose, the study could ask farmers either their minimum WTA to plant more trees on their farm (by giving up the option to other crops) or their maximum WTP for an upstream afforestation project that reduces soil erosion downstream. However, such a study would need to pre-determine the level of the desired environmental service, say the specific number of trees to be planted, while farmers state their WTA (or WTP) for this service. If, on the other hand, the objective is to assess the intensity of environmental service that different farmers are willing to provide, then an attribute based method (ABM) is more appropriate.

The objective of an ABM type study is to estimate respondents' preferences for a divisible set of attributes of an environmental good (Holmes and Adamowicz, 2003). Respondents can be asked to choose between two versions of an environmental program that differ by attribute levels. Including price as a variable can then help in estimating the economic value of these attributes. For instance, potential participants of a forestry program can be asked to choose between either planting additional timber trees or fruit trees on their farms, with the program assistance varying depending on which tree species is selected. This will help in determining different levels of environmental service that can be available as well as the total program cost for each of these levels.

The present study therefore incorporated a variant of the ABM to assess the feasibility of a forestry program in Lake Victoria basin by estimating demand for the number of tree seedlings and the kinds of tree seedlings at different price schedules. Farmers were asked to elicit the kinds of tree species and the number of additional trees they would be willing to plant under three different scenarios, one where they would receive free seedlings, a second where they would have to pay KSH 10 (Kenyan Shillings)[1] per seedling, and a third where they would receive KSH 10 per seedling. There were thus three observations per respondent, although in each case the farmer would receive the seedling, and only the net price would vary.

One of the important requirements for a stated preference study is to make the scenario realistic for the respondent by clearly specifying the good and reminding her that participation in providing the good is voluntary (Carson *et al.*, 2001). The present study incorporated this feature by presenting realistic price schedules and by reminding respondents that they could decline to plant more trees. Furthermore, respondents were told that payments would only be made six months after the seedlings were planted and on the basis of the actual number of surviving seedlings. Another requirement is to include relevant demographic characteristics of the respondents (Carson, 2000). For the present study, the list of relevant socio-economic variables was adopted from characteristics that have been found to be significant by previous agroforestry

[1] The exchange rate at the time of the study was USD 1 = KSH 75.

studies: gender, age, and marital status of the respondent, total farm land available with the household, ownership status (whether or not household has secure title), percent land area under food crops, annual expenditure of the household in the previous year (as a proxy for the annual income), total livestock[2] owned by the household, kind of roof on the dwelling, total agricultural labor[3] available at the household, if the household had a member with a permanent job outside the farm, and the geographical location of the farm (see table 1.1). The study estimates a set of two demand equations:

$$Y_i^1 = f(P, Z_i, H_i) \quad \text{------------------------------------} \quad (1)$$

$$Y_i^2 = g(P, Z_i, H_i) \quad \text{------------------------------------} \quad (2)$$

Where the number of tree seedlings 'Y_i^1' and the kinds of tree seedlings 'Y_i^2' that a household 'i' demands is a function of price of seedlings 'P', respective household characteristics 'Z_i' and farm characteristics 'H_i'.

The two demand equations were estimated on with data from a survey of 277 households, conducted from June to August 2005 in western Kenya[4]. These households were selected with stratified random sampling. The survey was conducted in the Nyando and Yala river basins

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2 Since the primary purpose was to see if this variable was significant in explaining demand for forestry, instead of calculating total livestock units, the study summed up the number of large animals (cows, bulls, sheep, and goats) for each household.

3 Again, the study used a simple approach of summing up the total number of adults (>16 years) at the household and applying the following weights for individual members: 0 = no involvement on family farm, ½ = part-time involvement, and 1 = full-time involvement on family farm.

4 In all the survey covered 313 households. However, 36 observations had to be discarded due to missing values and incorrect entries in the database. There is a slight probability that this elimination could be biased against women headed households who could not respond to all the questions. Alternatives such as assuming mean values for missing observations or analyzing an unbalanced data set were not employed however.

where particular sub-locations were selected as the first level of stratification. The target population for this survey therefore comprised all the inhabitants of the two river basins. For each sub-location, we selected the farthest point from the main road that was accessible by car and starting from this point, three researchers then went in opposing directions to interview the first five households in each direction.

Respondents were usually the senior most male or female available in a house. Interviews were conducted as per a survey instrument that was administered to all respondents. The survey questionnaire was pre-tested and modified several times to make it realistic and culturally appropriate for the local population. The data were analyzed using STATA software.

1.3. BRIEF DESCRIPTION OF THE DATA

Out of the 277 respondents included in this study, 44.8 percent were male, 69.7 percent were married, while 28.2 percent were either widowed or separated. The average age of the respondent was 46.4 years (see table 1.1). Most farmers were smallholders with 4.9 acres average land ownership per household, 53.1 percent of which was under food crops in the year before the survey. Only 38.9 percent of the households had at least one secure land title for different pieces of land they farmed on. The average labor availability per household for farm work was 3.6 units. The average annual expenditure per household was KSH 45,314 in the previous year with 76.5 percent of the families living in dwellings with metal roofs. Only one fourth (25.9 percent) of families had at least one member with a permanent job outside the family farm. The respondents were about equally distributed across the two geographical strata with 56.9 percent of respondents located in Nyando River basin.

Since each respondent was offered three price schedules, she decides about the specific mix of tree species in each case and the number of seedlings she wanted to plant. Table 1.2

shows the mean response under each scenario: when the farmer buys seedlings at KSH 10/seedling, when the farmer is offered free seedlings, and when the farmer is paid KSH 10/seedling for planting and protecting additional trees.

If the farmers have to buy seedlings, they are willing to plant an average of 44 seedlings per household. Demand per household increases to 203 seedlings if farmers receive free seedlings and further to 245 seedlings per household if they receive a direct economic incentive to plant additional trees (please see figure 1.1). 62.1 percent of the households prefer to plant at least one timber tree species when they have to buy seedlings, increasing to 86.2 percent when seedlings are available for free. Interestingly, the trend is non-monotonic as the willingness to plant timber species reduces slightly to 82.3 percent when farmers receive economic incentives to plant new trees along with free seedlings (table 1.2). It is also important to note that most timber species listed by the respondents such as *Eucalyptus*, *Casuarina equisetifolia*, and *Gravellia pteridifolia* are fast growing trees that are exotic to the area.

1.4. ECONOMETRIC ANALYSIS

We estimate the two demand equations (1) and (2) through three different procedures in order to utilize the panel nature of our data (there are three observations per respondent for each of the two demand equations). First, the two demand equations are estimated separately using relevant panel data (fixed effects, random effects) methods. This is followed by joint estimation of the two demand equations using the Seemingly Unrelated Regression (SUR) method. Finally, we estimate the marginal effect of tree species on the number of trees that a household would like to plant by combining the two equations into one. While the specifics of each method are discussed separately, in general, each of them produces an identifiable model since our main explanatory variable – price of tree seedlings – is introduced exogenously.

1.4a. Panel data model to estimate demand equations

In order to estimate the marginal effect of the price of the tree seedlings, the two demand equations can be rewritten as:

$$\text{Log}\,(Y_{it}) = \alpha_1 P_{it} + \alpha_2 Z_i + \alpha_3 H_i + C_i + E_{it} \quad \text{-----------------------} \quad (3)$$

$$W_{it} = \beta_1 P_{it} + \beta_2 Z_i + \beta_3 H_i + D_i + U_{it} \quad \text{-----------------------} \quad (4$$

i = 1,2,3,…..277

t = The three prices offered to each respondent, i.e. -10, 0, +10.

Y_{it} = Number of trees farmer '*i*' is willing to plant at price '*t*'

W_{it} = Choice of tree species farmer '*i*' makes at price '*t*'

= { 1 if farmer selects at least one timber tree species
0 if farmer doesn't select any timber tree species

P_{it} = Price for individual '*i*'. It takes three values for each respondent: 0 (respondent gets free seedlings), -10 (respondent needs to pay KSH 10/seedling), and +10 (respondent gets paid KSH10/seedling for planting trees)

α, β = Respective slope parameters for the two equations

Z_i = Observable demographic characteristics for individual '*i*'.

These include age, gender, marital status of the respondent. Also included are household characteristics such as farm land, labor availability, and annual expenditure.

H_i = Observable farm level characteristics for respondent 'i', such as location of the farm and if the household own the title to this farm.

C_i , D_i = Respective unobservable characteristics for individual 'i' in the two equations

E_{it}, U_{it} = Respective error terms in the two equations

Both equations (3) and (4) represent panel data model with three observations per individual farmer corresponding to three price schedules. In this model, the within farmer variation is provided by price 't', while between farmer variation is provided by demographic characteristics 'Z_i' and farm level characteristics 'H_i'.

We estimate equation (3) by fixed effects (FE) and random effects (RE) panel models. As discussed above, both fixed effects and random effects models will produce consistent estimates since our key panel variable, 'price' is introduced exogenously (i.e. it is uncorrelated with the unobserved heterogeneity C_i *or* D_i). In section 4c below, when one of the panel variables is likely to be correlated with the unobserved heterogeneity, we discuss the criteria for selecting between the two models. Finally, to account for left censoring of the dependent variable in equation 3 {log (Y_{it}) or log (number of trees)} at zero (10 percent or 83 observations), we also use random effects tobit (RE tobit) to estimate the relevant parameters. The results are reported in table 1.3. Most variables are of the same sign and within the same range across the three models, which indicates the robustness of these estimates.

Columns 2, 3, and 4 in table 1.3 indicate that apart from price, the other significant explanatory variables include the gender of the respondent, the age of the respondent, labor availability at the household level, and whether or not the household has a formal title to its farm.

Since the coefficients are virtually the same, we report estimates from the random effects model (column 3) in the following discussion. As suggested by Pattanayak *et al.* (2003), the economic incentive on seedlings has a strong positive effect on willingness to plant trees. Each KSH 1 incentive per seedling increases the mean willingness to plant trees by 11 percent (coeff. -0.11 on price) i.e. by 18 trees (each percentage change is equal to 1.6 trees). This makes sense in a developing country such as Kenya where access to seedlings or germplasm is an important determinant of success of an agroforestry program and where farmers may not have the required financial resources to bear the upfront costs of buying these seedlings (Roshetko *et al*., 2007a). Similar to Marenya and Barrett (2007), gender has a strong effect on willingness to plant trees. *Ceteris paribus*, each male is willing to plant almost 100 more trees more than a female (coeff. 0.66). Family labor supply also has a positive effect, with the presence of each additional member with full time involvement in agriculture resulting in an average increase in 21 trees that the household would like to plant (coeff. 0.13). Interestingly, older respondents are less likely to plant trees than their younger counterparts, though the effect is small (coeff. -0.02). As suggested by Roshetko *et al*. (2007b), we also find that secure tenure to farmland has a huge positive effect and increases the mean willingness to plant trees by 30 percent or almost 50 trees (coeff. 0.30). With a formal land title, farmers perhaps feel more secure in planting high value and long gestation tree crops, although this result is in contrast to Nkamleu and Manyong (2005), who found that farmers in Cameroon were more likely to invest in live fencing through trees as a way to strengthen their claims over land for which they did not own a formal title. Further, the wealth status of the household as reflected by the total expenditure in the previous year is only significant at 88 percent. However, as expected, the sign is positive, which shows that better off households are more likely to plant trees. However, many of the other variables such as access to off-farm income (permanent employment outside the farm), farm area, and location of the farm are insignificant at the usual confidence intervals.

In order to identify the marginal effects of various explanatory variables on the choice of tree species (equation 4), we again use fixed effects and random effects models. Since the dependent variable is binary (1 = respondent selects at least one timber species), we also use random effects logit (RE logit)[5] to estimate the demand parameters (table 1.4). As in the previous case, the estimates from the three models (columns 2, 3, and 4) are similar in magnitude and have the same signs. Since the same variables are significant across both random effects and random effects logit models, for ease of interpretation we use results from the random effects model (column 3, table 1.4) in the following analysis.

The three variables that have a significant effect on choice of tree species include price along with the respondent's age and gender. Surprisingly, none of the other household or farm level variables is significant. As expected, price of tree seedlings influences choice of tree species, though the effect is small; each incentive of KSH 10 per seedling increases the probability of selecting at least one timber species by 0.1 percent (coeff. -0.01 on price). On the other hand, older people are less likely to select timber trees, although the marginal effect is quite small (coeff. -0.002). The strongest determinant of choice of tree species is the gender of the respondent, with males much more likely to prefer timber trees than females (coeff. 0.09). We think that this is due to existing customs amongst local communities in western Kenya, which dictate that women are not allowed to plant trees, especially timber species on family farms (Fortmann, 1985). Since women can only plant a restricted list of species, the effect shows up in

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[5] The RE logit model can be written as: $log(Pr_{it}/1\text{-}Pr_{it}) = \beta_1 P_{it} + \beta_2 Z_i + \beta_3 H_i + D_i + U_{it}$ where Probability '*Pr*' = 1 denotes the probability that individual '*i*' selects at least one timber tree species at price '*t*'. The right hand side of the model is as before in equation (4).

their reduced preference for timber trees and as we observed above, even for the number of trees that they would like to plant.

1.4b. Seemingly Unrelated Regression (SUR) to jointly estimate demand equations

An important aspect of the two demand equations (3) and (4) is that they refer to the same individual '*i*'. Therefore, we expect that even after accounting for various explanatory variables, the combined residual from equation (3) i.e. $(\hat{c}_i + \hat{e}_{it})$ will be correlated with the same from equation (4), i.e. $(\hat{d}_i + \hat{u}_{it})$. Indeed, we find that:

$$\rho\{(\hat{c}_i + \hat{e}_{it}), (\hat{d}_i + \hat{u}_{it})\} = 0.4107 \qquad \text{-----------------------------} \ (5)$$

Equation (5) indicates that there is medium to strong positive correlation between the two combined residuals. This does not, however, affect the consistency of our previous results, since as we noted earlier, the main explanatory variable, 'price' is introduced exogenously in both equations. However, we can exploit this result to improve the efficiency of our model by jointly estimating the two demand equations through Seemingly Unrelated Regression (SUR) (Zellner, 1962). Wan *et al.* (1992) follow this approach to estimate a set of production functions. According to SUR, we can combine the two sets of demand equations (3) and (4), and rewrite them as follows:

$$Y_{git} = \beta_{g1}P_{git} + \beta_{g2} Z_{gi} + \beta_{g3} H_{gi} + \mu_{git} \quad \text{-----------------------} \ (6)$$

g = number of equations, i.e. $g = 1, 2$

= { 1 denotes that dependent variable is log (number of trees)
    2 denotes dependent variable is respondent's preference for timber species

i = 1,2,3,…..277, as before

t = The three prices offered to each respondent, i.e. -10, 0, +10, as before

P_{it} = Price for individual '*i*' as before.

β_g = Respective slope parameters for equation '*g*'

Z_{gi} = Observable demographic characteristics for individual '*i*' in equation '*g*'

H_{gi} = Observable farm level characteristics for respondent '*i*' in equation '*g*'

C_i , D_i = Respective unobservable characteristics for individual '*i*' in the two equations

μ_{git} = Respective error terms in equation '*g*' for each panel variable '*t*'

Equation (6) represents a set of six equations for each individual '*i*': combination of two demand equations ($g = 1, 2$), each of which in turn contains three panel equations ($t = -10, 0, +10$). In order to estimate these six equations jointly, we use the method suggested by Biørn (2004), which has been programmed into STATA command '*xtsur*' by Nguyen (2008). The estimation results are reported in table 1.5.

Comparison of results from table 1.5 with those from tables 1.3 and 1.4 show that although most variables retain their coefficients as before, we gain on precision. However, there are also some important variations. Table 1.5 shows that price, gender of the respondent, household labor availability, economic well-being of the household (log of expenditure in the previous year), size of land holding (square root of farmland), and possession of secure title to farmland are all significant in explaining the demand for tree seedlings. As before incentive per seedling has a positive effect on willingness to plant (coeff. -0.11 on price). Similarly, demand for trees is much higher amongst males than females, and the coefficient value (0.71) is slightly more than what we observed in table 1.3. Secure title has a positive effect on willingness to plant as before (0.3), as is the effect of higher labor supply at the household level (0.14). There are two additional variables that are now significant at 5%, log of annual expenditure (as a measure of the household's economic well being) has a positive effect to demand for trees. Increase in expenditure by KSH 1 has an associated elasticity of 0.23 percent (coeff. 0.23). The size of landholding also has a positive effect (coeff. 0.24), which is in line with the finding of Marenya and Barrett (2007) in terms of factors that result in higher propensity of agroforestry adoption. More farm size provides flexibility to the household to divert land from food crops to more permanent tree crops.

Variables that affect choice of tree species now include price of seedlings, age and gender of the respondent, socio-economic status of the household (as indicated by whether or not the household dwelling has a metal roof), land holding, secure tenure to farmland, labor supply, and location of the household's farm (table 1.5). As before, incentive per seedling has a positive effect on probability to select at least one timber species (coeff. -0.01 on price). Similarly, males are more likely to pick at least one timber species, though the magnitude of the effect is now larger (0.12). On the other hand, increasing age has a small positive effect on likelihood of selecting timber trees (0.005) as compared to the earlier case when age had a small negative effect on selecting timber trees (table 1.4). Also, the sign on age is now reversed between the demand for trees (-0.002) and preference for timber trees (0.005). This indicates that older farmers prefer to plant slightly fewer trees, but they have a higher preference for timber trees.

The same is also observed for location of the farm in either of the two watersheds Nyando or Yala. Location of a farm in Nyando is associated with a strong preference for timber trees (0.12), although it is also associated with a lower mean willingness to plant trees than in Yala (coeff. of -0.11 in table 1.5 when the dependent variable is log of the number of trees that a household demands). Field transects indicate that Nyando is drier and more erosion prone than

Yala. This implies that a higher proportion of farmland in Nyando is marginal and we believe that farmers in Nyando therefore have less flexibility in terms of the area they can divert to trees. However, they would still like to receive quick returns from this land by selecting timber trees that mostly include fast growing exotics such as *Eucalyptus*. Higher labor availability (0.03), more land holding (coeff on square root of land holding is 0.07), and secure tenure (0.07) all have a positive effect on preference for at least one timber species. Similarly, the socio-economic status of the household, as indicated by the presence of a metal roof on the main dwelling, also results in positive demand for timber trees (0.14). These factors indicate that availability of more resources for a household translates into higher demand for timber trees.

1.4c. Trade-off between demand for trees and timber species

In the previous discussion, we looked at the marginal effects of various explanatory variables on demand for trees and on demand for timber species. In section (4a), we estimated the two demand equations separately, while in section (4b), we estimated them jointly, though still as a system of two independent equations. However, in order to estimate the marginal effect of preference for timber species on demand for the number of trees, or to estimate the trade-off between the two variables, we need to combine them into a single equation as follows:

$$\text{Log}\,(Y_{it}) = \beta_1 W_{it} + \beta_2 P_{it} + \beta_3 Z_i + \beta_4 H_i + C_i + \mu_{it} \quad \text{-----------------------} \quad (8)$$

i = 1,2,3,…..277, as before

t = The three prices offered to each respondent, i.e. -10, 0, +10, as before

Y_{it} = Number of trees farmer '*i*' is willing to plant at price '*t*', as before

W_{it} = Choice of tree species farmer '*i*' makes at price '*t*', as before

= { 1 if farmer selects at least one timber tree species

0 if farmer doesn't select any timber tree species

P_{it} = Price for individual '*i*' as before.

β = Respective slope parameters

Z_i = Observable demographic characteristics for individual '*i*', as before

H_i = Observable farm level characteristics for respondent '*i*', as before

C_i = Unobserved heterogeneity for individual '*i*', as before

μ_{it} = Error term, as before

The main difference between equation (8) and the previous equations is that preference for timber trees (W_{it}) is now added on the right hand side as one of the explanatory variables. Since both *Log* (Y_{it}) and (W_{it}) are jointly determined by the same household 'i', this may perhaps lead to the notion that equation (8) suffers from simultaneity issues and is therefore unidentified. However, as Wooldridge (2002b, page 529) explains, the two variables are not simultaneously determined through a market equilibrium as is the case of typical demand and supply equations. Although equation (8) can again be estimated by both fixed effects (FE) and random effects (RE) methods, a crucial assumption for RE estimates to be valid is (Wooldridge, 2002a):

$$Covariance\ (W_{it},\ C_i) = 0 \qquad \text{------------------------------------} \quad (9)$$

Table 1.6 reports the respective FE and RE parameters for equation (8). However, the subsequent Hausman specification test (Hausman, 1978) is significant at 1% (table 1.7) which means that the assumption in equation (9) is invalid and there exists correlation between choice of tree species (W_{it}) and the individual specific heterogeneity (C_i) in the right hand side of equation (8). Hence, we can only consider the FE estimates as consistent:

$$Log(number\ of\ trees\ demanded) = 1.87^{*} \quad - 0.09\ price^{*} + 2.2\ species^{*} \quad \text{--------} \ (10)$$
$$(0.108) \quad (0.005) \quad (0.133)$$

*Overall R-sq = 0.3682   No. of observations = 822   No. of groups = 274   * Significant at 1%.*

Equation (10) indicates that selection of timber species is associated with more demand for number of trees. *Ceteris paribus*, selection of at least one timber tree species results in twice as much additional demand for number of trees as when compared to selection of all non-timber species by a respondent. Further, the selection of timber species is equivalent to providing a monetary incentive of KSH 25 per seedling to generate the same level of demand for trees in the area.

1.5. DISCUSSION: SIGNIFICANCE OF RESULTS

The results presented in this paper confirm that direct economic incentives to land stewards can indeed improve the provision of an environmental service; *ceteris paribus*, farmers in Western Kenya are willing to plant about 18 more trees for every KSH of direct payment to them. This result is robust to different econometric approaches. Admittedly, the price range covered in this study is limited between +10KSH/seedling and -10KSH/seedling, but even within this price range, the effect on demand for seedlings is significant. The partial effect is almost the same as the slope coefficient on labor supply, which implies that provision of KSH1 of economic incentive per seedling has the same effect as adding one adult member to a household who works full time on the family farm. The estimated slope coefficients from the RE model (column 3 in table 1.3) can also be used to construct a demand curve for a forestry program in the study area. Demand is seen in terms of the number of additional trees that farmers are willing to plant, both when farmers receive per tree economic incentive and when they have to pay for seedlings themselves. Figure (1.2) shows that demand for tree seedlings amongst sampled households (n=277) goes down from 125,000 seedlings at an economic incentive of KSH 25 /seedling to almost zero when farmers have to pay KSH 25/seedling (this is the choke price at which a forestry program is unlikely to generate much demand in the area).

These results have a direct significance for ICRAF and other implementing organizations in the region. These organizations can use the results from this study to further explore demand for forestry in the region. For instance, farmers in the Yala River Basin are much more likely to plant trees than farmers in the Nyando River Basin. Therefore, a forestry initiative in the area such as WKIEM is well advised to begin its activities in Yala rather than in Nyando. During this phase, implementing organizations can try to identify factors that constrain adoption of forestry in Nyando and as the program matures, use their experience to introduce appropriate activities in Nyando.

The paper also raises concern for local and international NGOs like ICRAF that support planting of indigenous tree species instead of exotics. The results presented here clearly show that people are more likely to demand timber species such as *Eucalyptus*, *Casuarina equisetifolia*, and *Gravellia pteridifolia* rather than fruit or slow growing indegenous trees. Availability of such exotic timber species also raises people's willingness to plant more trees on their farms. Since exotics can sometimes be associated with long run ecological disaster, especially on dry lands, research organizations will need to come up with suitable economic incentives to promote indigenous tree species in the area. This may include provision of differential economic incentives, for instance providing higher payment per tree when farmers select indigenous tree species.

1.6. CONCLUSION: LIMITATIONS OF THE STUDY

The purpose of this study was to assess the feasibility of a forestry program in Lake Victoria Basin by exploring farmers' willingness to plant additional trees on their farms. The study is able to confirm that there is significant potential for a forestry program in the region, especially if farmers are offered direct economic incentives to take up plantations. Mean willingness to plant trees increases almost six times from 44 trees per household to 244 trees per household when farmers receive an economic incentive of KSH 10/seedling as compared to when they have to pay KSH 10/seedling. At the usual planting density of 2.5m X 2.5m, this translates to putting about 0.5 acres of farm land per household under tree plantations (10 percent of the mean landholding per household in the area) when it receives an economic incentive of 10KSH/seedling along with free seedlings. The study is also able to confirm some results reported by previous agroforestry studies. For instance, women are less likely to choose timber species than men, while families with higher labor availability are more likely to plant new trees.

While these results are encouraging, the study also suffers from some important limitations. The price schedule explored in the survey is rather limited and can only predict demand within a narrow range. Since the purpose of the present study was to explore whether economic incentives have any effect on provision of an environmental service, the answer is unconditional yes. A subsequent study will however need to explore economic incentives in greater depth by offering more price choices. Further, the study does not account for endowment effects. For instance, it assumes a one to one correspondence between demand for additional tree seedlings and the number of trees that a farmer is likely to plant. It does not deal with the difference in farmers' perceptions when they get free seedlings versus when they have to pay for them.

Finally, while the study demonstrates the positive effect of payments that are conditional on survival of the tree seedlings, it still does not address the question of impermanence. The impact of contract duration in terms of the minimum number of years for which the farmers need to protect their trees (beyond the first six months) on mean willingness to participate in the forestry program remains unexplored. Similarly, the study does not include the effect of provision of fines and penalties on farmers' demand for tree seedlings. This is an important issue because in many forestry-based PES projects, farmers receive upfront payments to take up new plantations. However, once the payments end, they have little incentive to continue protecting the trees, threatening the sustainability of the project. Therefore, more work is needed on how to estimate demand for PES/forestry projects when the payments also include the provision of continuity of protection in the long run.

Appendices

Table 1.1: Descriptive statistics of variables used in the econometric models
(n = 277)*

Variable	Description	Continuous variable		Dummy variable
		Mean	Std.Dev.	
Price**	Net price per seedling for the farmer (in KSH). Three price schedules were offered.	0	8.17	
Gender	Gender of the respondent. 1 = male, 0 = female			1 = 44.8%
Age	Age of the respondent in years	46.4	15.48	
Marital status	Marital status of the respondent. 0 = not married, 1 = married, 2 = separated/widowed			0 = 2.2% 1= 69.7% 2 = 28.2%
Land	Land owned by the household (in acres)	4.9	5.96	
Title	Possession of formal land title. 1 = if the household has a title to at least one piece of land 0 = no formal title			1 = 38.9%
Percent Farmland Under foodcrops	Proportion of total land under food crops (in percent)	53.1	25.98	
Livestock	Total number of large livestock owned by the household	7.1	8.58	
Dwelling Roof	Kind of roof on the dwelling. 1 = metal sheets, 0 = thatch/grass			1 = 76.5%
Labor Availability	Total agricultural labor available at the household (units) after accounting for part-time and full-time involvement	3.6	2.06	
Access to Permanent Job	If a household member has a permanent job 1 = at least one member has a permanent job, 0 = no member has a permanent job			1 = 25.9%

Table 1.1 (cont'd)

Annual Expenditure	Total annual expenditure of the household during previous year (in KSH)	45,313.8	139,799.7	
Block	Geographical location of the farm 1 = Nyando river basin 0 = Yala river basin			1 = 56.9%
Willingness to Plant additional trees	If the household would like to plant additional trees. 1 = yes, 0 = no			1 = 99.6%

*Sample size is 277 for all variables except for Age (n = 275) and Dum_Block (n = 276).
** Price introduces panel effect in the model with three observations/respondent, n = 831

Table 1.2: Descriptive statistics of dependent variables
(n = 277)

Variable		**Buy Seedlings** (farmers pay KSH10/seedling)	**Free seedlings** (farmers get free seedlings)	**Get Paid** (farmers get paid KSH10/seedling)
Number of seedlings demanded	Mean	44	203	245
	Std. Dev.	115.9	425.8	493.5
Choice of tree species	Dummy variable (%) 1 = if the respondent chose at least one exotic timber species 0 = if no timber species were selected	1 = 62.1%	1 = 86.2%	1 = 82.3%

Table 1.3: Determinants of demand for tree seedlings in Lake Victoria Basin

Dependent Variable = Log (number of trees), i.e. Log (Y_{it})

	Fixed Effects	Random Effects	Random Effects Tobit
Price per seedling (KSH)	-0.11(0.006)***	-0.11(0.005)***	-0.12(0.006)***
Gender of respondent (1 = male, 0=female)	(dropped)	0.66(0.16)***	0.67(0.16)***
Age of respondent (years)	(dropped)	-0.02(0.005)***	-0.02(0.005)***
Secure land title (0/1)	(dropped)	0.30(0.15)***	0.33(0.16)***
Access to off-farm income (0/1)	(dropped)	-0.19(0.18)	-0.19(0.19)
Labor Supply per HH (number)	(dropped)	0.13(0.04)***	0.14(0.04)***
Presence of metal roof on dwelling (0/1)	(dropped)	-0.13(0.18)	-0.15(0.19)
Log (annual expenditure in KSH)	(dropped)	0.10(0.07)	0.12(0.08)
Square root of land holding in acres	(dropped)	0.09(0.08)	0.10(0.09)
Location (1 = Nyando, 0 = Yala)	(dropped)	-0.07(0.17)	-0.05(0.19)
Constant	3.58(0.0001)***	2.46(0.71)***	2.25(0.78)***
Number of observations	822	822	822
Number of groups	274	274	274
	R-sq. = 0.2261	R-sq. = 0.3105	Log Likelihood = -1508.77
	Prob. > F = 0.00	Prob. > F = 0.00	Prob>chi sq = 0.00 83 left censored observations 739 uncensored observations

Figures in parentheses represent robust standard errors.
*** Significant at 1%
** Significant at 5%
* Significant at 10%

Table 1.4: Determinants of choice of tree species

Dependent variable: Choice of tree species, i.e. W_{it}

	Fixed Effects	Random Effects	Random Effects Logit
Price per seedling (KSH)	-0.01(0.002)***	-0.01 (0.002)***	-0.1(0.02)***
Gender of respondent (1 = male, 0=female)	(dropped)	0.09 (0.04)***	0.89(0.40)***
Age of respondent (years)	(dropped)	-0.002(0.001)*	-0.03(0.01)*
Secure land title (0/1)	(dropped)	0.05 (0.04)	0.58(0.40)
Access to off-farm income (0/1)	(dropped)	-0.04(0.05)	-0.52(0.47)
Labor Supply per HH (number)	(dropped)	0.01(0.013)	0.09 (0.09)
Presence of metal roof on dwelling (0/1)	(dropped)	0.01 (0.05)	0.15(0.48)
Log (annual expenditure in KSH)	(dropped)	0.02(0.02)	0.18(0.21)
Square root of land holding in acres	(dropped)	0.009 (0.02)	0.12(0.24)
Location (1 = Nyando, 0 = Yala)	(dropped)	0.47 (0.05)	0.55(0.45)
Constant	0.78 (0.0001)***	0.59 (0.20)***	0.15(1.91)
Number of observations	822	822	822
Number of groups	274	274	274
	R-sq. = 0.0376	R-sq. = 0.0704	Log likelihood = -372.79
	Prob >F = 0.00	Prob >F = 0.00	Prob >chi sq. = 0.00

Figures in parentheses represent robust standard errors.
*** Significant at 1%
** Significant at 5%
* Significant at 10%

Table 1.5: Joint Estimation of the two demand equations by combining Seemingly Unrelated Regression with Panel Data Model (n = 825)

	Coefficient	Standard Error
Dependent Variable = Log (number of trees), i.e. Log (Y_{it})		
Log (annual expenditure in KSH)	0.23***	0.03
Age of respondent (years)	-0.002	0.005
Price per seedling (KSH)	-0.11***	0.005
Square root of land holding in acres	0.24***	0.09
Secure land title (0/1)	0.31**	0.16
Labor Supply per HH (number)	0.14***	0.04
Gender of respondent (1 = male, 0=female)	0.71***	0.16
Location (1 = Nyando, 0 = Yala)	-0.12	0.17
Dependent Variable =Choice of tree species, i.e. W_{it}		
Presence of metal roof on dwelling (0/1)	0.14***	0.05
Age of respondent (years)	0.005***	0.001
Price per seedling (KSH)	-0.01***	0.001
Square root of land holding in acres	0.07***	0.02
Secure land title (0/1)	0.07*	0.05
Labor Supply per HH (number)	0.03***	0.01
Gender of respondent (1 = male, 0=female)	0.12***	0.04
Location (1 = Nyando, 0 = Yala)	0.12***	0.05

*** Significant at 1%
** Significant at 5%
* Significant at 10%

Table 1.6: Trade-off between demand for number of trees and for timber trees through single demand equation

Dependent Variable = Log (number of trees), i.e. Log (Y_{it})

	Fixed Effects	Random Effects
Price per seedling (KSH)	-0.09 (0.005)***	-0.09 (0.005)***
Choice of timber species (0/1)	2.24 (0.133)***	1.96 (0.12)***
Gender of respondent (1 = male, 0=female)	(dropped)	0.5 (0.15)***
Age of respondent (years)	(dropped)	-0.01 (0.005)**
Secure land title (0/1)	(dropped)	0.19 (0.15)
Access to off-farm income (0/1)	(dropped)	-0.11 (0.18)
Labor Supply per HH (number)	(dropped)	0.11 (0.04)***
Presence of metal roof on dwelling (0/1)	(dropped)	-0.14 (0.19)
Willingness to plant trees (0/1)	(dropped)	1.27 (1.21)
Log (annual expenditure in KSH)	(dropped)	0.07 (0.08)
Square root of land holding in acres	(dropped)	0.08 (0.09)
Location (1 = Nyando, 0 = Yala)	(dropped)	-0.15 (0.18)
Constant	1.87 (0.108)***	0.08 (1.38)
Number of observations	822	822
Number of groups	274	274
	R-sq. = 0.3682	R-sq. = 0.4242
	Prob. > F = 0.00	Prob. > F = 0.00

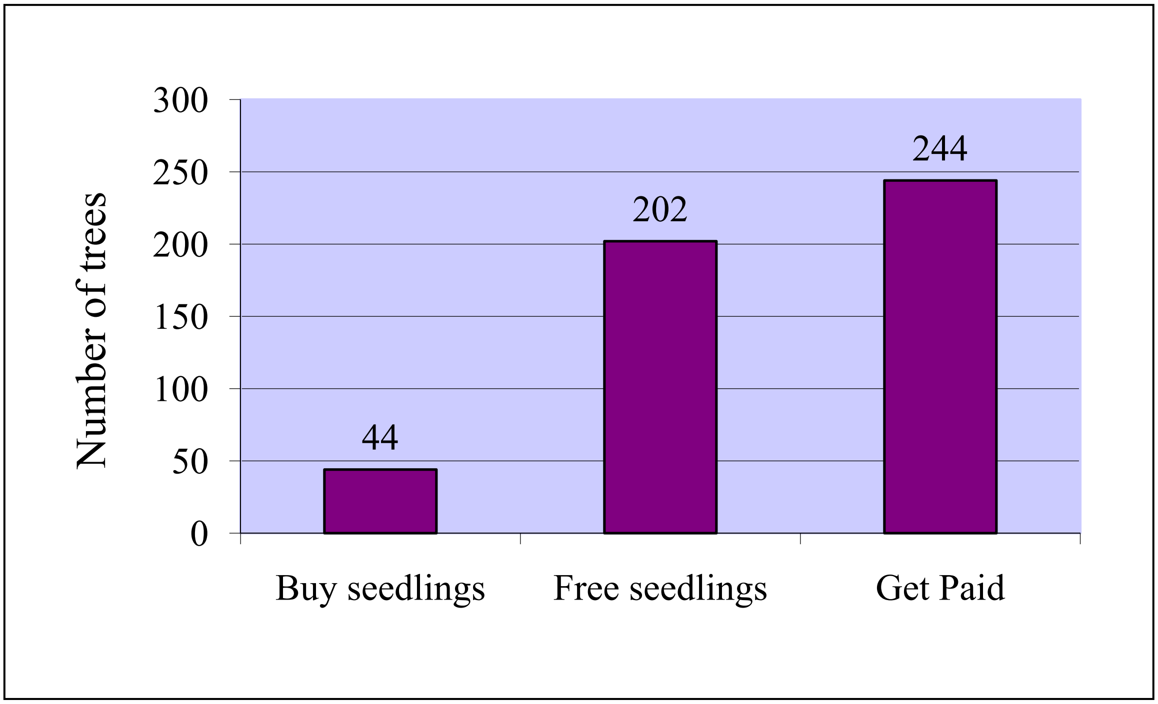
Figures in parentheses are standard errors.
*** Significant at 1%
** Significant at 5%

Table 1.7: Results of the Hausman Specification Test

	Coefficients		Difference	Standard
	FE (2)	*RE (3)*	**(2) – (3)**	**Error**
Price	-0.09	-0.09	0.00	0.0002
Choice of tree species	2.24	1.96	0.28	0.065

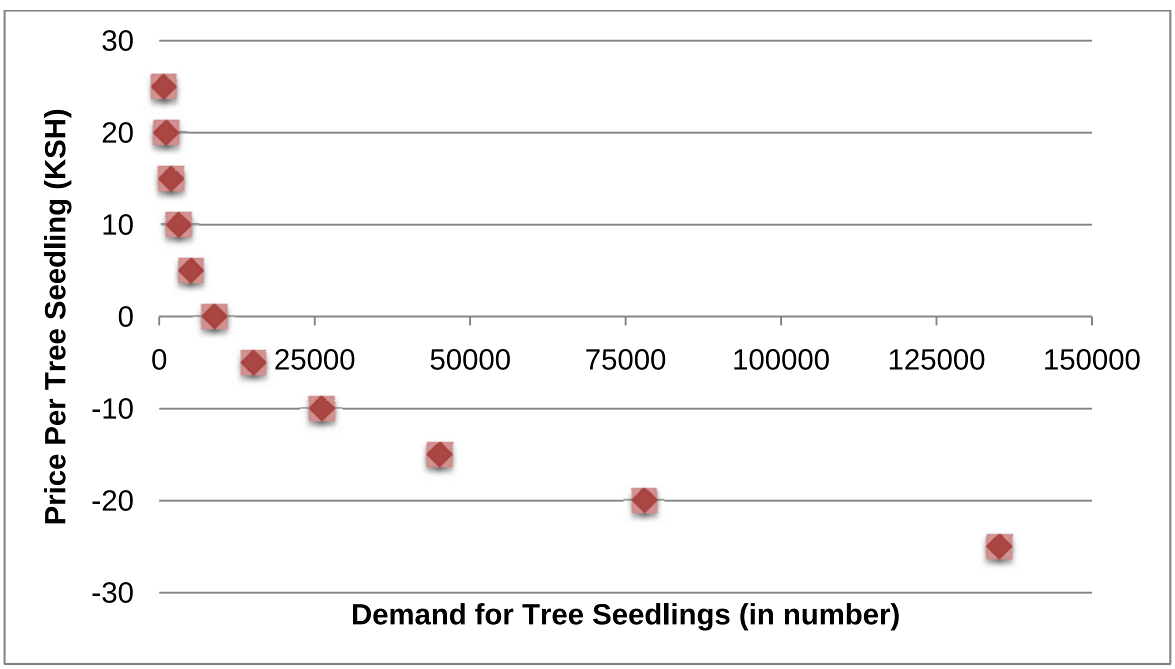
Chi sq. = 18.66
Prob. > Chi sq. = 0.0001

Figure 1.1: Mean number of trees under different scenarios



"For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this dissertation."

Figure 1.2: Estimated demand schedule for tree seedlings



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CHAPTER 2: ESTIMATING 'PAYMENT' IN PAYMENTS FOR ENVIRONMENTAL SERVICES: RESULTS FROM FIELD AUCTIONS IN THE ULUGURU MOUNTAINS, TANZANIA

2.1. INTRODUCTION

This paper estimates the level of payment necessary to procure carbon sequestration services through payments for environmental services in the Uluguru Mountains, Tanzania. Payment for environmental services (PES) is a new conservation paradigm that focuses on incentive payments to land stewards for investing in new land use practices that lead to conservation or production of specific environmental services (i.e. positive externalities) (Wunder, 2005). In general, conserving land-based environmental services with off-site benefits is difficult when it is not in the private interest of the land stewards or the associated opportunity cost is high (Pagiola and Platais, 2007). PES helps in aligning private interests of land stewards with the value that wider society places in such services (Engel *et al*., 2008). Payments under PES can either come from eventual users of environmental services or from conservation agencies that are interested in environmental protection. The efficacy of the PES approach depends on the level of economic incentive available to service providers; the incentive should be direct and it should adequately compensate the service provider for the opportunity cost of investing in a new land use practice (Ferraro and Kiss, 2002). PES thus mimics a market transaction where the price determines how much of the good is produced.

In recent years there has been rapid growth in PES-based projects to secure valuable environmental services across the globe (Huang *et al*., 2009; Southgate and Wunder, 2009). A seminal paper on this work identified more than 250 PES schemes operational in different parts of the world (Landell-Mills and Porras, 2002). PES examples vary widely and include such projects as China's Grain for Green program spread over more than 100 million hectares of erosion prone land (Yin and Yin, 2010), the Nhambita Community Carbon Project in Africa that aims to protect 11,000 hectares of forestland in Mozambique (Jindal, 2010), a local payments for watershed conservation project in Heredia, Costa Rica that protects upstream watersheds for downstream water users (Kenney, 2009), and a World Bank funded biodiversity conservation project in Nicaragua (Pagiola *et al*., 2008).

As envisaged in the Kyoto Protocol's Clean Development Mechanism and as observed from several forestry projects across the globe, PES has also become the dominant approach in securing forest based carbon sequestration services through absorption and storage of atmospheric carbon by trees (Miles and Kapos, 2008). There are now numerous projects that pay local land owners to sequester carbon by planting new forests or by protecting existing ones[6] (Hamilton *et al*., 2010; Jindal *et al*., 2008). Success of these projects is therefore directly linked with the effectiveness of the PES approach, which in turn depends on identifying a price that reflects the value of conservation while compensating land owners' opportunity costs. If the payment is too low, land owners will remain under-compensated implying that many potential suppliers will opt out of the project. If on the other hand the payment is too high, service producers will claim all the surplus from the transaction and the project will fail to deliver an adequate level of environmental service for the buyers or what conservationists call 'the biggest bang for the buck' (Pagiola and Platais, 2007; Jack *et al*., 2008). The challenge of achieving this has brought a lot of skepticism to the PES approach (Kosoy and Corbera, 2010).

[6] Technically, growing new trees in afforestation projects is different from conserving existing forests that come under the purview of reduced emissions from deforestation and forest degradation (REDD). There is a move now to combine the two under a proposed REDD+ regime (Van Noordwijk *et al*., 2009).

One of the constraints of the PES approach is that in the absence of competitive markets for environmental services such as biodiversity and watershed conservation, it is hard to determine the price or payment to offer to land stewards as suppliers. When markets do exist, as in the case of carbon sequestration, they are so differentiated that there is no single price that can be paid (Hamilton *et al*., 2010). *Ex ante* determination of price is also necessary because many projects either include onetime contracts or are of long duration whereby renegotiation of the contract is costly once it has begun. For instance, carbon sequestration projects need to ensure the long duration or permanence of carbon stored through project activities (Haites, 2004). Therefore, the terms of the project, including the payment level, have to be clearly laid out *ex ante* in order to obtain a long term commitment from the suppliers. If these terms are changed in the middle of the project, land stewards may discontinue their conservation efforts, jeopardizing the entire carbon that has been stored historically. Moreover, it is difficult to directly transfer cost estimates from one project to another since the cost of implementing a new land use practice is often site (and farmer) specific. When measuring production costs is expensive, especially on new project sites, providers may have little incentive in revealing their true costs. Estimating an efficient payment level is therefore both methodologically and practically significant for PES projects.

One potential method to estimate payments is through conservation auctions where PES contracts are allocated to potential service providers through competitive bids (Ferraro, 2008). Compared to conventional auctions, the roles of buyers and sellers (or service providers) are reversed in these auctions and successful bids from potential service providers are decided on the basis of how low they are rather than how high (Ferraro, 2008; Giampietro and Emiliani, 2007). Although such conservation or reverse auctions have become popular in developed countries such as the US, Australia and the UK, they have yet to be fully explored in developing country contexts (Latacz-Lohmann and Schilizzi, 2005). This is an important gap considering that a high proportion of PES projects including most carbon sequestration and REDD projects are proposed for the developing countries. Many of these projects can gain from a method that can help in calibrating an efficient level of payment to service providers. Moreover, most auctions are only able to collect data on bids from potential environmental service providers but not on their socio-economic profiles. As a result, researchers are unable to measure the extent to which poorer land stewards participate in these auctions or whether or not they are actually awarded any PES contracts. For a large number of developing country PES projects with a focus on poverty alleviation, this is a serious limitation.

This paper addresses several of these concerns. It is based on field experiments in the Uluguru Mountains of Tanzania where local farmers were invited to submit bids on the amount of money they were willing to accept in return for providing carbon sequestration services through adoption of agroforestry practices on their fields. It is organized as follows: the next section presents a review of auction theory and empirical evidence to identify why an auction can be an appropriate economic institution to estimate payments in PES projects. This is followed in section three by a description of the context in which the study was undertaken, including details on the specific auction format (second-price sealed bid, uniform pricing) that was used in the field. Section four presents results from field trials and their implications for project managers. Analysis of farmers' bids and an econometric model of their household characteristics help to answer several important questions that are discussed in detail: (i) what level of payment is necessary to generate carbon sequestration services in the area, (ii) to what extent are poorer households likely to be contracted, and (iii) how would different targeting approaches affect the level of environmental service generated. This also includes a simulation of different policy options such as giving higher weight to poor participants and how these options affect payment levels, project costs and area covered.

2.2. INFORMATION ASYMMETRY AND AUCTIONS

Producing environmental services often requires a change in land use (Antle and Stoorvogel, 2006). For instance, in order to generate carbon sequestration services, farmers will need to plant additional trees on their farms. If such trees are not privately profitable this will result in a decline in profits for the farmer, both from additional costs incurred in purchasing and planting new seedlings, as well as from a change in labor inputs and a potential decline in crop yields from the farm area now occupied by trees. This decline in profit or the opportunity cost of adopting the new land use will inhibit the farmer from doing so. If a farmer were to be compensated or paid for the loss in profit, she would be willing to adopt the new set of land use practices. However, only the farmer knows a large proportion of this opportunity cost (e.g. change in labor inputs) and this creates an information asymmetry between the farmer and the project manager (Ferraro, 2008).

To formalize, let the production function for farmer *'i'* be represented as y_i^j where $j = 0$ denotes conventional set of practices and $j = 1$ denotes the new land use practices that includes tree planting. Further, $y_i^0 = f(h_i x_i^0)$, where y_i^0 is the output per farmer from a conventional set of practices, x_i^0 denotes the inputs used by the farmer (e.g. labor, seeds, fertilizers etc.), and h_i is the efficiency of with which these inputs are converted into outputs. Following Khanna *et al.* (2002), the efficiency of input use can be construed as a function of the biophysical characteristics of the farm l_i (soil quality, location of the farm) as well as the farmer specific characteristics z_i (age, gender, education of the farmer), i.e. $h_i = g(l_i, z_i)$. The production function $f(\bullet)$ has the usual properties with $f' > 0$, and $f'' < 0$. If $c(x_i^0)$ is the cost function associated with using the inputs and P the set of output prices, the gross profit for the farmer from the conventional set of practices is found by solving:

$$\pi_i^0 = max\ \{Pf(g(l_i, z_i)x_i^0)) - c(x_i^0)\} \quad \text{--------------------- (1)}$$

The farmer selects the optimal level of inputs x_i^0 such that:

$$Pf'(g(l_i, z_i)x_i^0)) - c'(x_i^0) = 0 \quad \text{-------------------- (2)}$$

With the profit from the conventional set of practices being:

$$\pi^*{}_i^0 = Pf(g(l_i, z_i)x^*{}_i^0)) - c(x^*{}_i^0) \quad \text{------------------- (3)}$$

Similarly, under the new land use practice where the farmer plants additional trees on her farm (*j = 1*), the maximum profit can be written as:

$$\pi^*{}_i^1 = Pf(g(l_i, z_i)x^*{}_i^1)) - c(x^*{}_i^1) \quad \text{------------------- (4)}$$

And, the change in profit or the opportunity cost of the farmer *'i'* as:

$$\Delta\pi^*_i = \pi^*{}_i^0 - \pi^*{}_i^1 \quad \text{------------------- (5)}$$

Usually, provision of carbon sequestration services requires not only planting of new tree seedlings, but an *ex ante* assurance to protect the trees for a certain number of years (Haites, 2004). If under a new PES contract a farmer is required to protect her trees for say *T* number of years, then her total opportunity cost can be written as (Miller and Tolley, 1989):

$$b_i = \int_0^T \Delta\pi^*_i\ e^{-rt}\,dt \quad \text{------------------------- (6)}$$

If there are N heterogeneous farmers who operate in a watershed, the farmers can be ordered by their opportunity cost of providing carbon sequestration services (Paarsch and Hong, 2006):

$$b_{1:N} \leq b_{2:N} \leq \ldots\ldots\ldots \leq b_{N:N} \qquad \text{------------------------- (7)}$$

Where $b_{1:N}$ is the opportunity cost of the lowest cost provider, and $b_{N:N}$ is that of the highest cost provider. If the ordering as in (7) were known to the project manager, then she could not only calibrate the level of payment that would induce the local farmers to adopt the new land use practice but also estimate the supply of carbon sequestration services at each payment level. However, there is an information asymmetry between the farmers and the project manager such that only the farmers know their opportunity costs. Asking farmers to state their opportunity costs (say in the form of a stated preference survey) may not result in correct ordering as farmers lack incentive to reveal their true costs (Ferraro, 2008).

Some authors have suggested how a set of two different contracts, one for the low cost providers and the other for high cost providers, can help address this information asymmetry and encourage self-selection of potential service providers (Wu and Babcock, 1996; Gren, 2004). However, if there are multiple cost types, it is not only tricky to formulate such screening contracts but also extremely difficult to apply in practice unless one knows the distribution of opportunity costs among the target population (Ferraro, 2008). A possible solution to this problem is conservation auctions where potential service providers are invited to place bids on what payment they are willing to accept in return for providing a specific level of the environmental service, with the competition among bidders ensuring that they have an incentive to reveal their true opportunity costs (Latacz-Lohmann and Schilizzi, 2005; Cason and

Gangadharan, 2004; Latacz-Lohmann and Hamsvoort, 1997). An ordering of bids can then be used to estimate the supply curve for the provision of the environmental service across the entire landscape (Platinga *et al*., 2001; Jack *et al*., 2008).

Conservation or reverse auctions have been tested in many developed countries both to estimate the level of payment in PES projects and to allocate the actual conservation contracts. Perhaps the best known example of such auctions is the US Conservation Reserve Program (CRP), which pays farmers to set aside their land from production purposes to conservation use. The program began in 1985 to protect ecologically vulnerable land from soil erosion and for conserving other valuable natural resources (Rousseau and Moons, 2008). Farmers received an annual payment per acre for removing land from crop production provided their bids were below the maximum rental rate (bid cap) fixed by federal officials. Since 1990, bids from farmers have been weighted on the basis of an environmental index that scores parcels of land on the basis of the environmental benefits their inclusion in the program would provide to society. Parcels with the highest score are enrolled first, followed by parcels with a lower score and so on until the enrollment targets are met (Khanna and Ando, 2009). Nationwide, several million hectares of land are enrolled under CRP through auctions with significant cost savings for federal agencies (Classen *et al*., 2008). In Georgia, Cummings *et al*. (2004) used a series of auctions to inform state policy makers on how best to buy back irrigation permits from local farmers in drought years. Similarly, the BushTender program in Australia uses conservation auctions to promote native vegetation and biodiversity protection on private lands (Latacz-Lohmann and Schilizzi, 2005). Stoneham *et al*. (2003) report how the allocation of contracts through these auctions resulted in high biodiversity benefits at a reduced cost when compared to a fixed-price approach. Despite several other examples of conservation auctions across the industrialized world, to the best of our knowledge there are only two examples of conservation auctions in developing countries – one pertaining to watershed management contracts in Indonesia (Jack *et al*., 2008) and the other on tree planting contracts in Malawi (Jack, 2010). Both of these were experimental auctions. Clearly, field application of conservation auctions in developing country settings remains underexplored.

Perhaps one reason why conservation or reverse auctions have been used so rarely in developing countries is their perceived complexity (Ferraro, 2008). In general, auctions need thick markets or a large number of potential bidders to operate well (Klemperer, 2002a), which may not be always feasible. In addition, there are many auction formats to choose from ranging from the ascending English auctions to the descending Dutch auctions. Though in theory the different auction formats produce the same outcome (Myerson, 1981), in practice the results may vary due to diverse risk preferences and a divergence in information processing capability of potential bidders (Athey *et al*., 2004). From a PES perspective, therefore, the specifics of auction design affect the efficiency of contract allocation and the level of payment that service providers receive.

Researchers differentiate between an independent values paradigm where bidders' value of a contract (or opportunity cost of a change in land use) is unrelated, and a common values paradigm where bidders' valuations are correlated (Milgrom, 1989). In a PES context, where the cost of adopting a certain practice is farmer- and farm-dependent, and where service providers cannot resell the conservation contracts they receive, an independent values paradigm is more appropriate (Paarsch and Hong 2006). Auction outcomes also depend on whether the bids are submitted orally or as sealed bids. While oral bids favor strong bidders, sealed bidding can improve the chances of weak bidders to win the auction (Athey *et al*., 2004)[7]. Further, sealed bids help in estimating the supply curve for environmental service provision as the entire spectrum of bids from potential service providers are observed by the auctioneer, as compared to oral bidding where only a small sample of the bids are observed (Paarsch and Hong 2006).

For threshold benefits (e.g. a certain proportion of a watershed must be brought under conservation for any discernable downstream benefit), or in order to produce a marketable level of ES (e.g. a minimum number of carbon offsets that are needed to cover administrative costs of a project), PES projects often allocate multiple contracts in the form of land parcels that are required to follow the recommended land use. These multiple contracts can be auctioned simultaneously and/or sequentially. If service providers can bid for multiple contracts, then the marginal value to them of each additional contract decreases with the number of contracts they have already obtained (Krishna, 2002). In a simpler design, each service provider can be asked to bid for only a single contract, while the auctioneer can still allocate multiple contracts to all the bidders whose bids were equal to or below the highest accepted bid. In this case, however, the auctioneer still needs to decide between discriminative payments (where each service provider receives a payment equal to her bid) and uniform payments (all winning bidders receiving the same level of payment). In an auction experiment, Cason and Gangadharan, 2005) found that even though bidders mark up their bids to earn profits in a discriminative price auction, it is still more efficient than the uniform price auction. As expected, the conservation agency captures most of the surplus (including producer surplus) in a discriminative price auction as compared to the uniform case where most bidders receive much higher payments than their bids. However,

[7] Strong bidders are the ones who are more likely to win an auction while weak bidders are less likely. In a conventional auction, bidders with high valuation of the object being auctioned are strong bidders while the ones with low valuation are the weak bidders.

for PES settings in developing countries, discriminative price auctions may be politically infeasible or perceived as unfair by local landholders (Ferraro, 2008). Further, uniform price auctions may provide a higher incentive for bidders to reveal their true opportunity costs (Cason and Gangadharan, 2005).

In a seminal paper, Vickrey (1961) showed how second-price sealed bid auctions have a dominant truth-revealing equilibrium strategy and produce efficient outcomes. In other words, potential service providers can do no better than by revealing their true opportunity costs when asked to bid in a second-price sealed bid or Vickrey auction. If they bid lower than their opportunity cost, the value of the PES contract (i.e. the payment they receive) is less than their opportunity cost and they may end up with a loss. If they bid higher than their opportunity cost (in order to gain a profit), they may not get the contract at all. However, since the winners stand to receive payment equal to the lowest rejected bid (which will be higher than their bid except for the marginal bidder), their dominant strategy is to place a bid equal to their opportunity cost. In spite of this incentive compatibility, however, Vickrey auctions are rarely used in practice, not just in PES settings but also in sale of other objects that are routinely allocated through auctions. Rothkopf *et al*. (1990) propose that the two most important factors that thwart the use of Vickrey auctions are the fear of bidder collusion and resistance among bidders to reveal their true values (or costs) to others. Klemperer (2002a) suggests that 1) the presence of thick markets where many bidders compete and 2) using a sealed bid process should help address bidder collusion. Further, resistance among bidders to conceal their true costs can be addressed by keeping the winning bids secret (Rothkopf *et al*., 1990) and through the uniform payment system where only the last rejected bid is announced by the auctioneer.

Econometrically, a second-price sealed bid (or Vickrey) auction model is identified because of the dominant equilibrium strategy for all bidders to reveal their true costs (Paarsch and Hong, 2006). Therefore, using a set of farm and farmer specific observables, one can potentially estimate the marginal effect of each of these factors on the farmer's bid as observed in the auction, i.e. from eqs. 1 through 7:

$$b_i = \text{Ø}(l_i, z_i, x_i) \qquad \text{--------------------------} \quad (8)$$

where individual 'i' specific bid 'b_i' is a function of farmer specific characteristics 'z_i', farm specific characteristics 'l_i', and set of inputs 'x_i'. Eq. 8 can be deterministically written in the form of a typical econometric model where the log of observed bids is regressed on observed characteristics:

$$\log (b_i) = \alpha + l_i \beta_1 + z_i \beta_2 + x_i \beta_3 + \mu_i \qquad \text{--------------------------} \quad (9)$$

to estimate the set of slope coefficients $\{\beta = (\alpha, \beta_1, \beta_2, \beta_3)\}$ and the error term 'μ' accommodates for functional misspecification or any relevant unobservables. Lucking-Reiley *et al*. (2007) use this approach to analyze the determinants of bids placed in online eBay auctions on US one cent pennies, while Sun and Hsu (2007) specifically look at the effect of seller reputation on bids in online auctions. Jack *et al*. (2008) attempt this approach within context of conservation or procurement auctions for PES contracts but do not get a significant model.

2.3. DATA AND METHODS

The Ulugurus are part of the Eastern Arc Mountains, which extend from southern Kenya to the southern highlands of Tanzania. Located in Morogoro district, Tanzania, the Uluguru Mountains provide several valuable environmental services including biodiversity, carbon sequestration, and watershed regulation. The mountains are an important center of floral and faunal diversity and are home to at least 16 endemic vertebrate and 135 endemic plant taxa (Polhill, 1968). This degree of endemism in the Ulugurus is exceptional in tropical Africa, putting these mountains among the continent's ten most important conservation sites (Burgess *et al*, 2002). The Ulugurus are also the source of the River Ruvuu, which provides water to Dar-es-Salaam, the biggest city in Tanzania and a major economic zone. However, many of these environmental services are under threat due to rapid deforestation in the mountains. Recent surveys report disappearance of some endemic faunal species while heavy flow of silt during rains threatens the quality of water in the entire network of the River Ruvuu. Reversing this deforestation and land degradation is a must if the valuable environmental services flowing out of the area are to be preserved. As a result, many conservation projects have been initiated in the Ulugurus, with many focusing on PES as a way to incentivize local farmers to adopt more sustainable land use practices (Katoomba Group, 2007).

One potential way to revitalize the local ecosystem is by growing trees on agricultural fields (Neufeldt *et al.*, 2009; TAFORI, 2006). In addition to efforts to protect the remaining forest, tree planting on agricultural fields could help revitalize the local ecosystem. With the growth in international carbon markets, the trees could also generate saleable carbon offsets. Replacing agricultural crops with trees would however reduce farmers' incomes, requiring sufficient compensation for them to voluntarily adopt such a practice. The objective of the present study is to use conservation or reverse auctions in the field to estimate the level of payment that would induce local farmers to adopt these carbon forestry practices on their farms. The study also looks at ways in which PES projects could improve their targeting under different policy objectives. The field work was undertaken in collaboration with the World Agroforestry Centre (ICRAF) under its PRESA project (Pro-poor Rewards for Environmental Services in

Africa). The PRESA project is exploring the use of PES approach to conserve threatened landscapes across different countries in Africa, and the Ulugurus in Tanzania are one of the core project sites.

The field work for this study was undertaken in Kinole catchment of Morogoro district. The catchment contains a sizeable chunk of the Uluguru South Reserve Forest and is the source of one of the important tributaries of the River Ruvuu. The study area comprised ten villages in this catchment, of which Tandai is the local government headquarters and the main market place for all the other villages. The entire area is quite remote and there is only one fair weather road that connects it to Morogoro and beyond. Three out of the ten study villages are located higher up in the catchment, while five villages are not even connected to this fair weather road and locals need to trek on steep slopes to access it (table 2.1). Agriculture is the main source of livelihood in the area, with many households augmenting their income through casual labor or small businesses, especially in Tandai. Maize and cassava are the main food crops while banana and pineapple are the main cash crops. With the improvement in marketing infrastructure in recent years, the production of banana and pineapple has grown many fold and each day several lorries laden with bananas and pineapples can be seen leaving for the nearby towns of Morogoro, Chalinze, and even Dar-es-Salaam.

Data for the study were collected over a twelve month period in 2008 and 2009, with a set of field auctions conducted in March 2009. During several rounds of focus groups in the area, local farmers expressed a high willingness to participate in a potential carbon project which gave them incentives to plant trees on their farms. Many of them favored timber trees over fruit trees because they felt that the local marketing infrastructure was inept to handle more horticultural crops. These focus groups were followed by a survey with 400 randomly selected households in the area to collect relevant demographic and agriculture related information. The survey was administered through a written questionnaire, preferably with the head of the household or, in his/her absence, with the next most senior member in the family. The questionnaire included sections on household profile (gender of the household head, number and age of different household members), agricultural profile (number of farms, major crops, farm expenditure in the previous year), assets owned (type of house, ownership of livestock, and number of durable assets), and questions on the household's time preference with regard to any cash incentive. At the end of the questionnaire, the household was given a written invitation (with a unique identification number) to participate in the conservation auction in the area.

The auction was held at the main marketplace in Tandai village. Only the households that had participated in the survey and thus had written invitations with them were invited to attend the auction. Out of the 400 households covered in the survey, 268 attended the auction. Comparison of household data showed no systematic differences between households that did not attend the auction and those that did. After all the participants had assembled in the central market place, several rounds of mock auction were conducted first where familiar objects such as bananas and cash vouchers for cell phone minutes were auctioned to train farmers on how the actual auction would operate. Any questions from the audience were duly answered and the entire process was explained in detail several times. Once the participants said that they were comfortable with the auction process, two separate auction rounds were conducted inviting farmers to provide *sealed bids* for carbon or tree planting contracts. The entire exercise took five or six hours with a break for snacks and refreshments in between.

Farmers were asked to bid for the minimum payment they would be willing to receive for planting 80 trees over 0.5 acres (at a spacing of 5x5 m) and for protecting them for at least three years. During these three years, farmers were responsible for looking after their trees, although they were free to grow crops in between the trees. However, in order to reduce the transaction cost of making repeated payments and in order to provide an upfront incentive to farmers, the entire payment for the three year contract was payable up front[8]. However, farmers were also told that there would be external monitoring during these three years and if they looked after their trees well, there was a good chance that the contract would be extended (at a renegotiated price) after three years. The three year contract period was selected to give sufficient time to the PRESA project to look for carbon buyers willing to purchase carbon offsets generated by the tree plantations, while local farmers had enough time to look after the trees until they became well established and needed less maintenance and protection. Farmers were also told that they were free to decide how to use the trees if for some reason the contract was not extended after three years.

There were two auction rounds, each consisting of a separate carbon contract focusing on a different mix of tree species; *Khaya anthoteca* (African mahogany) and *Tectona grandis* (Teak) in the first round, and *Khaya anthoteca* and *Faidherbia albida* (Winter thorn) in the second one. These species were selected after consultations with the regional experts at Tanzania Forestry Research Institute, taking into account the local ecology. *Khaya anthoteca* is an indigenous tree in the area while both *Tectona grandis* and *Faidherbia albida* have done well in experimental trials (Godziszewski, 2009; Okorio and Maghembe, 1994). In both rounds, farmers were told that they would receive free tree seedlings procured from a reputed nursery in Morogoro, and they were asked to bid for their cost of planting and maintaining the tree seedlings. At an average price of 500 Tanzanian Shillings (TSH) per seedling, the total value of

[8] This is similar to many PES projects where participants receive in-kind incentives that are mostly provided up front and are semi-conditional at best.

tree seedlings per carbon contract was thus TSH 40,000 (USD 31.50)[9]. In the first round, farmers were invited to bid for a mix of 80 trees (40 each of *Khaya anthoteca* and *Tectona grandis*) on an area of 0.5 acres, while in the second round, which was also the final round, farmers were again invited to bid for planting a mix of 80 trees (this time a mix of 40 trees of *Khaya anthoteca* plus 40 trees of *Faidherbia albida*) on 0.5 acres. Winners in both the auction rounds were selected using the uniform second price rule (or Vickrey auction) with the last rejected bid setting the equilibrium price. Price information was not shared between rounds and winning bids were only announced after both the auction rounds had been completed. Each participant could bid in both rounds but could only receive a single carbon contract. So in the event of a participant winning in both rounds, she had to choose one of the two.

In all, 268 bids were received in each of the two rounds. However, 17 of these bids were disallowed because they were either illegible or outrageously high. Subsequent discussions with these farmers revealed that they had mistakenly added another zero in their bids. In the limitations section, we discuss the implications of excluding these bids from our analysis. Table 2.2 presents details of the remaining 251 households whose bids were included in the auction. 69 percent of the participants were males, while almost 80 percent were born in the local area with the rest migrating from outside. The average age of the participants was 43 years and they had completed an average education of 4.4 school years. On average, each household consisted of 7 people (including children) and owned 5 farm plots. The average ownership of animals and poultry birds was 0.16 livestock units[10]. In the previous year, the local households had spent an average of TSH 164,265 (USD 129.30) on agricultural expenses, out of which TSH 67,323 was

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[9] The exchange rate in March 2009 was USD 1 = TSH 1270.

[10] Livestock units estimated according to ILCA (1990).

for hiring labor. Further, 30 percent of all households ran a small business or had a household member with a regular job. Almost 68 percent of households had come in contact with the Wildlife Conservation Society of Tanzania (another local NGO) to plant trees on their farms in 2002-04.

2.4. AUCTION RESULTS

One of the primary objectives of this study was to estimate the level of payment that would elicit conservation investments from local farmers in a potential PES project. Required payments should cover farmers' opportunity costs, thus their bids from the two auction rounds should represent their perceived opportunity cost of adopting the recommended land use change (in this case planting a mix of 80 trees over 0.5 acre and protecting them for at least three years). This assumption underlies the paper.

In terms of field results, the bids observed in the two auction rounds (round one: *Khaya anthoteca* + *Tectona grandis* and round two: *Khaya anthoteca* + *Faidherbia albida*) were quite similar (table 2.3). However, there was a marked heterogeneity across farmers as indicated by a big difference in minimum and maximum bids. The minimum bid in round one for a three year contract was TSH 1,400 while the maximum was TSH 450,000. In comparison, the minimum bid in round two for a similar three year contract was TSH 2,000 while the maximum was again TSH 450,000. The distribution of the bids in both rounds was skewed to the right with the mean bid in each round (round one: TSH 143,840 or USD 113.30 and round two: TSH 138,253 or USD 108.90)[11] being more than the respective median bid (round one: TSH 130,000 and round two:

[11] As a point of reference, in 2008 the average per capita income in Tanzania was USD 440 (World Bank, 2010). Further, at an average wage rate of TSH 1,500 per day in the area, a mean bid of TSH 143,840 represents 96 days of wage labor spread over three years, or about 32 days each year.

TSH 126,000). The spread of the bids in the two rounds was also similar with a standard deviation across bids in round one of TSH 96,105.5 and TSH 93,105.4 in round two.

Starting from the lowest bidders, farmers were contracted until the researchers' small conservation budget was exhausted. In all, the 32 lowest bidding farmers or households (15 in round one and 17 in round two) received three year carbon contracts at the end of the auction. Following the uniform pricing rule, each of the 15 winning bidders in round one received a payment of TSH 30,000, while the 17 winning bidders in round two received TSH 20,000 each. These payments were in addition to the free tree seedlings that were provided to each winning bidder. In all, 2,560 trees were planted as a result of the carbon contracts allocated through the auction.

2.4.1 Checking for Collusion

Collusion or cooperative bidding is an important concern in auctions (Klemperer, 2002a; McAfee and McMillan, 1987). A tacit agreement among bidders to bump up the price can seriously jeopardize the efficiency with which the conservation contracts are allocated. Repeated interaction through multiple auction rounds facilitates communication among bidders, allowing them to cooperate or collude (Klemperer, 2002b). Similarly, provision for revision of bids during the auction process can help low cost providers inflate their bids, resulting in efficiency losses (Cummings *et al*., 2004). In general, sealed bid auctions involving many bidders are less susceptible to collusion (Klemperer, 2002a).

In the conservation auctions in Tanzania, though we used sealed bids and the participants were discouraged from communicating during bidding, prior familiarity among participants could have resulted in collusion. In addition, the seating pattern during the auction could facilitate group bidding (where participants sitting together bid alike), a concern that has also been raised by Jack (2010).

To check for potential collusion we followed a three-step process. During the auction, it was observed that most participants sat together in small groups of five to seven people. When the sealed bids were collected from these participants, we were able to identify the groups to which these bids belonged. In all, 41 groups comprising a total of 232 participants were identified. The rest of the participants were dispersed individually in the auction hall and their bids were not included in this analysis as there was little risk of collusion from their side. To check for collusion, we took the bids from round two, in which collusion was more likely because round one may have already helped participants to become familiar with each other. As the first step, we did an F-test for similarity of mean bids across these 41 groups (table 2.4). The test was reported significant which implied that differences in bids across groups were more than differences in bids within these groups.

To ascertain whether or not this indicated collusion between bidders, we plotted the mean bids of different groups with respect to the overall mean of all the auction participants (figure 2.1). The graph shows that out of the 41 groups, mean bids from 39 groups were within one standard deviation of the overall mean, which means that except for two groups, the average bidding did not vary much across groups. However, high mean bids in these two groups (mean bids TSH 292,917 and TSH 204,167) would indicate collusion only if there was low dispersion or spread of the bids in these two groups with all group members bidding high. The box plots of bids for each of the 41 groups (figure 2.2) show that in fact the bids in these two groups were highly dispersed, implying that even though some group members bid high, others within these two groups bid low (standard deviation TSH 180,419.07 and TSH 149,780.39 respectively).

Interestingly, the box plot for group number 37 did show joint bidding (mean TSH 140,000; SD TSH 5,000). However, since this behavior was limited to only one group and the mean bid of the group was close to the overall mean of the bids from all the auction participants, we can safely infer that there were little or no collusion in the overall auction.

2.4.2 Landscape level supply curve

Many environmental services such as watershed management and carbon sequestration have threshold effects whereby a minimum number of farmers (or acres) need to be contracted across a landscape in order to produce a viable level of environmental service (Parkhurst and Shogren, 2007). Platinga *et al*. (2001) use the equilibrium bids observed during the CRP auctions to estimate regional supply curves for conservation lands across nine states in the US. Similarly, Jack *et al*. (2008) use the auction data to estimate a hydrological supply curve for two micro-watersheds in Indonesia. We follow a similar approach to estimate a supply curve for provision of carbon sequestration services through tree planting on private lands in the Uluguru mountains. The bids observed in the auction can therefore be ordered according to equation (7) to estimate the marginal cost of environmental service provision from the Uluguru Mountains. There are two important assumptions that we make in extrapolating auction results from a sample group to the local population: first, that our auction participants are a good representative of the entire population in the Kinole area, and second, that local residents would only enter into PES contracts if the payment they receive is more than their opportunity cost. In other words if they fail to comply with the contract requirements, they may face penalties which deter them from accepting contracts that do not compensate them adequately.[12]

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[12] While the first assumption is fairly reasonable in our case, the second is still to be tested in a developing country context. Usually, non-compliance results in discontinuation of payments, but we are unaware of cases where financial penalties have been enforced.

Figure 2.3 shows that the upward sloping marginal cost or supply curve with bids from the two rounds mostly overlap with each other. The graph shows that at the mean payment of TSH 148,000 (USD 116.60) per half acre, about 62 acres (out of the 125.5 acres that were included in the auction) could be enrolled in a tree planting program for a minimum of three years. Since our auction participants were a random draw from the area and each farmer was eligible for only one tree planting or carbon contract over 0.5 acres, the curve can also be used to estimate the provision of carbon services through tree planting for the entire Kinole catchment representing 1,227 households (table 2.1, column 2). This fulfills another important objective of identifying the level of payment necessary to enroll a given target of acreage (or households) or to estimate the amount of area than can be brought under a PES project with a fixed conservation budget. For instance, for a low enrollment target of 33% of the local households (or about 41 acres out of the 125.5 acres included in the auction), and using a uniform payment arrangement, a PES project would need to pay TSH 100,000 per household (or per 0.5 acres). For the catchment as a whole this would lead to enrollment of about 368 local households (or 184 acres) at a total cost of TSH 368,000,000 (USD 289,763). Similarly, for a high enrollment target of 80%, the project would need to pay TSH 200,000 per household[13], leading to enrollment of 982 households (or 491 acres of private land) at a total cost of TSH 196,400,000.

Finally, although Figure 2.3 does give an idea of the loss of consumer surplus by using uniform payments over discriminative pricing (the area between the horizontal dotted line and the solid dots representing the supply curve), it should be used with caution since the bids from potential service providers would have been different if they had been informed that the auction process would involve discriminative pricing. In all likelihood, they would have inflated their

[13] It is important to note that this excludes the cost of supplying tree seedlings and any other project administrative costs.

bids (Cason and Gangadharan, 2005) leading to a different supply curve than the one we observe now. However, in contrast to the BushTender trial auctions in Australia where Stoneham *et al.* (2003) expect that landowners' bids also included information rents, we believe that in the present case the use of the uniform Vickrey pricing rule results in reduction (or even almost disappearance) of rents as the dominant strategy of the bidders was to reveal their true expected opportunity costs.

2.4.3 Participation of the poor

Participation of the poor is an important concern for PES projects in developing countries since many projects are either specifically taken up to augment rural incomes through conservation payments or are located in areas with widespread poverty (Gong *et al*., 2010; Pagiola *et al*., 2008; and Uchida *et al*., 2007). There is contrasting evidence from the field with some projects better able to demonstrate participation of poorer households (e.g. Jindal, 2010) than others (e.g. Miranda *et al.*, 2003). In general, participation of the poorer households is linked to whether or not they are low cost providers. Under any payment system, PES projects are more likely to contract low cost providers (who gain a higher surplus from the deal) than the high cost ones. But even then, policy makers and project managers may be interested to know the extent to which poor households are able to participate in PES projects in a given context.

For the PES work in the Uluguru Mountains, auction data supported by demographic data from the household survey provide a reasonable estimate of the extent to which poor households are low cost providers. While bids observed in the two auction rounds indicate the opportunity cost of individual households to adopt agroforestry/carbon contracts, the value of their asset ownership as collected during the household survey was used as an estimate of their wealth status. The correlation between the bids (which represent the bidder's expected opportunity cost)[14] and the asset ownership (wealth status) is weak and negative at -0.07. This indicates that many of the poor households may be high cost providers while many of the better-off households may have a lower cost of providing carbon services. This is confirmed when the wealth status of the households is plotted against their bids in the auction (figure 2.4). Many of the poor households with asset ownership estimated to be less than TSH 50,000 did signal a low opportunity cost in terms of their bids (and were indeed contracted in the auction), which were lower than the mean bid of TSH 138,253 for the overall group. However, a significant proportion of poor households also reported a high bid, below which they would evidently be disinclined to enroll. On the other hand, many better-off households with asset ownership in excess of TSH 250,000 were also low cost providers and were in fact included in the list of 17 households that were contracted under this study immediately after the auction. These results indicate that some poor households but not all were able to participate in PES activities. For a project that would specifically like to contract the poorer households first, there are thus efficiency and budgetary implications to which we return in section five below.

There are many possible reasons for some poorer households' high bids. They may own only a small number of agricultural plots, so that diverting them from food and cash crops to trees would have a high opportunity cost. Similarly, poor households may also face a labor constraint, making labor-intensive investment in a new land use practice expensive, or they may attach high risk to locking their land into a contract that requires maintaining tree cover for a minimum of three years. We check for some of these variables presently by exploring more carefully the determinants of bids received during the auction.

2.4.4 Determinants of bids

[14]The bids in the two auction rounds were similar; we used the ones from round two for this analysis.

An econometric analysis of auction bids with respect to bidder characteristics or covariates is usually untenable for two important reasons: (1) many bids may remain unobserved in auction formats that elicit oral bidding resulting in truncated data, and (2) when the auction is not truth revealing, the auctioneer only observes the bid but not the underlying valuation of the contract (Rezende, 2008). However, in the Uluguru auctions, use of sealed bidding with Vickrey uniform second pricing helps to address both these constraints and makes the econometric model identifiable (Paarsch and Hong, 2006). Sealed bidding ensures that all bids are observed and uniform second pricing makes the auction incentive compatible for bidders to reveal their true valuation in the form of their bids. Thus modifying equation (9) to account for two rounds of auctions that we conducted, we can analyze the marginal effects of various characteristics on observed bids as:

$$log\ b_{it} = \alpha + D_t + l_i \beta_1 + z_i \beta_2 + x_i \beta_3 + \mu_{it} \text{-------------------------- } (10)$$

where, as before, individual 'i' specific bid 'b_i' is written as a function of farmer specific characteristics 'z_i', farm specific characteristics 'l_i', and set of inputs 'x_i'. The 't' subscript represents the two auction rounds ($t = 1,2$), with the dummy variable 'D_t' taking the value '0' when $t=1$ (first auction round) and '1' when $t=2$ (second auction round). $\beta = (\alpha, \beta_1, \beta_2, \beta_3)$ are the respective parameter estimates. Eq. 10 can be solved using the ordinary least squares for each of the two auction rounds (columns 1 and 2 in table 2.5). However, by accounting for the fact that we have two observations per individual in the form of separate bids in the two auction rounds, we also use Pooled OLS (column 3 in table 2.5) and a random effects panel data model (column 4) to get more precise estimates (Wooldridge, 2002). All four models report estimates that are robust to system heteroskedasticity with standard errors clustered at the individual level.

As table 2.5 shows, the overall regression model is significant and most variables have the same sign and magnitude across all the four models. For the ease of interpretation, unless mentioned specifically, we therefore report the estimates from Pooled OLS (column 3).

As expected, the dummy on bid round (D_t) is insignificant since the bids across the two auction rounds were quite similar (figure 2.3). Farmer-specific variables that returned significant (z_i) include gender and age of the bidder, livestock units owned by the household, and the wealth status of the household as reflected by value of its asset ownership. On average, males tended to bid higher than females. The slope coefficient for gender in the case of the Pooled OLS model (column 3, table 2.5) is 0.21, which means that males bid 21 percent higher than females. Recall that each percentage change in bid is equal to about TSH 1,400 (USD 1.10). This means that *ceteris paribus* on average a bid from a male was higher by TSH 29,400 than a bid from a female, perhaps representing the higher opportunity cost that males attached to their labor inputs for the new land use practice. An increase in the age of the bidder by one year resulted in 0.6 percent increase in the bid. Similarly, increase in livestock ownership by 1 unit (which in turn is equal to 10 goats or 100 chickens) reduces the bid by 29 percent or by TSH 40,600. Ownership of livestock provides an alternate source of income to the household, thereby reducing the risk attached with a new land use practice. However, as we observed earlier, asset ownership has a small negative effect on the bid with increase in wealth by TSH 1,000 only reducing the bid by 0.01 percent. Although this is a small effect, it is significant across all the four models. We already discussed the significance of this result in section 4.3 above on participation of the poor. Since both labor constraint and number of plots are controlled in the model, it is more likely that poor households bid higher as they faced a higher risk of locking their land in a new crop with respect to the better-off households who have additional wealth/income to cushion them if the new land use did not work out.

An interesting variable that has a significant impact on the bid is whether or not the bidder also responded to the survey questionnaire administered a few weeks before the auction. The questionnaire covered demographic characteristics as used in equation (10) above, along with a few questions on the household's willingness to participate in a carbon contract involving agroforestry adoption. For this, the household was provided with some hypothetical incentives that the project was considering and the household was asked to respond on whether or not it would be willing to participate. The minimum incentive level was no payment and the maximum hypothetical incentive was a payment of TSH 45,000 per annum. In most cases, it was the head of the household who responded to the survey, while only in 8 percent of the cases (over a sample of 400 households), the head was unavailable and so the questionnaire was administered to the next adult member in the household. However, due to the economic significance of the auction, we anticipate that it was only the head of the household who participated in bidding. The dummy variable that reflects whether or not the head of the household responded to the survey is significant and has a huge negative effect on the bids (43 percent). This probably implies that farmers who were already aware of the nature of the carbon contract and had some idea about the payment level bid much lower than others. Even though the variable is significant across all the four models, it needs more investigation since there isn't much variation in the variable itself with only 8 percent of the bidders not contacted by the previous survey.

In contrast to some of the conservation auctions in Malawi (Jack, 2010), the farmer's time preference as reflected by whether or not she reported high preference for immediate returns was insignificant across all the four models. This is perhaps due to the fact that the entire payment for the three year contract was paid to farmers up front and so their time preference did not affect their bid values.

In terms of inputs (x_i), as expected the main variable that is returned significant is labor inputs measured in terms of the number of household members or household size. On average, each additional household member reduced the bid by 4 percent or by TSH 5,600 which reflects the decrease in opportunity cost when a household has additional labor available to invest in a new land use practice. In terms of farm-level characteristics (l_i), several variables are significant: number of plots per bidder, average distance of the bidder's plots to the nearest road, average elevation of the plots, and location of the plots (whether or not the plots are located in either of the two main villages Tandai and Kalundwa). Surprisingly, increase in ownership of farm plots results in higher bids, with each additional plot resulting in an average increase by 4 percent or TSH 5,600. This though is not a large increase. Managing diverse practices on a small number of plots may thus have lower opportunity cost than managing them on more plots, especially if they are located far away from each. (We were unable to get reliable data on inter-plot distances.)

During the survey (or even in the auction afterwards), we were unable to obtain precise data on the location of each plot that a household owned. Instead, we demarcated the local area into ten micro-catchments and estimated the average elevation of these micro-catchments and their average distance from the nearest road, and whether or not they corresponded to one of the two main villages of Tandai and Kalundwa. So, for each plot, we have data on whether or not it lies in either of the two main villages, its average distance from the nearest road, and its average elevation, based on which of the ten micro-catchments it is located in. Table 2.5 shows that farmers with plots located in either of the two main villages bid higher by 28 percent which indicates that land located in either of the two main villages is more valuable. On the other hand, a greater distance from the nearest road resulted in higher bids, with a 100 m increase in distance raising the bid by 2 percent on average. This is an unexpected result that needs deeper investigation within the community, because we expected the opportunity cost of land to decrease when it is located away from the road. Perhaps farmers find it difficult to access such plots and so they attach a higher opportunity cost. But even then, putting such land under permanent tree cover should actually be preferable to annual crops which may need more frequent care. On the other hand, if it is more difficult to look after trees on plots that are too far from the road, then it makes sense for farmers to associate higher cost for planting and protecting trees on these plots. Finally, for every 10 m increase in elevation, the bids reduced by 3 percent, which indicates the lower opportunity cost of land in the higher parts of the local watershed. Although we do not have empirical data on average slope in each micro-catchment, transect walks in the local area do show that upper parts of the watershed are more steeply sloped than the lower ones, which is also confirmed by Yanda and Munishi (2007). So as the average elevation increases, the increasing slope makes it more difficult to grow crops, thus reducing the opportunity cost of land.

Finally, to the best of our knowledge this is one of the few econometric analyses of auction bids in a developing country context. Even though the R square (the percentage of explained variance) is low for all the four models, the analysis still provides useful insights to policy makers and PES managers on the marginal effects of various socio-economic variables on auction bids, which can help them in designing conservation contracts that are appropriate for a given context.

2.5. ALTERNATE TARGETING OF CONTRACTS

Economists have suggested a range of targeting tools to capture the heterogeneity in environmental benefits and opportunity cost of changing land use across land parcels that can potentially be contracted in a PES project (Babcock *et al.*, 1997; Ferraro, 2003). Using marginal benefit and cost curves, these targeting tools can help in understanding trade-offs among different contracting arrangements. They include (i) using a cost-only approach to target parcels of land with the lowest opportunity cost first, which would maximize the acreage enrolled under a PES project, (ii) using an environment-only targeting under which parcels with the highest environmental benefits are enrolled first, and (iii) targeting parcels using the environmental benefit-opportunity cost ratio, which would produce a cost-efficient outcome or what is called 'the biggest conservation bang for the buck' (Ferraro, 2003; Babcock *et al*., 1996).

In recent years, a lot of emphasis has also been placed on designing PES projects in a way that enables poor households to participate as potential service providers (Pagiola e*t al.*, 2008). Under a take-it-or-leave-it system where most PES projects offer a fixed level of payment, poor households may find it difficult to participate if their opportunity cost of providing the environmental service is more than the payment they are offered. However, under a pro-poor approach, a fourth way to target PES contracts is that (iv) parcels of the poorest households are enrolled first and the payments are scaled according to respective opportunity cost of the household to adopt the recommended land use change (Gauvin *et al.*, 2010; Jack *et al.*, 2008).

Often however, PES managers do not have reliable data on specific opportunity costs of different land parcels and have to depend on average cost estimates to evaluate the outcomes under different targeting arrangements. Data from field auctions such as in the case of the US

Conservation Reserve Program is handy in such cases since it provides a good measure of the opportunity cost of changing land use over different parcels of land. The auction process in the Uluguru Mountains is helpful in this regard since it not only provides a good estimate of the opportunity cost of adopting carbon agroforestry activities, but it also generated information on the wealth status of various households, which can be used for pro-poor targeting. Another advantage of this approach is that PES managers and policy makers can *ex ante* estimate the efficiency trade-offs from different kinds of targeting. The magnitude of the tradeoff will of course vary from context to context depending on the extent to which poorer households occupy environmentally sensitive lands and are also low cost providers (Babcock *et al*., 1997). In general, the tradeoff is minimized when there is high positive correlation among the three variables and is maximized under high negative correlation (Ferraro, 2003).

Following the usual formulation, we can represent ordering or ranking of land parcels as per $rank_i = ess_i / bid_i$ where '$rank_i$' the rank of an individual parcel 'i' is the ratio of the environmental services that the parcel generates 'ess_i' to its opportunity cost or auction bid 'bid_i' (Stoneham *et al.*, 2003). Under a cost-only approach (i), parcels with the lowest bids 'bid_i' are selected first, while in the environment-only approach (ii), parcels with the highest environmental benefits 'ess_i' are selected first. Recall, however, that in the case of the PES work in the Uluguru Mountains, each carbon agroforestry contract requires maintaining a standard mix of 80 trees on parcels of 0.5 acres, which would yield approximately the same amount of carbon service or environmental benefit (ess_i) from each parcel of land[15]. With no variation in carbon

[15] Though the carbon sequestration rates vary with the tree species and the quality of land, such effects can be ignored for a short duration contract as in the present case.

services 'ess_i', the cost-only approach (i) and benefit-cost ratio approach (iii) collapse into the same thing (which we call here as efficient targeting) where parcels are ranked only using the inverse of the opportunity cost or bid $1/\ bid_i$. Finally, under the pro-poor approach (iv), households with the lowest asset ownership '$asst_i$', are selected first, and receive payments that are commensurate to their respective opportunity costs.

Using data from the two auction rounds in the Uluguru Mountains, we explore the trade-offs among these targeting approaches by constructing Lorenz curves as in figures 2.5 and 2.6. The horizontal axis represents the cumulative acreage contracted under PES activities while the vertical axis represents the cumulative budget necessary to pay for these contracts. In both the figures, the solid line sloping upwards represents the efficient targeting approach, which enrolls maximum acreage under a given budget. The pro-poor curve (dotted line) represents the acreage when priority is given to the poorest households (which have the lowest '$asst_i$' values). In order to simulate outcomes when agroforestry adoption also produces a local environmental service (e.g. slope stabilization on higher elevations) that varies depending on location of land parcels (average elevation), we draw a third curve (hyphenated) that captures this heterogeneity in environmental benefits. In the Uluguru Mountains, many government officials and forestry experts have recommended extension of a line of trees on higher elevations in order to stabilize mountain slopes (Yanda and Munishi, 2007). In this case, a PES project would select lands that are located on higher elevation, followed by lands located on the lower reaches of the watershed. Since we do not have elevation data for each individual parcel, we use the average elevation of the micro-catchment in which a particular land parcel is located. An added advantage of this approach is that it reduces the transaction costs associated with monitoring and supervision since all available land in a micro-catchment (with the highest average elevation) is contracted first before moving to the next micro-catchment (with a lower average elevation).

Figures 2.5 and 2.6 show the tradeoffs in terms of efficiency losses when efficient targeting is replaced by pro-poor or environment targeting in auction rounds 1 and 2 respectively. In both cases, the curve for environment targeting lies in between the efficient cost and the pro-poor cost curve, which indicates that enrolling poorer households first is associated with a higher price compared to cost-only targeting, or even to targeting land parcels in priority micro-watersheds (environment targeting). Table 2.6 estimates the magnitude of these tradeoffs under different enrollment targets. Based on auction results from round 1 (where 100% enrollment corresponds to 125.5 acres), enrolling 25% of the potential land (i.e. 31.375 acres) would induce an additional cost of TSH 4,589,200 (USD 3,615 under environmental targeting, and an additional cost of TSH 5,238,800 under pro-poor targeting when compared to the most efficient cost-only targeting. The corresponding additional cost for 50% enrollment (as marked in figure 2.5 by dotted lines) are TSH 4,835,900 under environment targeting and TSH 7,874,700 under pro-poor targeting. The corresponding additional cost for a 75% enrollment target is still higher at TSH 5,551,900 for environment targeting and TSH 8,975,000 under pro-poor targeting.

In round 2, where a 100% enrollment target corresponds to 123.5 acres, the additional cost for 25% enrollment targeting (or 30.875 acres) are TSH 4,544,000 under environment targeting and TSH 4,870,000 under pro-poor targeting (table 2.6). Again as marked in figure 2.6 by dotted lines, for a 50% enrollment target, environment targeting will come at an additional cost of TSH 4,380,600 and pro-poor at TSH 6,829,600. The corresponding numbers for 75% enrollment target are TSH 4,714,600 under environment targeting and TSH 8,056,100 under pro-poor targeting. Since farmers who participated in the two auction rounds were randomly selected from the local area, these numbers can also be extrapolated to estimate the tradeoffs at the level of the entire local landscape. For example, 251 bidding households in round 1 represent approximately 20 percent of all households (1227) in the area (table 2.1). Therefore, enrolling 25% of all households across the entire landscape will induce additional cost of TSH 22,946,000 (USD 18,068) under environmental targeting and TSH 26,194,000 under pro-poor targeting.

These estimates explicitly state the magnitude of the tradeoffs involved in diverging from most efficient targeting towards alternate targeting arrangements such as giving preference to poorest households first. The objective of this analysis is not to take an ethical stand on whether or not PES projects should target poorer households first, but rather to make it clear that policy makers and buyers of environmental services should be prepared to bear additional cost for going in for these alternate targeting approaches.

Again, while this analysis is useful in estimating the tradeoffs involved in following alternate targeting approaches, it should be used with caution when estimating specific budgetary allocations for these different approaches. There are two important reasons for this: (1) the estimates are based on auction results where bidders were informed that contracts would be awarded on the basis of the bids (or the opportunity cost of a specific land parcel) alone. If the bidders knew that their bids would instead be ranked using alternate scaling criteria, such as a poverty score, there is evidence from existing studies that they would change their bids to maximize their gains from the scaling criteria (Kirwan *et al.*, 2005). (2) Similarly, the bids were selected using the uniform pricing rule (where each contracted household receives the lowest rejected bid) while the trade-off analysis conducted above is based on discriminative payments, where each household receives a payment equal to its opportunity cost. Again, studies suggest that current bids would not constitute equilibrium bids (and hence could not be used to estimate the additional budget needed for alternate targeting) if bidders knew that contracts would be allocated under a discriminatory payment system (Cason and Gangadharan, 2005).

Therefore, in order to use the results of the current auction to estimate the specific budget requirements for different targeting approaches, we need to proceed with the uniform pricing arrangement under which all contracted households receive the same payment. For ease of computation and inference, we consider only the efficient targeting under which land parcels are contracted according to lowest opportunity cost first, and pro-poor targeting under which land parcels belonging to the poorest households are contracted first. Figures 2.7 and 2.8 show the cost of contracting under these targeting arrangements for the two sets of carbon contracts from round 1 and 2 respectively, while table 2.7 presents the total budgetary requirements under these two targeting arrangements for different enrollment targets.

The horizontal axis in the two figures (2.7 and 2.8) denotes the acreage enrolled as before, but note that the vertical axis now represents the bid or the opportunity cost for a particular land parcel and not the cumulative cost. Along the x-axis the bids of all auction participants are presented in increasing order of the value of their assets, from the poorest to the wealthiest. The efficient cost curve (hyphenated line) in both figure 2.7 and 2.8 represents an ordering of bids with lowest bid first and so on, exactly the supply curve as in figure 2.3. The pro-poor curve (solid line in both figures 2.7 and 2.8) on the other hand, is constructed by first selecting the poorest households (with the least asset ownership or '$asst_i$') and then plotting their respective bids in the graph. The spikes in this curve indicate high bidders. As we noted in section 4.3 above, many poor households are high cost providers and so their bids zig-zag up and down without following a monotonic order.

Under efficient targeting and for a 25% enrollment target, the total budget required for round 1 contracts is TSH 5,670,000 (USD 4,464.60). However, under a strict pro-poor targeting where no household is excluded from enrollment, and for a 25% enrollment target (as shown by the dotted line in figure 2.7), the total payments now rise to TSH 25,515,000. This represents an additional budget of TSH 19,845,000 (USD 25,203). The reason for this massive increase in budget is that one household in the bottom 25% of bidders reported a high bid or opportunity cost of TSH 400,000 and as per the Vickrey rule, it would receive a payment equal to the next rejected bid of TSH 405,000, but so would all the other contracted households in this group. It would result in windfall gains for them and a significant increase in the overall budget. The same trend is repeated for a 50% enrollment target % where the additional budget requirement is TSH 39,690,000 (USD 50,406). For 75% enrollment, it is TSH 48,786,000 (USD 61,958). Table 2.7 also reports respective budget increases for round 2 contracts under strict pro-poor targeting for enrollment targets of 25% (TSH 19,530,000 or USD 24,803), 50% (TSH 39,060,000 or USD 49,606), and 75% (TSH 53,650,000 or USD 68,136).

This analysis presents a conundrum. On the one hand, using a Vickrey uniform pricing rule auction format ensures that farmers' bids represent their true estimates of their opportunity costs. If, however, these bids are used for alternate targeting of PES contracts such as following a strict pro-poor approach, and if poor households do not necessarily have low opportunity costs, then the required PES budget can escalate substantially. In such a scenario, offering lower payments to households may not be a good strategy because even though the households may accept these contracts, they may not comply with the project requirements in the long run, thus risking the sustainability of the project. If on the other hand, farmers are informed during the bidding stage about the use of a poverty index in ranking their bids, it may present a potential moral dilemma for them since in most developing country settings, rural incomes are self-reported by households. Although discriminatory price auctions can address some of these concerns, they have yet to be tested in developing country contexts. Finally, one approach that might work is to ease the strict pro-poor criterion to a more moderate pro-poor stance. Under such an approach, the wealthiest households may be excluded from PES contracts as ineligible, but thereafter all the remaining households are contracted as per the cost-efficiency approach. Although not the first best strategy, this would help keep the project budget low while the exclusion of the wealthiest households will ensure that at least some of the poorer households are able to receive PES contracts.

2.6. DISCUSSION AND EXTENSIONS

This paper tests the feasibility of running field auctions in developing country settings to both allocate PES contracts and estimate the payment that needs to be made to local land stewards for adopting the recommended land use practices. In the case of the Uluguru Mountains in Tanzania, we were able to attract bids from 268 local households for participating in agroforestry activities to produce carbon services. Using the Vickrey uniform pricing format, we contracted 32 farmers for carbon agroforestry contracts for a period of three years. Auction bids also helped to estimate a landscape level supply curve which will assist local resource managers to scale up PES activities across the entire landscape in the area. Using the auction results as well as the socio-economic data we collected in a survey, we were also able to determine that many but not all of the poor households were able to participate in the PES activity. Extending PES contracts to all poor households would escalate overall project costs, making explicit the tradeoffs involved in diverging from cost-only targeting to a more pro-poor targeting approach.

A critical concern underpinning the whole exercise, however, is the extent to which local farmers were able to estimate their opportunity cost of adopting the new land use practice and report it in their bids. Recall that out of 268 bids in each round, about six percent of the observations (or 17 bids) were not included in the analysis because they were either illegible or too extreme. Subsequent discussions with farmers who made these bids revealed that they had mistakenly added extra zeroes or put the decimal in the wrong place. Even though we had hired several educated people to help farmers in preparing and submitting their bids, clearly more people were needed to help with the auction. Although this may raise the administrative overheads, there would be several benefits including better quality data in the form of clearly written auction bids. If, on the other hand, participating farmers underestimated their opportunity costs, they would of course be unable to comply with the requirements of the contract. Initial assessments from the field suggest that most contracted farmers did indeed comply with the contract and duly planted tree seedlings on their farm plots.[16] In this regard, we think that extensive training before the actual auction and spending enough time in the field to design PES contracts that are appropriate for a given context are both very useful.

Validity of the auction results is also indicated by the auction bids which follow a normal distribution and are consistent across the two rounds. If participants did not understand the auction process well, we would expect the auction bids to be clustered together based on the small group that a particular respondent was sitting with. However, as we observed in the discussion on collusion and cooperative bidding, we find that even within small groups, the bids are well distributed. Auction bids are also within the mean opportunity costs reported by some other studies in the area with a focus on changing land use from seasonal cropping to more

[16] More detailed field assessment of compliance rates are planned for December 2010.

permanent vegetation. Finally, participants knew well enough that the auction would be followed by actual tree planting contracts. Since it was not a hypothetical exercise, they were more likely to take it seriously and report a bid that was closer to the minimum payment they would need to adopt the new land use practice.

An important limitation of this work is that due to constraints of time and resources, we could not collect plot level data which reduced the precision of our estimates from the regression analysis of auction bids on farm level and household level characteristics. A possible extension of this work can therefore be a more comprehensive landscape level model that integrates socio-economic data with more precise plot level biophysical data (Khanna and Ando, 2009; Lynch and Lovell, 2003). Such a model would also be able to capture the potential threshold effects in a landscape such that PES managers can quantify the minimum acreage of land that they would need to enroll in order to produce a viable level of the environmental service. Another potential benefit of such a model will be to reduce the threat of leakage where adoption of conservation practices in one part of a landscape or watershed is offset by resource degradation in another part. By explicitly working out the trade-offs from conservation and resource extraction in different parts of a watershed, a landscape level model can help in estimating the level of incentives necessary for local people to conserve the entire landscape. These incentives can be in the form of an agglomeration bonus for individual landholders to pool their lands or as group contracts where all individuals stand to gain by cooperating at the group level (Parkhurst and Shogren, 2007).

Finally, the payment estimates presented here correspond to a very specific contract that involves planting and protecting a standard mix of 80 trees over three years to produce carbon sequestration services. It is hard to generalize these estimates for other environmental services or even for additional species of trees that are not included in the present contract. On the other hand, it would be quite infeasible to conduct repeated auctions in the same area for provision of different environmental services. One potential solution is to use the auction data to design screening contracts for provision of other environmental services, particularly the ones that are strong complements of carbon sequestration from tree planting (e.g. slope stabilization through tree planting). Screening contracts refer to a set of contracts with varying effort and payment level such that when offered to potential service providers, they result in self-selection of the low cost providers from the high cost ones. Although there is a voluminous literature on this subject, screening contracts have rarely been applied in a field setting (Ferraro, 2008). One strong reason they have not been used for conservation contracting is paucity of reliable data on distribution of opportunity costs of different land parcels/service providers. Field auctions such as the one conducted in the Uluguru Mountains in Tanzania fulfills this important gap and can potentially be the first step in designing and testing screening contracts in actual field settings for provision of various environmental services under PES projects. Clearly, there is ample scope for further investigation on this subject.

Appendices

Table 2.1: Details of study villages in Kinole catchment, Morogoro district

Name of the village	Total number of households	Number of households in study sample	Distance from nearest road (meters)*	Distance from nearest market place (meters)*	Elevation (meters)*
1. Tandai	375		100	200	465
2. Lukenge	72		1850	1850	766
3. Doga	69		650	660	530
4. Nyange	123		2300	2350	629
5. Chohola	90		50	3800	414
6. Kalundwa	138		100	3470	465
7. Tonya	96		50	882	468
8. Kisambwa	160		50	2080	471
9. Jahimbwa	34		300	2480	469
10. Lusegwa	70		523	904	451
Total/Average	1227		597.30	1867.60	512.80

Note: * Pertains to average distance from the village center or the elevation of the village center

Table 2.2: Mean values for households that participated in the field auctions (n = 251)

Variable	Mean	Standard Deviation	Minimum	Maximum
Male headed HH (0/1)	0.69	0.46	0	1
Age of the HH head (years)	43	14.85	16	90
HH Size (number of people)	7	3.1	1	17
Education of HH head (years completed)	4	3.4	0	10
HH head born in the same village (0/1)	0.79	0.40	0	1
Location of the HH in main village (0/1)	0.47	0.50	0	1
HH reported high discount rate (0/1)	0.4	0.49	0	1
Participation in WCST activities (0/1)	0.7	0.47	0	1
Farm ownership (number of plots)	5	2.6	0	17
Farm ownership (area in acres)	8.9	13.1	0	177.3
Total Agricultural Expenditure (TSH)	164,264.5	292,624.5	0	2,426,000
Expenditure of Hiring Labor (TSH)	67,322.7	138,937.5	0	1,500,000
Animal Ownership (Livestock Units)	0.16	0.33	0	2.58
House contains good toilet (0/1)	0.09	0.28	0	1
Value of Assets owned (Thousand TSH)	250.60	1691.44	0	24,260
Head of the HH reported to survey (0/1)	0.9	0.26	0	1

Source: Author's survey, 2008-09

Table 2.3: Characteristics and summary statistics of auction results

Auction Details	Round 1	Round 2
Nature of contract	*Khaya anthoteca + Tectona grandis*	*Khaya anthoteca + Faidherbia albida*
Auction		
Format	Sealed bid second price	Sealed bid second price
Reservation price	No	No
Succeeding rounds		Sequential
Bids		
Number of bids	251	247
Minimum bid	TSH 1,400	TSH 2,000
Maximum bid	TSH 450,000	TSH 450,000
Mean bid	TSH 143,840	TSH 138,253
Median bid	TSH 130,000	TSH 126,000
Standard deviation	TSH 96,105.5	TSH 93,105.4
Salient rules		
Payment criteria	Uniform, lowest rejected bid	Uniform, lowest rejected bid
Tie deciding rule	Random	Random
Auction outcomes		
Number of winning bids	15	17
Payment per contract	TSH 30,000	TSH 20,000
Total Area contracted	7.5 acres	8.5 acres
Total number of trees planted	1,200	1,360

Note: All bidders were eligible to bid in both rounds. Winning bids for each round was announced only after the completion of both the rounds.

Table 2.4: ANOVA results for checking collusion among auction participants seated together

Number of obs = 232 R-squared = 0.2875
Root MSE = 85.2614 Adj R-squared = 0.1383

Source	Partial SS	df	MS	F	Prob > F
Model	560187.358	40	14004.6839	1.93	0.0019
group	560187.358	40	14004.6839	1.93	0.0019
Residual	1388476.65	191	7269.51124		
Total	1948664.01	231	8435.77491		

Table 2.5: Determinants of Auction Bids

Y = Log(auction bids)	**OLS Round 1 Bids**	**OLS Round 2 Bids**	**Pooled OLS Both Round Bids**	**Random Effects Both Round Bids**
Bid Round (Dummy = 1)			0.07 (0.05)	0.06 (0.05)
Gender of bidder (Dummy = 1)	0.16 (0.12)	0.26 (0.15)*	0.21 (0.12)*	0.24 (0.11)**
Age of bidder	0.009 (0.004)**	0.004 (0.004)	0.006 (0.004)*	0.006 (0.004)*
High Time preference (Dummy = 1)	0.12 (0.12)	0.08 (0.12)	0.1 (0.1)	0.07 (0.10)
Responded to survey (Dummy = 1)	-0.47 (0.19)**	-0.39 (0.18)**	-0.43 (0.16)***	-0.42 (0.23)*
HH Size	-0.05 (0.02)***	-0.04 (0.03)*	-0.04 (0.02)**	-0.04 (0.02)**
Job/Business (Dummy = 1)	0.09 (0.13)	- 0.02 (0.14)	0.04 (0.12)	0.02 (0.12)
Toilet in the house (Dummy = 1)	-0.18 (0.195)	-0.26(0.24)	-0.23 (0.19)	-0.23 (0.19)
Animal ownership (Units)	-0.43 (0.28)*	-0.15 (0.16)	-0.29 (0.20)*	-0.27 (0.16)*
Asset Value	-0.0001 (0.00002)***	-0.0001 (0.00003)***	-0.0001 (0.00002)***	-0.0001 (0.00004)***
Number of plots	0.04 (0.02)**	0.04 (0.02)*	0.04 (0.02)**	0.03 (0.02)
Distance to nearest market	0.00 (0.00004)	0.00 (0.00006)	0.00 (0.00004)	0.0002 (0.00004)
Distance to nearest road	0.004 (0.0002)*	0.00002 (0.0003)	0.0002 (0.0003)	0.0002 (0.0002)
Elevation	-0.004 (0.002)**	-0.0009 (0.002)	-0.003 (0.002)	-0.002 (0.002)*
Located in main village (Dummy = 1)	0.26 (0.12)**	0.31 (0.15)**	0.28 (0.12)***	0.27 (0.13)**
Constant	6.4 (0.81)***	5.1 (1.04)***	5.7 (0.85)***	5.7 (0.70)***
N	250	246	496	496
Prob > F	0.0001	0.03	0.002	0.007
R sq.	0.1367	0.0913	0.1005	0.099

Standard errors, robust to system heteroskedasticity in parentheses. ***Significant at 1% **Significant at 5% *Significant at 10%

Table 2.6: Trade-offs from different targeting approaches

Auction Round	Targeting Approaches	Cost of contracting (in Thousand TSH) under different enrollment targets		
		25%	50%	75%
	Efficient	2802.7	9287.8	18351.8
*Round 1**				
	Environment	7391.9	14123.7	23903.7
		(4589.2)	(4835.9)	(5551.9)
	Pro-poor	8041.5	17162.5	27326.8
		(5238.8)	(7874.7)	(8975.0)
	Efficient	2593.5	8963.5	17713.5
*Round 2***				
	Environment	7137.5	13344.1	22428.1
		(4544.0)	(4380.6)	(4714.6)
	Pro-poor	7463.5	15793.1	25769.6
		(4870.0)	(6829.6)	(8056.1)

Note: Figures in parentheses represent loss in efficiency with respect to cost of enrollment under efficient targeting.

* In Round 1, there were a total of 251 valid bids, each corresponding to 0.5 acres. The total acres that could potentially be contracted was 125.5 acres. Therefore, 25% enrollment target corresponded to 31.375 acres, 50% to 62.75 acres, and 75% to 94.125 acres respectively.

** In Round 2, there were a total of 247 valid bids. So the total number of acres that could potentially be contracted was 123.5 acres. Corresponding acreage for 25%, 50%, and 75% was 30.875 acres, 61.75 acres, and 92.675 acres respectively.

Table 2.7: Budgetary allocation under uniform pricing and alternate targeting

Auction Round	Targeting Approaches	Cost of contracting (in Thousand TSH) under different enrollment targets		
		25%	**50%**	**75%**
*Round 1**	Efficient	5670	17010	35814
	Pro-poor	25515 (19845)	56700 (39690)	84600 (48786)
*Round 2***	Efficient	5580	16740	29600
	Pro-poor	25110 (19530)	55800 (39060)	83250 (53650)

Note: Figures in parentheses represent additional budget needed with respect to cost of enrollment under efficient targeting.

* In Round 1, there were a total of 251 valid bids, each corresponding to 0.5 acres. The total acres that could potentially be contracted was 125.5 acres. Therefore, 25% enrollment target corresponded to 31.375 acres, 50% to 62.75 acres, and 75% to 94.125 acres respectively.

** In Round 2, there were a total of 247 valid bids. So the total number of acres that could potentially be contracted was 123.5 acres. Corresponding acreage for 25%, 50%, and 75% was 30.875 acres, 61.75 acres, and 92.675 acres respectively.

Figure 2.1: Checking for potential collusion among auction participants seated together

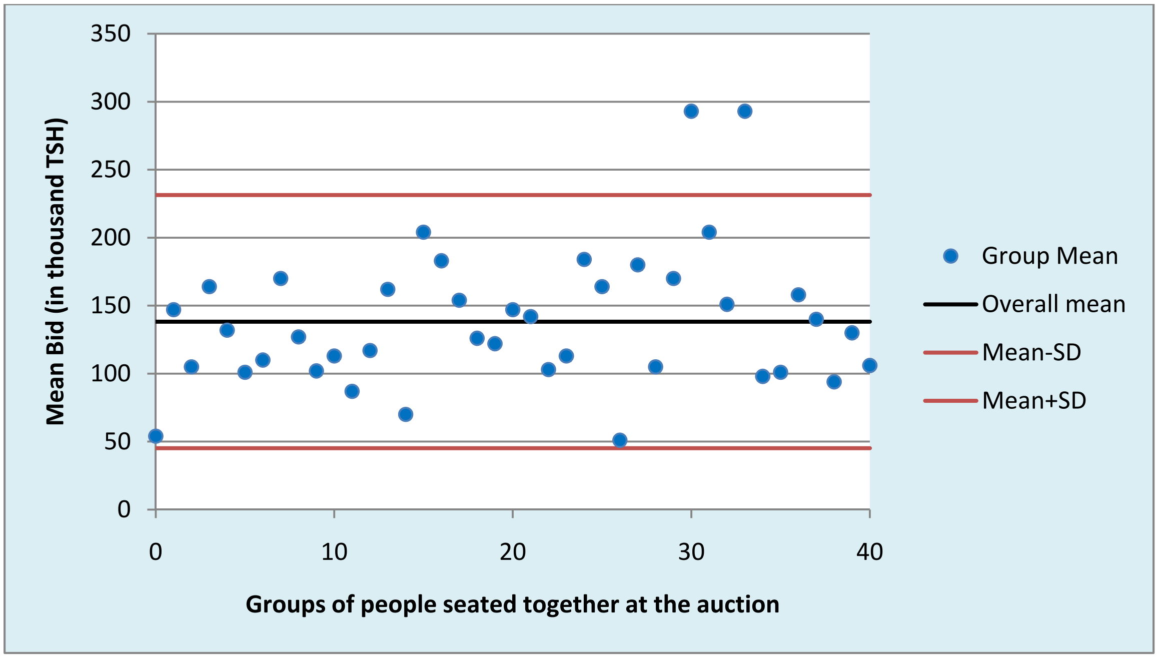


Figure 2.2: Box Plots of auction bids received from groups of participants seated together

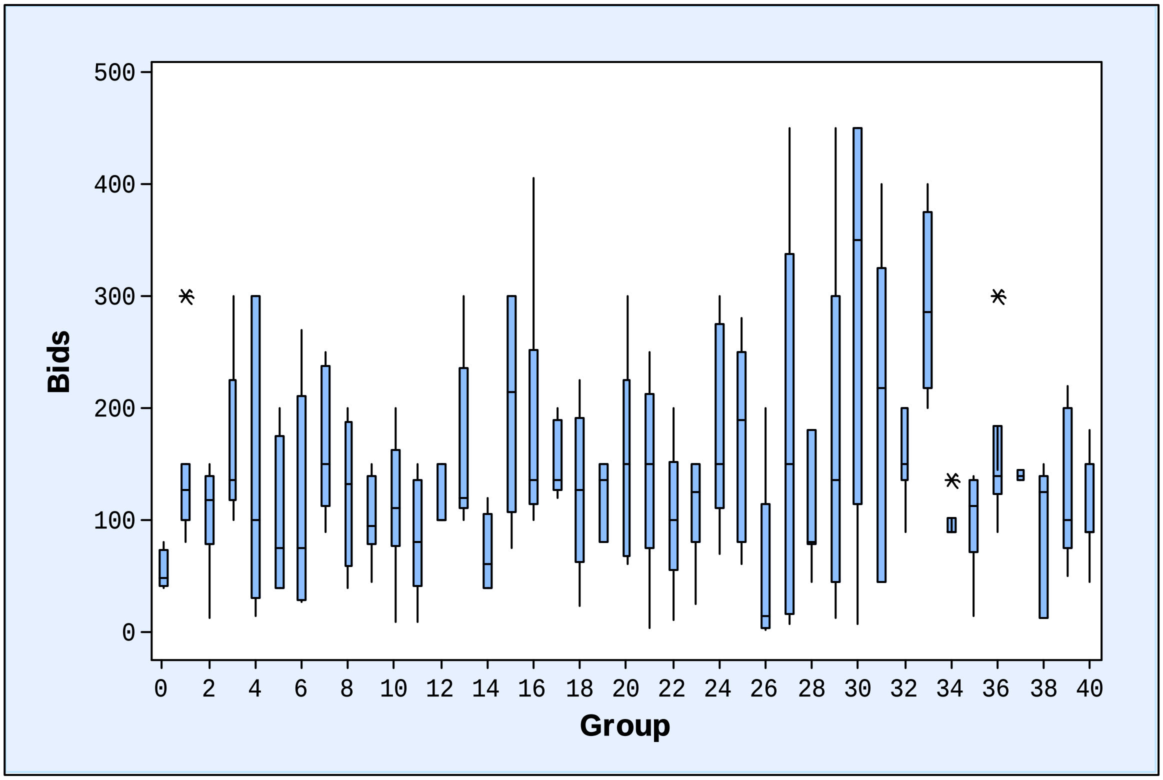


Figure 2.3: Estimated supply curve for enrolling private land for tree planting

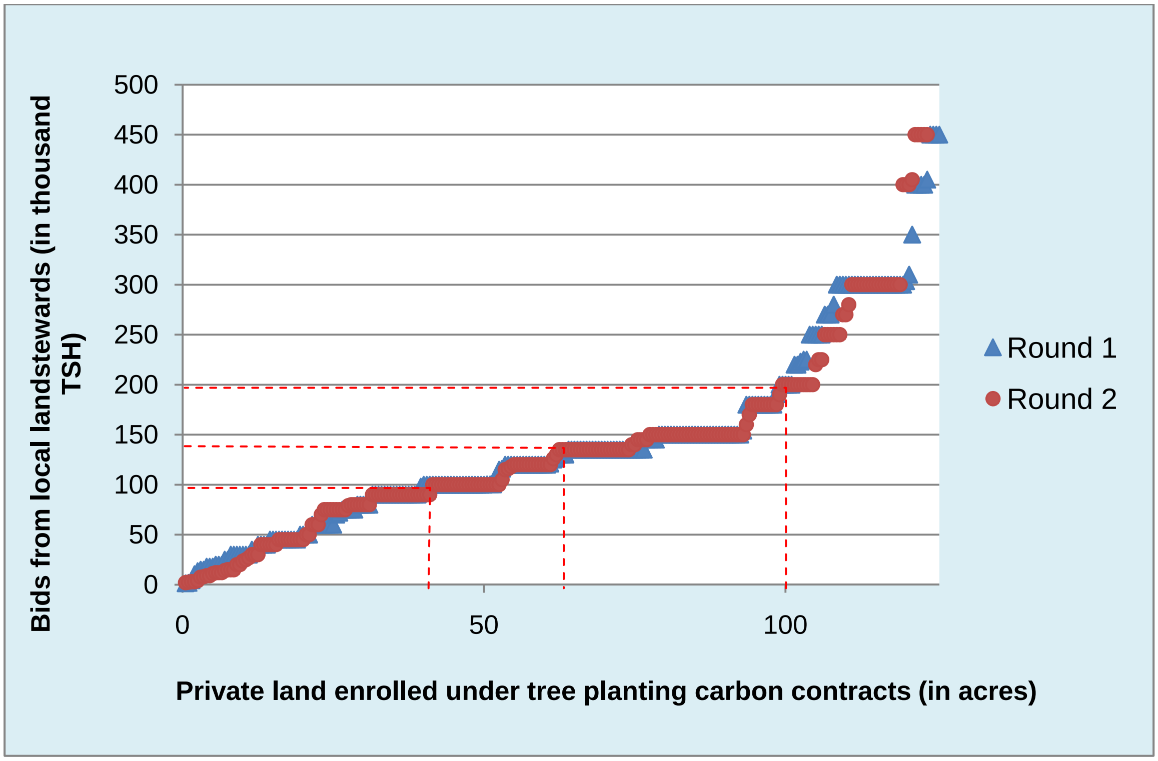


Figure 2.4: Relationship between the wealth status and the auction bids

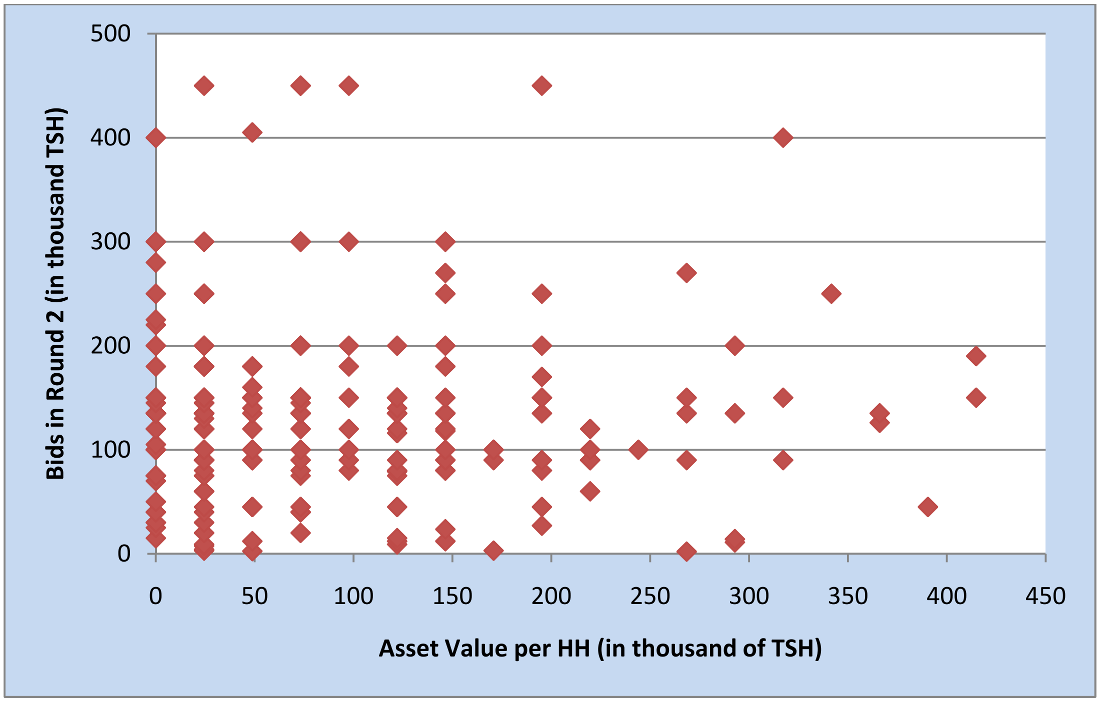


Figure 2.5: Trade-offs in alternate targeting of carbon contracts (Round 1 bids)

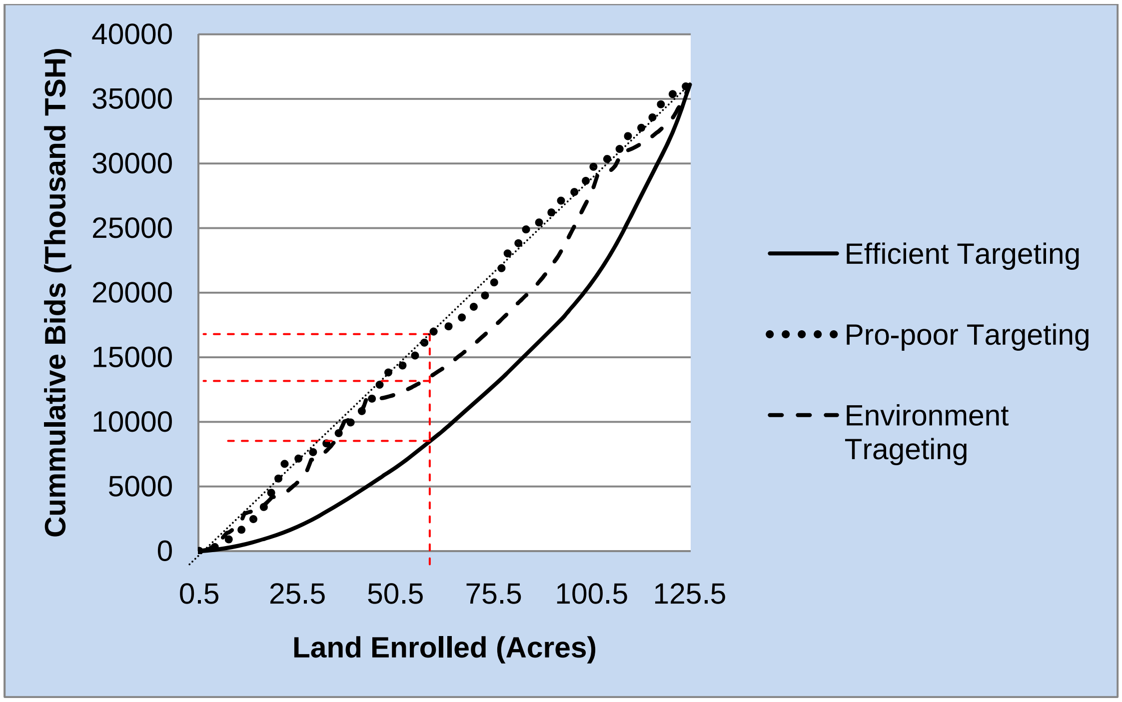


Figure 2.6: Trade-offs in alternate targeting of carbon contracts (Round 2 bids)

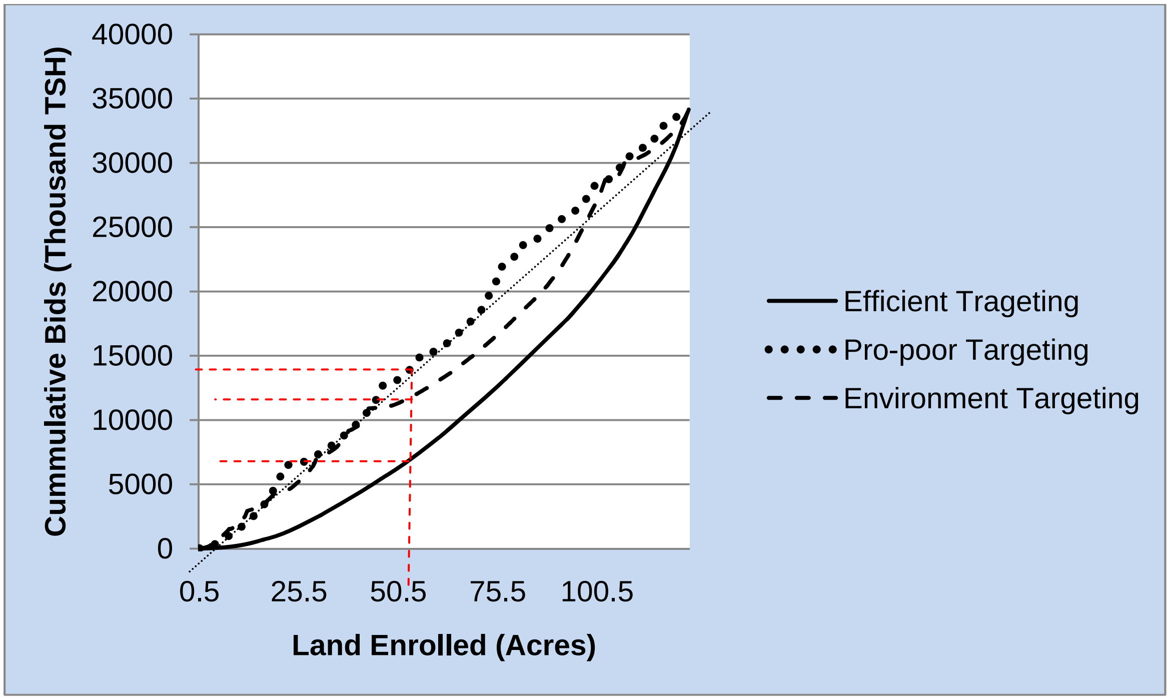


Figure 2.7: Budgetary allocation under uniform pricing and alternate PES targeting

(Round 1 bids)

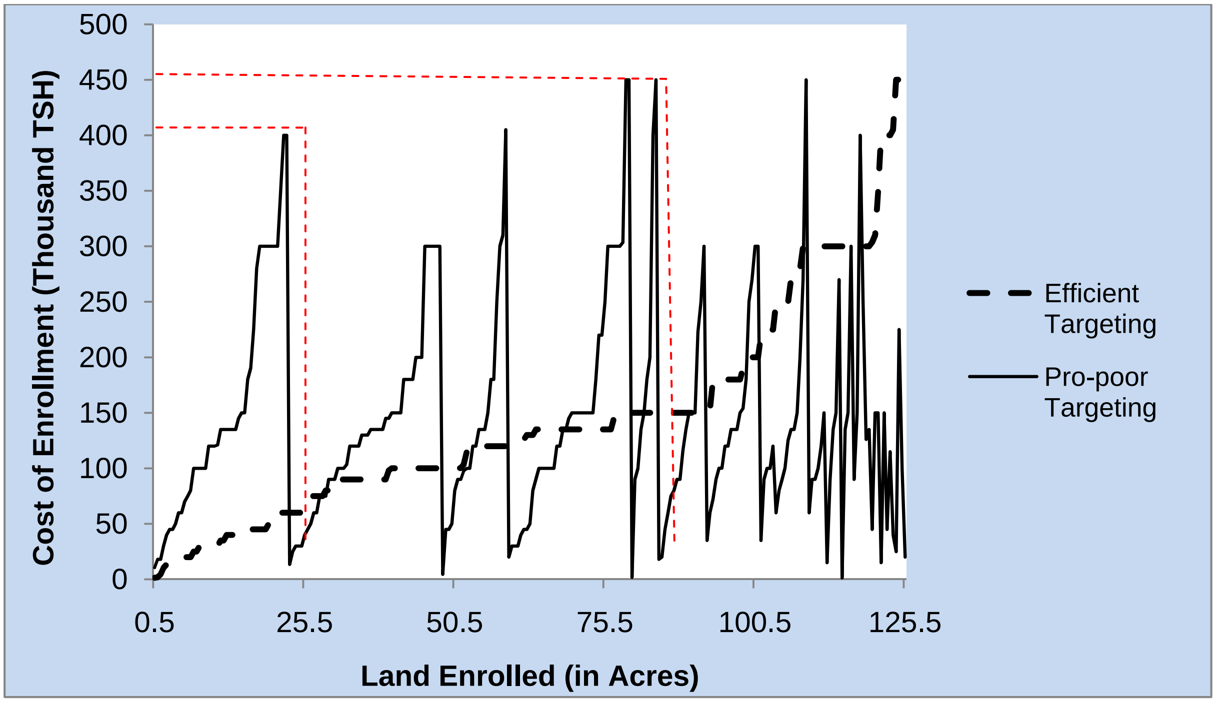
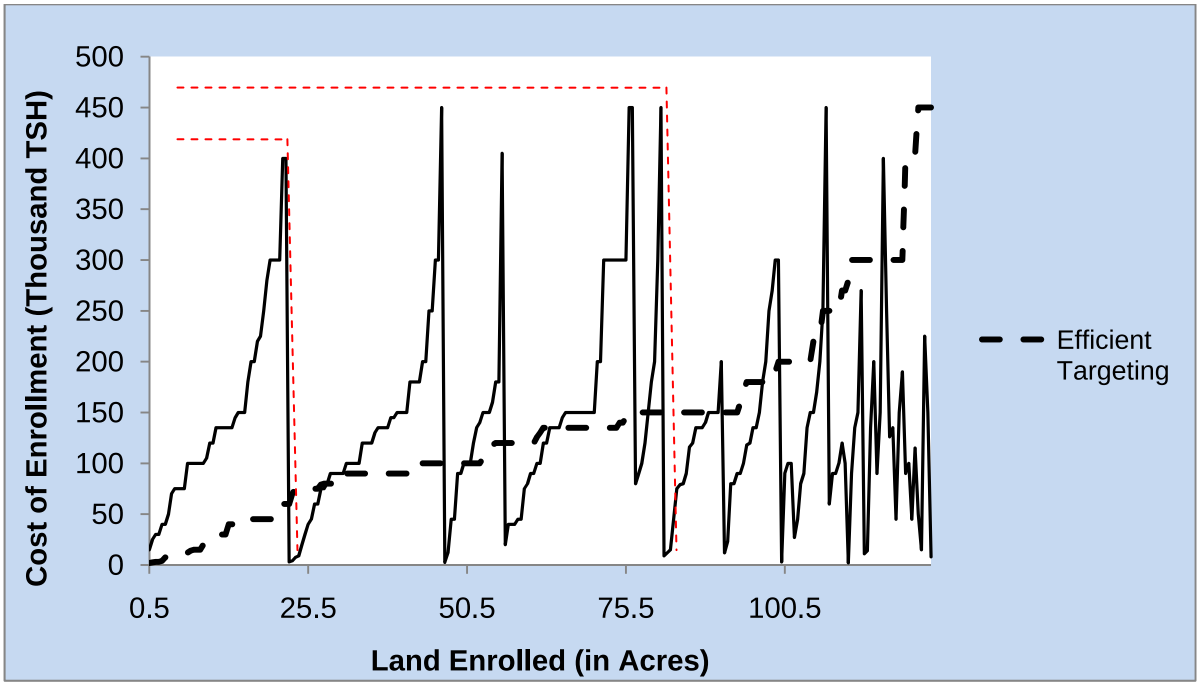


Figure 2.8: Budgetary allocation under uniform pricing and alternate PES targeting (Round 2 bids)



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CHAPTER 3: REDUCING POVERTY THROUGH CARBON FORESTRY? EXPLORING IMPACTS OF THE N'HAMBITA COMMUNITY CARBON PROJECT IN MOZAMBIQUE

3.1 INTRODUCTION

For all the discussion of local benefits of community based carbon mitigation projects, literature on actual measurement of such benefits is scarce (Engel *et al.*, 2008; Uchida *et al*., 2007). Most existing studies either present anecdotal evidence of project impacts or at best, an estimate of potential benefits (e.g. Tipper, 2002; Aune et al., 2005). Even though some studies have looked at impacts of large-scale national afforestation programs that are linked to carbon mitigation activities, such as the Sloping Land Conservation Program (SLCP) and the Natural Forest Protection Program (NFPP) in China (e.g. Liu *et al.*, 2010; Uchida *et al.*, 2007), empirical evidence of welfare effects of small-scale carbon forestry projects remains sketchy.

This gap in the literature is disconcerting for several reasons. Carbon mitigation, particularly through community forestry, follows the payments for environmental services (PES) approach whereby service providers receive payments for their conservation efforts, in this case through planting new forests and protecting existing ones (FAO, 2009; Jindal *et al.*, 2007) Since areas with potential to provide forest based carbon services also coincide with existence of large-scale poverty, there is an expectation among policy circles that using PES mechanisms to support carbon mitigation will lead to poverty alleviation (Perez et al., 2007; UNEP, 2002). As a result, the number of forest conservation based carbon mitigation projects in developing countries has grown steadily, with 19 reported from Africa alone (Hamilton *et al*., 2010; Jindal *et al.*, 2008). However, one cannot assume that these projects will definitely benefit the participating households, or would even be accessible to the local poor. For instance, projects that involve large-scale plantations can potentially have adverse outcomes for the poor, while in others the local poor may be unable to participate due to insufficient resources (Eraker, 2000; Corbera *et al.*, 2007). Lack of information on poverty impacts of these carbon mitigation projects is thus a legitimate concern.

Secondly, not all developing countries can afford large PES-like programs such as China's SLCP or South Africa's Working for Water, which are funded from national budgets. Instead, many poor countries view international carbon markets as a source of funds to support their own forest conservation and poverty alleviation programs (Gutman, 2003). However, without access to quality data on existing projects, national policy makers cannot design and replicate appropriate projects in their own countries.

In addition, many PES projects either do not fulfill the strict notion of conditionality or may have an add-on development component that is not linked directly to the provision of an environmental service (Engel *et al.*, 2008). While it is important to get a more realistic estimate of the impact of the PES component by differentiating it from the developmental activities going on in the area as part of a bigger project, most PES studies do not make this distinction. The resultant estimates may thus be biased and will not reflect the true impact of the PES component. Finally, concerns regarding impermanence and leakage of emission reduction from forestry have been widely expressed in environmental literature (Alix-Garcia *et al*., 2010), but documentation on actual experience in the field is limited. Field research on these issues can provide valuable insights on how to address them in future projects.

This paper attempts to fill some of these gaps through a detailed investigation of the N'hambita Community Carbon Project that pays local farmers in a remote part of Mozambique for carbon mitigation services through on-farm agroforestry and avoided deforestation activities. The paper addresses three gaps in the literature introduced above: (i) it estimates local impacts of a small, community based project that makes conditional payments for carbon services, (ii) it differentiates the impact of these payments from other development activities that are also part of the project, and (iii) it assesses leakage and permanence of the carbon mitigation activities that the project carries out.

The main finding from this review is that even though the project has been beneficial for the community, carbon payments alone have been insufficient to move people out of poverty. On the other hand, households employed in various microenterprises promoted by the project have certainly become better off than other households, both those that participate in carbon sequestration activities and those that do not. Upfront payments and flexibility regarding adoption of agroforestry practices have been effective in creating a huge demand for these carbon mitigation activities leading to a widespread diffusion of agroforestry in the area. However, they also expose farmers to long-term contractual obligations and exacerbate the risk of impermanence and leakage of emission reduction for which they are being paid. We review these impacts in detail, starting with a description of the project.

3.2. THE N'HAMBITA COMMUNITY CARBON PROJECT

The N'hambita Community Carbon Project is located along the periphery of the Gorongosa National Park (GNP) in Sofala province of Mozambique. The local community was relocated to this area after the creation of the park in 1948. However, the relative peace in the area was disrupted when it became one of the focal points of armed struggle during Mozambique's long civil war from 1975-92. As a result, thousands of local families were displaced to urban centers and lost access to their farmlands (Howell and Convery, 1997). With the advent of peace in 1992, many families started returning to their villages. However, they had few avenues for a decent livelihood and the poverty rates in the area remained among the highest in the country with more than 88% of the population living below the poverty line (Simler *et al.*, 2004).

The N'hambita project was initiated to provide an alternate source of income to these people through improved forest-based land use practices that could also produce carbon reduction services for sale in international markets (UOE, 2002). The project began its field activities in 2003, making it one of the earliest forest based carbon mitigation projects in Mozambique. It was initially funded by the Eurpoean Union, but since the end of the pilot phase in 2008 it has operated on the revenue from sale of carbon offsets (each offset equals one ton of carbon dioxide or tCO_2 sequestered by the project) to international buyers such as the MAN group and the CarbonNeutral Company[17].

The project operates in all six villages of the Chicale *regulado* (a traditional administration unit measuring about 20,000 hectares managed by a local chief or *regulo*). Five of the six villages are located deep inside the forest, with the nearest paved road several kilometers away (table 3.1). None of the villages is electrified and there is only one primary health centre for the entire area, located in Pungue. N'hambita, Mbulawa and Pungue had small grocery shops in the village, but the main market for the area is in Gorongosa, about 60 km away. Although all villages except Bue Maria have a primary school in the village, the nearest secondary school is in Gorongosa. According to Hegde and Bull (2008), there are a total of 1026 households in the area, with Mbulawa being the most populated with 414 households.

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[17] Project details can also be found at www.miombo.org.uk.

The project carries out various activities, some of which produce carbon offsets while others are more development oriented. For the purpose of this review, we have categorized the main activities of the project into the PES component and the development component, based on whether or not the benefits that local people receive are conditional on adoption of conservation practices that yield carbon offsets (table 3.2).

(I) PES Component

The PES component relates to activities that produce carbon offsets. The project offers regular payments to the local community with the amount determined by the nature of the activity and the number of carbon offsets its yields. This includes carbon sequestration through adoption of agroforestry on private farms and reduced emissions from deforestation and degradation (REDD) activities on community owned woodlands.

(i) Carbon sequestration through agroforestry

The project invites local households to plant trees on their farms that result in sequestration of atmospheric carbon into woody biomass. In return the households receive an annual payment for seven years, depending on the amount of carbon sequestered on their farms. The households can choose from a menu of agroforestry systems that the project offers: planting mango (*Mangifera indica)* and cashew (*Anacardium occidentale)* orchards, setting up woodlots with siris (*Albizia lebbeck*) and African mahogany (*Khaya nyasica*), intercropping with acacia (*Faidherbia albida*), planting native hardwoods such as panga panga (*Millettia stuhlmannii)* along the boundary of the *m'shambas* (farmers' fields), or planting fruit trees such as tamarind (*Tamarindus indica)* within the homestead. The specific carbon sequestration rate of different systems depends on density of plantations and the choice of tree species (table 3.3) and ranges from 10 to 181 tCO_2/ha. These sequestration rates have been estimated on the basis of maintaining trees for a period of 100 years (Tipper, 2008).

Each agroforestry system is designated as a separate contract and generally covers about 0.25-1.5 ha of a household's field or *m'shamba* land. A household can enroll for multiple contracts, either by adopting the same agroforestry activity on multiple plots or by taking up different agroforestry activities on the same plot (e.g. combining boundary planting with fruit orchards). In return, the N'hambita project monetizes carbon offsets generated by the new agroforestry systems with an annual cash payment to the contracted household. It is important to note that while carbon offsets are generated over 100 years, farmers are paid the entire value of these offsets during the first seven years of the contract. For instance, intercropping with *Faidherbia albida* generates a total of MTN 20,187/ha ($807.50) as carbon payments over the first seven years.[18] An important concern regarding project's sustainability is whether the newly established trees will continue to be protected once cash payments end. We return to this issue in more detail below.

(ii) Reduced emissions from deforestation and degradation (REDD)

In addition to carbon sequestration, the local community also receives carbon payments for REDD activities in communally owned miombo woodlands around the Gorongosa National Park. These are open canopy dry deciduous forests dominated by trees such as *Brachystegia*, *Julbernardia* and *Pterocarpus*. Major drivers of deforestation in these forests include clearance for agriculture, tree felling for charcoal production, uncontrolled burning, and logging for timber (Herd, 2007). Remote sensing images show that between 1999 and 2007, the average rate of

[18] In September 2008, $1 = MTN 24.23

deforestation in the area was 2.4% per annum (Tipper, 2008). This would denude the entire forest by 2040 unless conservation initiatives are effective in reversing the deforestation.

In order to reduce this deforestation, the N'hambita project has introduced two main activities in the area: a total ban on tree felling, and formation of fire patrols that guard against fire outbreak in the forests. These activities began in 2006 in a selected block of 5,000 ha and since then have expanded to 11,071 ha. The project team estimates that over ten years, these REDD activities will generate carbon offsets of 73.3 tCO_2/ha, based on a net reduction in biomass loss in the area (Tipper, 2008).

The N'hambita project combines these REDD offsets with carbon sequestration offsets from agroforestry activities and sells them as one lot in international voluntary carbon markets. After deducting overheads and commissions payable to brokers, the project has thus far paid farmers an average of $4.50 per tCO_2, which is much higher than the average price in most voluntary carbon markets. For instance, in 2007, the average price of carbon in Chicago Climate Exchange was only $3.13 per tCO_2 and since then it has fallen below $1 per t CO_2, while the N'hambita project has continued to pay the much higher price of $4.50 per tCO_2 (CCX, 2010; Capoor and Ambrosi, 2009). This indicates the success with which the project is able to negotiate deals with high profile buyers who are willing to pay this premium on carbon offsets. However, this also results in significant transaction and administrative costs (such as high brokerage fees) which account for almost 60% of the entire project cost. During the pilot phase from 2003-08, most of these costs were supported by the European Union. Since then the project meets them through the carbon revenue it generates. In order to scale up the number of offsets it sells in international markets, it has increased the number of contracted farmers in the Chicale *regulado* an expanded to newer regions (such as Zambézia and Quirimbas provinces in northern Mozambique). In the last few years the project has sold 116,807 tCO_2 worth more than $900,000, an important achievement considering that these offsets have been mainly sold in the voluntary market, which absorbs a smaller volume of carbon offsets than the Kyoto market.

Grace (2008) estimates that by 2007, the project had paid a total of $223,750 to the local community for agroforestry and REDD activities, with more payments expected shortly. However, the actual flow of money into the community varies by activity. In case of carbon sequestration, most of the money is paid directly to individual contract holders, while a small proportion goes into a community trust fund. REDD payments, on the other hand, are divided into two; one-half is deposited into the community trust fund and the other paid as wages to people who patrol the forest block against fire outbreak. Figure 1 shows the project's components.

(II) Development component

The development component consists of various microenterprises that the project has promoted in the area to provide alternate livelihoods. In addition, most of the project staff has been hired from the local community and since their monthly salary contributes significant cash inflows for the community, we also categorize this as part of the development component.

(i) Promotion of microenterprises

To promote alternate livelihoods and improve local incomes, the project supports several microenterprises (MEs) including nurseries, a community saw mill, a carpentry shop, bee-keeping, and a vegetable garden. Employment in these MEs is not conditional on participation in carbon mitigation activities though most people who are employed in MEs have also enrolled for agroforestry contracts. While the MEs were initially supported from donor funding, the project team is now working towards making them self-sustaining by linking them with the local market. For instance, the carpentry shop received a large order to supply furniture to the tourist lodge in Gorongosa National Park, while the nursery is trying to obtain a seedling contract from other development agencies in the area.

(ii) Project staff

A unique aspect of the project is that most of the staff is located on site and is drawn from the local community. This includes agroforestry extension workers, administrative staff, drivers and mechanics for project vehicles, and other casual staff. Like the ME staff, the project staff receives a regular monthly wage that translates into additional cash inflow into the community. In all, MEs and the project employ about 170 people with wages ranging from MTN 1,200 per month ($49.50) for a forest nursery worker to MTN 15,000 per month ($619.10) for a senior extension worker. In the following discussion of project impacts, we try to differentiate the impact of these wages from that of the carbon payments that the local community receives.

3.3. DATA AND METHODS

PES projects differ from integrated conservation development projects in that payments are directed only at those who can provide an environmental service, conditional on their actually doing so (Wunder, 2005; Ferraro and Kiss, 2002). In this regard, Greig-Gran *et al*. (2005) provide a useful framework that not only looks at impacts of PES on project participants but also reviews the extent to which local poor people are indeed able to participate in such projects. Further, Pagiola *et al*. (2005) suggest that impacts should not be limited to income alone but should also include other non-income impacts such as changes in access to wage labor or other employment opportunities in the area. We find both these approaches useful and complementary. Therefore, we combine the two approaches to focus on five key themes with respect to the N'hambita project: (1) the extent to which poor people participate in the project, (2) impacts on project participants' livelihoods, (3) impacts on non-participants, (4) wider spillover effects in the community, and (5) environmental impacts. For livelihood impacts, we considered indicators such as household income, asset ownership, livestock ownership, education attainment, and access to wage labor. Relevant indicators to measure the environmental impacts were the number of carbon offsets produced by the project as well as leakage and threats to permanence of these offsets.

There were two main challenges in conducting an objective assessment of the project impacts: isolating project impacts from wider changes in the region due to impressive growth in the country's overall economy, and differentiating the impact of the PES component (carbon payments) from the development component (wages from employment in various microenterprises). In order to address these challenges, our main estimation strategy was to follow stratified random sampling whereby we distributed the local households into three categories: households that participate in both agroforestry activities and MEs, households that participate in only agroforestry activities, and households that participate neither in agroforestry activities nor in MEs. Ideally, we would have liked to form a fourth category of households that participate in only MEs but not agroforestry. However, we were unable to find such households as everyone who was employed in any ME also possessed an agroforestry contract.

Continuing with the household as the unit of analysis, we compared the before-project status of households in each of these categories with the after-project status. Assuming that changes in the wider economy would have had similar effects on all households in the area, we were thus able to differentiate the impacts of the project from those of macro changes as well as impacts of the PES component from those of the development component of the project. Further, to check for any systematic differences or potential selection bias across households that either participated in the project (agroforestry contracts, employment in ME) or those that did not, we conducted a before-project cross-sectional analysis of sampled households. Finally, in order to estimate the spillover effects of the project on the entire community (impact of improvements in educational infrastructure on community wide literacy rate) we compared averages across all sampled households in the six project villages with randomly sampled households from six neighboring villages outside the project area.

The main data for this review were collected through a household survey conducted in May 2008. Based on the census compiled by Hegde and Bull (2008), we divided the local population in the project villages into three strata and then randomly sampled about 25% of households from each stratum: (i) households with both agroforestry contracts and with at least one member employed in an ME (n=54), (ii) households with only agroforestry contracts (n=170), and (iii) non-participating households that had neither agroforestry contracts nor employment in MEs (n=46). We also conducted the same survey among 64 randomly selected households in the control villages. The total sample size for the household survey is 334.

The survey focused on important demographic and socio-economic variables related to project impact. There were two main sections in the survey questionnaire. Section one focused on the status of a household in 2008 (or the after-project scenario), while section two collected information from the same household for 2001 (before-project scenario) using the recall method. Recall has been extensively used by researchers to study the impacts of an external intervention (e.g. Uchida *et al.*, 2007; Mullan *et al.*, 2010). In order to minimize errors associated with recall, we selected 2001 as the reference year since it was vivid in peoples' memory as the year when the local river had last flooded. Both section one (after-project) and section two (before-project) covered the same set of variables, i.e. the number of people in the household, their educational status, agricultural profile of the household including livestock ownership, extent of participation in the N'hambita project, and assets ownership. It is also important to note that the year 2008 did not imply the end of the project. Like most forest based carbon mitigation projects, the N'hambita project is expected to run for many more years. Rather, it corresponded to completion of the first five years of implementation and the conclusion of the donor-funded phase.

Finally, to triangulate survey data and add depth to our analysis, we also collected qualitative data through semi-structured discussions with an additional set of respondents in the project villages (Chung, 2000): (i) respondents employed in various MEs and also contracted under agroforestry systems (group size 25), (ii) women, most of whom had only agroforestry contracts (group size 25), (iii) respondents who had neither agroforestry contracts nor employment in MEs (group size 14), (iv) new immigrants to the area, most of whom did not have carbon contracts (group size 24), and (v) members of the community association (group size 11). These discussions helped to understand people's perceptions of the project and enabled a richer interpretation of survey findings.

3.4 RESULTS: PARTICIPATION OF THE POOR

Although many PES projects have a pro-poor focus, there are concerns regarding the extent to which local poor people and smallholders are actually able to participate in them (Gong *et al*., 2010; Pagiola *et al*., 2008; and Uchida *et al*., 2007). In Costa Rica's national PES program for instance, Miranda *et al.* (2003) found that in their study area, most of the participants were relatively well off landowners. In general, poor households may be unable to participate in PES projects due to insecure tenure, insufficient land to set aside for PES activities, high transaction costs, or high upfront investments needed to adopt new land use practices (Grieg-Gran *et al.,* 2005; Pagiola *et al.*, 2005). Also relevant for PES projects are the factors that affect adoption of new agricultural technology by smallholders: assured tenure, access to technical assistance, and availability of savings to meet investment and maintenance costs of new land use practices (Mercer, 2004).

The N'hambita project has tried to address many of these concerns. Benefits of REDD activities, for instance, accrue to everyone in the local community irrespective of how much land they own or even the extent to which they participate in other project activities. The REDD payments go to a community trust fund managed by a democratically elected executive committee and are used for the benefit of the entire community (more on this in the section on spillover benefits). In contrast, participation in agroforestry activities is more selective and depends on individual households for whether or not to enroll in the program. However, instead of saying yes or no to one standard agroforestry contract, households have the flexibility to choose their preferred land use from a menu of agroforestry systems that the project offers. Once a household enrolls for a particular system, it receives free seedlings and technical assistance in the form of training on how to plant and manage the new trees. Further, the project has frontloaded the carbon payments, with 30% of the payment being offered in the first year, which helps participants meet initial investment costs in the new land use system. As a result of these flexible arrangements, there is high demand for agroforestry contracts, and as of 2008, 852 or about 80% of all households in the area had enrolled in the project. Further, all land in Chicale *regulado* is owned by the entire community as common property and after taking permission from the local chief (the *regulo*), individual households can demarcate a piece of land to set up their own farm (Jindal, 2004). In time, the household gets *de facto* ownership of this farmland. In our field survey, we did not come across any landless household, and therefore the issue of tenure insecurity does not apply to the N'hambita project.

Although this discussion indicates that a significantly high proportion of the local community is participating in the project, nevertheless it is useful to investigate whether or not the poorest households are indeed able to participate. We conduct this analysis through a two-step process. Following the approach of Pagiola *et al.* (2008), we first look at participation rates of households in different income categories in our sample, followed by standard regression analysis to identify any systematic barriers or factors that influence participation.

Figure 3.2 displays the distribution of sampled households in various income classes. About 39% of the households in our sample had an annual per capita cash income of less than MTN 100, while 20% of the households were between MTN 100 and 250 and so on. Only 4% of the sampled households had a per capita cash income of more than MTN 2,000 per annum. Since we did not use income as a variable in stratification of our sample, these percentages roughly represent the income distribution for the whole community. When we look at the percentage of sampled households within each income category that were enrolled in agroforestry contracts, we find that the poorest households were slightly overrepresented while the wealthiest were slightly underrepresented. For instance, 42% of participant households in our sample came from the poorest income category, while only 3% of the participant households came from the wealthiest group. This indicates that the poorest households were participating in agroforestry activities in the N'hambita project.

For the regression analysis, we estimated two models. In the first model (column 2 in table 3.4), we looked at factors that determine whether or not a household participates in an agroforestry activity. Probability of participation can therefore be expressed as:

$$Pr(P_i=1) = X_i\beta + U_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where probability $P_i = 1$ if household '*i*' decides to enroll for an agroforestry contract and 0 otherwise. *X* is the set of explanatory variables along with slope coefficients β, and U_i is the error term. Equation (1) can be modified and solved using the standard Logit model where the dependent variable L_i is log of the odds ratio of participation:

$$L_i = ln(P_i/1\text{-}P_i) = (X_i\beta) + U_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

In the second model (column 3 in table 3.4), we analyze the intensity of participation in the N'hambita project. Since a household can simultaneously enroll in multiple agroforestry contracts, we identify factors that determine the number of contracts that a household signs for. Since the dependent variable is censored on left hand side (the minimum number of contracts being 0) a Tobit model is appropriate in capturing the marginal effects of various household characteristics on intensity of participation (Pagiola *et al.*, 2008; Rajasekharan and Veeraputhran, 2002) [19].

Denoting Y_i as the observed number of agroforestry contracts for household *i*, and with *X*, β, and *U* being defined as before, we can write the Tobit model:

$$\left.\begin{array}{l} Y_i = (X_i\beta) + U_i = Y_i^{*} \\ \text{if } (X_i\beta) + U_i > Y_i^{*} \text{ and} \end{array}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

[19] An alternative is to use the two-stage Heckman correction. However, as Mercer (2004) points out, if there is no *prima facie* reason to assume that variables that explain the dichotomous decision of whether or not to participate and then the intensity of participation, the use of the Tobit model is more appropriate.

$$Y_i = 0, \text{ if } (X_i\beta) + U_i \leq Y_i^*$$

where Y_i^* denotes the underlying latent variable, which in our case was only observed when a household enrolled in a non-negative number of agroforestry contracts. We estimated both the Logit (equation 2) and the Tobit model (equation 3) using the relevant commands in STATA. The list of possible explanatory variables for the right hand side was drawn from relevant literature on agroforestry adoption (Mercer, 2004; Nkamleu and Manyong, 2005; Franzel, 1999). In a comprehensive review of such studies, Pattanayak *et al.* (2003) report five categories of factors that were most important in explaining agroforestry adoption: preferences, resource endowments, market incentives, biophysical characteristics, and risk and uncertainty. Based on this work, we included the following variables in our two econometric models: (1) household characteristics – gender of the household head, age of the household head, educational status of the household, household size, and year of migration into the community, (2) resource endowment – livestock ownership, number of *m'shambas* or fields, (3) off-farm income – any permanent job or wage labor, and (4) location of the household. According to table 3.1, all villages except one (Pungue) were located far away from the nearest paved road. Therefore, taking Pungue as the base (dummy =0), we checked for the marginal effects of a household being located in any of the other five villages viz. Bue Maria, Mbulawa, Munhanganha, Mutiambamba, and N'hambita.

The overall results were similar across the two models. Although the gender of the household head was insignificant, similar to Nkamleu and Manyong (2005) and Franzel (1999), we found both household size, and off-farm income (income from a regular job or a business) to be significant. Other factors that influenced participation were: whether the household migrated into the community in the previous five years, total annual cash income of the household, and location of the household represented by villages that were away from the paved road. Household size had a strong positive influence on both the decision to participate and on the number of agroforestry contracts a household enrolled for, once it decided to participate. A larger household helped in supplying additional labor when a new land use practice was adopted. Therefore, addition of each member increased the odds of participating by 1.34 (coefficient value or log of odds ratio 0.29), while the predicted value of entering an extra contract increased by 0.14 However, if a household had migrated into the area within the last five years, it had a lower likelihood of both participating in the project (coefficient value -1.32) as well as possessing more agroforestry contracts (the predicted number of contracts fell by -0.53). This was an expected result as recent migrants were still establishing themselves in the community and were probably unaware of the project or how best to access it. Similar to the findings of Pagiola *et al.* (2008) in Nicaragua, the econometric analysis confirmed that poorer households had a slightly higher chance of both participating (-0.0008) in the project as well as in entering more agroforestry contracts (-0.0003). Participation in agroforestry activities ensured a regular source of cash income, which was important, especially for the poorer households. Interestingly, households that already had a regular income source in the form of a job or a small business were also more likely to participate in the project as well as to take up more agroforestry contracts. This could be due to their ability to pay for the initial investment in adopting a new land use and to absorb any associated risk. However, the extremely low magnitude of the respective coefficient values (0.0009, and 0.0004) shows that households with lower off-farm income also did not find it difficult to access the project. Finally, households that were located away from the paved road had a much lower probability of participating in the project than households that were located in the village Pungue, which was closest to the road (column 1). However, once the households started participating in the project, their intensity of participation measured in terms of the number of contracts they possessed, was largely unaffected by their location (column 2). This showed that remotely located households had difficulty in first accessing the project, perhaps because the information about the project activities was yet to reach them. But once they started to participate they had an equal chance of entering additional contracts.

In terms of implications for the participation of the poor in the project, this discussion indicates that the poorer households are indeed able to participate in the N'hambita project. Of the variables that we found significant, only one – annual cash income – was related directly to the economic status of the households, and even this showed that poorer households had a better chance of participating in the project. The other factors such as location or size of the household did not point towards any systematic barrier against the poor households.

3.5 PROJECT IMPACTS

According to our household survey, and based on the recall data reported to us for 2001, before the N'hambita project started, an average household in the area consisted of 3.5 people, of whom only one was literate (table 3.5). One third of all households were completely illiterate. Households owned an average of 1.4 *m'shambas* or fields, while almost all households grew food crops such as maize, cassava, pigeon pea, and sweet potato. 87.4% of households also cultivated fruits and vegetables while a lower percentage (79.6%) cultivated a cash crop, mainly sugarcane. 80% of households also purchased food from outside, spending an average of MTN 1973 for the entire year. Most households (91.9%) raised poultry birds while a smaller percentage also owned livestock (63.3%). The average annual cash income was only MTN 975.40 while households possessed an average of 2.3 durable assets such as a radio, bicycle, or a fishing rod etc.

By 2008, five years after the initiation of the N'hambita carbon project, many of these statistics had changed significantly. The average household size had increased to 5.03, the number of literates per household had increased to 1.6 while the proportion of completely illiterate households had fallen to 22%. The number of *m'shambas* per household also increased to 1.9, while the average livestock ownership fell. More than one-third of all households had at least one member with a job or ran a small business. Both the annual cash income and the average number of durables also increased to MTN 1740.60 and 2.44 respectively (table 3.5). Clearly, there were marked changes in the area. In this context, there were two broad questions that we wanted to explore: (i) the extent to which these changes could be directly ascribed to the N'hambita project, and (ii) differences in project impacts on three groups of households in the area – those that possessed both agroforestry contracts and jobs in MEs, those with only agroforestry contracts, and those with neither.

We also wanted to check for potential bias in the selection of the project participants. For instance, what if the participating households already owned more assets than the non-participants at the time the project first began? We compared this by conducting a before-project (2001) and an after-project cross-sectional analysis of the three groups of households. Table 3.6 shows that before the project started, there were few differences across households in the three groups except farm ownership (F-value from one way analysis of variance being 2.76), annual expenditure on food (6.23), and access to wage labor within the village (4.11)[20]. More importantly, the F-values for differences in average annual cash income (0.21) and asset ownership (0.56) were insignificant, which implied that there were no large systematic

[20] Non-participating households were involved in more wage labor activities primarily in the form of seasonal agricultural labor within the village. Perhaps, they received their wages in the form of agricultural produce, which explains why they incurred relatively lower expenditure on purchasing food from outside.

differences across households and they were mostly similar when the project activities first began in the area.

However, after the initiation of project activities, the situation changed quite a lot and the households in the three groups were no longer similar (table 3.7). A cross-sectional analysis of the same households in 2008 revealed that there were significant differences in of the number of literates per household (F-value 2.52), percentage of households with no literates (3.04), number of farms per household (3.57), household's annual expenditure on food (10.52), access to a permanent job or a small business (19.42), household's annual cash income (8.61), and the number of assets it owned (3.82).

So, although the households in the three groups were fairly similar before the project started, they underwent significant changes after the project was introduced. In order to assess these changes and to answer the two questions raised above, we use the difference-in-difference approach as follows (Uchida *et al.*, 2007; Wooldridge, 2002, pg. 284):

$$DD = [E(T_1|D=1) - E(T_0|D=1)] - [E(T_1|D=0) - E(T_0|D=0)] \quad \ldots\ldots\ldots\ldots\ldots (4)$$

Where DD is the difference-in-difference estimator, i.e. it compares before and after project status for project participants with respect to a similar change for non-participants. E(.) denotes the expected or the mean value for a particular group of households; D=1 represents households that participated in the project, while D=0 denotes non-participants. T_1 denotes the after-project status for a household (year 2008 in our case), while T_0 denotes the before-project status (2001). So DD estimates the average impact on participating households between 2008 and 2001 compared to the average impact on the control group for the same time period. Since we had three categories of households in the N'hambita project, we modified the approach slightly:

$$\left.\begin{aligned} DD_0 &= [E(T_1|D=0) - E(T_0|D=0)] \\ DD_1 &= [E(T_1|D=1) - E(T_0|D=1)] \\ DD_2 &= [E(T_1|D=2) - E(T_0|D=2)] \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

T_1 and T_0 have the same interpretation as before, i.e. they signify the after (2008) and before project (2001) status respectively. DD_0 measures the average change in non-participating households (D=0) between 2008 and 2001; DD_1 measures the average change over the same time period for in households that possessed only agroforestry contracts (D=1), and DD_2 measures the average change in the same period for households that had both contracts and jobs in MEs (D=2). Once we estimated DD_0, DD_1, and DD_2 for various impact variables, we conducted F-tests to check whether or not the mean changes were significant across the three groups of households. Our working hypothesis is that the project impact would be highest among households that had both ME jobs and agroforestry contracts, followed by households with only agroforestry contracts, and then by non-participating households that had neither of the two (table 3.8). We present these results in the form of project impacts on participants, non-participants, and the spillover effects in the community.

3.5.1 Impacts on project participants

The N'hambita project provides two direct benefits to local people: carbon payments to households that participate in agroforestry activities, and salaries to people who are employed in various microenterprises. The schedule of carbon payments is as follows: 30% of the contract value in the first year, 12% per year for the next five years, and then a final payment of 10% in the seventh year. By the time of our field survey in 2008, most participating households had received two or three rounds of payments; the average payment per household for the previous year (2007–08) was MTN 1923 ($80), equivalent to about two to three months of wage labor. In contrast, the average annual salary of an ME employee during this period was much higher at MTN 12,484 ($519)[21]. In our group discussions with project participants, many respondents said they used their money to buy roofing material, food and clothes for the family, or books and school stationery for their children. Some people also invested in agricultural seeds, while others bought household durables such as a radio or a bicycle.

Table 3.8 shows that average annual cash incomes before (2001) and after (2008) the project increased for households that possessed only agroforestry contracts (increase of MTN 566.30) as well as for households that had both agroforestry contracts and jobs in MEs (MTN 1865.11). The corresponding change for non-participating households, although positive (MTN 208.60), was relatively modest and statistically insignificant. Although an F-test for comparison of the three mean increases was also significant (F-value 14.25), this was only because of the huge increase in income for the group that possessed both agroforestry contracts and jobs in MEs. Households that participated in only agroforestry activities had more income than before, but this increase was statistically insignificant when compared to the mean change in income for non-participating households. Thus the impact of wages earned from employment in MEs was much stronger than the impact of carbon payments alone. The same was also verified when we analyzed the change in average asset ownership. Again, households with employment in MEs and with agroforestry contracts increased their ownership of durable assets by an average of

[21] Some people such as the forestry extension staff receive a fixed monthly salary while others such as carpenters get a piece rate.

0.41, which was much larger than the increase for households with only agroforestry contracts (0.04) or for non-participating households (a decrease of 0.11 per household). Predictably, there was also a huge increase in access to a regular job for households that received employment in the local MEs (51.85%) but not for the other two groups.

These results substantiate our working hypothesis stated in the previous section as the households with ME employment were much better off than others. However, there is one major departure: households with only agroforestry contracts were slightly better off than before but this change was not significant when compared to the change for non-participating households with neither ME jobs nor agroforestry contracts. In other words, the development component of the project had a significant livelihood impact on participating households, but the same cannot be said for the PES component. However, it is also important to note that most households had received only two to three rounds of carbon payments by the time this study was conducted. With more payments to come in the near future, the impact on participating households may increase. In addition, as the agroforestry systems mature, they will generate marketable products such as fruits, with additional financial benefits for participants.

3.5.2 Impacts on non-participants

By design, payments under a PES project accrue to service providers (Ferraro and Kiss, 2002). As a result, participating households can expect to gain more than non-participating households – an incentive mechanism to encourage land stewards to adopt more sustainable land use practices. An important concern regarding non-participants, however, is whether the PES project poses any risk to their livelihoods should they voluntarily decline to participate (Pagiola *et al.*, 2005).

Table 3.6 shows that before the project started, 60.9% of the non-participating[22] households earned wage labor in the village, mainly by providing seasonal agricultural labor to other households. By 2008, the proportion of non-participating households earning wage labor within the village dropped to 52.2% (table 3.7). This reduction of 8.7% (table 3.8) before and after the project was much bigger when compared to the change for households with both agroforestry contracts and ME jobs (-3.7%) and for households that had only agroforestry contracts (2.9%). For those households now employed in various MEs, the reduced access to wage labor is compensated. This is also true to a large extent for households that receive carbon payments from agroforestry contracts. However, the same cannot be said for non-participating households. There is insufficient data to establish whether or not the loss in wage labor income for non-participating households has resulted in an overall decline in their economic status. Their average asset ownership declined marginally (-0.11), but this change is statistically insignificant, while their cash income showed a modest increase (MTN 208.60).

Non-participating households may also face increased hardship from a complete ban on harvesting any resources from the large tract of miombo forest under REDD activities. However, the project tries to ensure that benefits from REDD activities reach the entire community. For instance, all REDD payments are transferred to a community fund that supports development of community infrastructure such as construction and maintenance of school buildings. We explore the spillover impacts of these activities presently.

[22] Technically, there are no non-participants in the project area since even these households participate in REDD activities. However, the attempt here is to explore the more direct impact of participation or non-participation in agroforestry activities.

3.5.3 Spillover effects in the area

In recent years, there has been impressive growth in public infrastructure in the area, mainly due to an overall improvement in Mozambique's national economy rather than direct project intervention. However, the project does play a role in creating demand for such infrastructure. The $80 of carbon payments that each participating household receives on average aggregates to about $70,000 per annum for the community. In addition, most people employed in MEs belong to the local community and spend a considerable proportion of their monthly wage within the area. This is a significant change for the local people, who until a few years ago had very few sources of cash income.

Rising disposable incomes have also resulted in expansion of economic activity in the area. With many households routinely buying household items such as soap and cooking oil, many small provision stores and grocery shops have opened in all the six villages, which is a considerable improvement given that most of these villages had almost no local shops till just a few years back.

Another important spillover benefit is the community trust fund which receives half of all REDD payments and a proportion of carbon payments from agroforestry activities. This fund is managed by the local community association which consists of 24 members representing different villages. In mid-2008, there were MTN 65,000 ($2,683) in the trust fund with more REDD payments (about $22,942) expected shortly. The association has mainly used this trust fund for community development activities such as construction and maintenance of school buildings and a local health clinic, that benefit the entire area irrespective of the participation status of individual households.

Apart from these qualitative impacts, there are two additional impacts that we explored empirically: change in literacy rates and a decline in livestock ownership. During focus groups, many participating households said they had used their carbon payments to pay for their children's school fees and school supplies. Both tables 3.5 and 3.7 show an impressive change in overall literacy rates in the area between 2001 and 2008; the average number of literates per household increased from 0.9 to 1.6 during this period, while the percentage of households with no literates fell from 33% to 22%. This change was equally impressive across both participating and non-participating households (table 3.8). In order to confirm whether or not the change in literacy rates was a spillover effect of the project, we compared the change in project villages with the change in control villages that were outside the project area[23]. Using the difference-in-difference approach as outlined before, but now comparing the mean change before-project (T=0) with after project (T=1) for households in project villages (D=1) with the change over the same period for households in the control villages (D=0):

$$DD = [E(T_1|D=1) - E(T_0|D=1)] - [E(T_1|D=0) - E(T_0|D=0)] \quad \ldots\ldots\ldots\ldots\ldots. (6)$$

Table 3.9 shows that even in the control villages, the average number of literates per household increased from 0.8 in 2001 to 1.8 in 2008, while the proportion of household with no literates fell from 40.6% to 23.4% over the same period. The difference between the mean change in the number of literates per household in the project villages (0.7) is not statistically significant from that in the control villages (1.0). The same result is found for the decline in proportion of households without literates where the difference-in-difference or the DD estimate (-6.1%) is close to zero. These results indicate that the increase in literacy rates is due to an

[23] Six villages from the neighboring area of Cudzu were selected as control villages.

overall increase in educational attainment in the entire region rather than any direct or indirect impact of the N'hambita project.

A ban on using a local forest or pastureland can also have an adverse impact on the community, especially in terms of a drop in livestock ownership as the animals can no longer be taken out for grazing (Jindal, 2000). Although, we do see a similar trend in the case of the N'hambita project where the livestock ownership declined by an average of 2.8 animals per household between 2001 and 2008 (table 3.8)[24], table 3.9 shows that even in control villages, the average livestock ownership decreased from 12.6 animals per household in 2001 to 7.4 animals per household in 2008. Comparison of the mean decline in the project villages (2.8) with the same in control villages (5.2) shows that the two were not significantly different from each other, i.e. DD was not statistically different from zero. This indicates that a fall in livestock numbers is a wider trend in the area. We could not establish whether this decline was due to some livestock disease or a result of a drought in the area or to changes in the structure of the economy, but as we can infer, the decline in livestock ownership was not due to the project, which is also confirmed by the decline in ownership of poultry birds in both the project and the control villages.

3.5.4 Environmental impact of the N'hambita project

We explore the environmental impact of the N'hambita project in terms of carbon offsets produced by agroforestry and REDD activities. The number of carbon sequestration offsets (in tCO_2) from agroforestry systems can be estimated as:

No. of carbon offsets = {(kind of agroforestry contract – baseline) – buffer} X area ………. (7)

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[24] Livestock here mainly refers to small ruminants such as goats and sheep. There were hardly any large ruminants in the area such as cows or bulls. Therefore, we measured livestock ownership in terms of number of animals owned per household.

The kind of agroforestry contract refers to different agroforestry systems offered by the project, each with a specific carbon sequestration rate. The baseline is the carbon stock of existing trees and shrubs on a site prior to new planting. To calculate the net number of carbon offsets, the project team subtracts the baseline from carbon sequestered through project activities (table 3.2). Since measuring actual carbon stock on each dispersed site is expensive, the project uses sample plots to estimate the existing stock of carbon for the entire area (Williams *et al.*, 2008; Sambane, 2005).

By May 2008, the project had 1,234 agroforestry contracts in operation, covering about 1,000 ha of farmland. According to our survey, boundary planting was the most popular, followed by fruit orchards, and homestead planting respectively. The project team estimates that during the previous five years, local farmers had planted more than 500,000 trees under different agroforestry systems, expected to generate a total of 82,056 tCO_2 as carbon sequestration offsets.

Avoided deforestation or REDD activities consist of protection and management of miombo woodlands around the Gorongosa National Park. On average, a well stocked area of miombo woodland contains 95.42 tCO_2 per ha, much of which is under threat of being emitted into the atmosphere due to deforestation (Grace *et al.*, 2007). To reduce deforestation, the N'hambita project pays the local community to protect 11,071 ha of miombo woodlands outside the GNP, while motivating community members to also conserve additional forest areas through selective logging and reforestation. The project team estimates that these protection and conservation activities have reduced emissions at the rate of 7.33 tCO_2/ha per annum since 2006, generating 154,457 tCO_2 as REDD offsets. This implies that the project has generated a total of

236,513 tCO_2 REDD and carbon sequestration offsets, placing it among the small to medium sized forestry carbon projects in Africa (Jindal *et al.*, 2008).

(i) Leakage

Leakage refers to unplanned emissions of carbon arising from activities outside the project boundary. For instance, project beneficiaries may plant trees at one site but cut trees in another, resulting in net release of carbon to the atmosphere. The three main drivers of leakage in the area are cutting of trees for charcoal production, uncontrolled burning of farmlands, and clearing of forest for agriculture. Charcoal production is an important source of livelihood in Mozambique (FAO, 2007). In Chicale *regulado*, Herd (2007) estimates that 35 ha of local woodlands are lost every year to charcoal production. The N'hambita project has tried to address this issue by promoting agroforestry as an alternative source of income and by educating charcoal producers to use efficient kilns that reduce wood intake. The project also discourages the local community from installing any new kilns in the area.

Burning of farmlands is an old cultural practice in the area. Farmlands or *m'shambas* are burnt in preparation for cultivation, to clear undergrowth around settlements, for honey collection, or to keep away dangerous animals. This increases the risk of carbon loss especially if the fire escapes to nearby forest areas (Zolho, 2005). Therefore, the project strictly dissuades contracted households from burning their *m'shambas*. However, in our survey, 16% of agroforestry contract holders confirmed that they had burned their *m'shamba* in the previous year. Although many of these respondents had also modified the burning to reduce the risk of wildfire, clearly it is not easy to end this old cultural practice and the project needs to do much more to reduce the chance of leakage.

The third and probably the most important driver of leakage in the area is the clearing of forest for agriculture. During the Mozambique civil war from 1977 to 1992, a large proportion of the population was displaced from rural to urban areas (Heltberg *et al.*, 2003). Since the 1994 peace accord, many people have returned to rural areas in search of better livelihoods (figure 3). For instance, 35% of our respondents migrated to the Chicale *regulado* from outside, As expected, the biggest influx of people was immediately after the return of peace in 1994. Relevant for the N'hambita project is the curve after 2003, which has lower peaks than earlier, but the arrival of new households still continues. This translates into potential leakage for the project as the incoming households clear forests to set up their farms. Dealing with this internal migration, however, is a national policy issue and the N'hambita project has little control over it. The project does try to reduce its impact though by encouraging migrants to enrol for carbon contracts provided they agree to conserve existing forests by not clearing additional land for *m'shambas*.

Interestingly, the practice of setting up new *m'shambas* is not limited to recent migrants alone. According to our survey, the average number of farms in the area increased from 1.4 per household in 2001 to 1.9 in 2008 (table 3.5). Previously settled residents may clear forests to set up new farm plots as their old plots become less productive with time (Jindal, 2004). Another reason could be that as more and more fields are put under agroforestry activities, farmers may need to clear additional forestland to grow food crops for the household needs. The latter, however, cannot be verified when we look at households in the control villages, where the number of fields per household also increased from 1.3 in 2001 to 2.0 in 2008 (table 3.9). If at all, this increase (0.7) is more than the increase in the number of fields per household in the project villages (0.5), but this difference is statistically insignificant.

(ii) Permanence

Permanence of carbon offsets is an important concern due to the temporary nature of forestry carbon stocks – a forest can be cut at any time, eventually releasing most of the sequestered carbon back into the atmosphere (Sedjo *et al.*, 2001). For the N'hambita project the most important threat to permanence is the extremely long contract period. The project estimates its carbon offsets based on a 100 year contract period. Assuming such a contract is enforceable, it produces high value long-term offsets but it subjects future generations to a rule they may not agree with. An alternative for the project is to shorten the contract period, to say ten years. However, that would produce temporary carbon offsets which carry a lower price in the market (Haites, 2004). This would greatly reduce the carbon payments to farmers and perhaps make the project financially unviable. So there is an inherent trade-off between contract duration and the payment that local farmers will receive for carbon offsets.

A related issue is the timing of carbon payments. To help farmers cover establishment costs of setting up new agroforestry systems, the project pays them the entire value of the carbon offsets over the first seven years. Thereafter, the agroforestry systems are expected to provide enough returns in the form of improved soil productivity, and timber and non-timber products for farmers to continue managing them well. Many systems such as mango and cashew orchards will also provide saleable products that can yield additional incomes. However, these benefits are yet to accrue as most trees are still very young and in many cases may not compensate for loss of carbon income. If some farmers do decide to cut their trees or stop caring for them after seven years, the entire project may be jeopardized. The project tries to address this threat by retaining 15% of all carbon offsets as a risk buffer. However, future experience will determine if this risk buffer is sufficient to address concerns regarding permanence of carbon offsets.

3.6 CONCLUSION: LESSONS FROM N'HAMBITA

A lot has been written about the potential poverty impacts of PES projects, especially forestry based carbon mitigation projects. While this paper does not contradict these claims, the analysis presented here offers a word of caution. The N'hambita community carbon project is a well run project and within a short period of time it has penetrated deep within the community with a participation rate of more than 80%. We also found that poor households are able to access the project and many of them have multiple carbon contracts in the form of agroforestry systems. The resultant carbon payments do supplement household incomes but not enough to move the households out of poverty. Poverty alleviation is a long, complex process and it is not realistic to ask PES projects, even with their community focus, to achieve it completely on their own. In contrast, the development component of the project has had an immediate economic impact through the employment opportunities it has created. However, the project cannot employ everyone in the community and this may not be even replicable when most of the project finance is raised from carbon sales in environmental markets.

There are also some useful lessons for the continuing negotiations on the role of forestry carbon projects in carbon mitigation strategies. Combining carbon sequestration on individual plots with REDD payments on community owned forests presents an interesting option. This natural complementarity helps reduce transaction costs relative to overall project benefits. Transaction costs for the N'hambita project are high but would have been much higher if the two activities were not combined. It is important to design such combined projects in ways that ensure that local communities retain flexibility to meet their timber and nontimber needs.

The menu of agroforestry systems offered by the N'hambita project also addresses the issue of flexibility to a certain extent. In contrast to many carbon sequestration projects that allow only one set of land use practices, this menu provides flexibility for individual households to select systems that suit their specific needs. Mixing native trees with other multi-purpose species also ensures that as the trees mature, farmers can fulfill many of their timber and non-timber requirements from their own farmlands, reducing the need to fell forest trees.

This flexibility comes at a price: escalating transaction costs related to monitoring and supervising individual contracts. Even in N'hambita, where a large proportion of carbon offsets comes from REDD activities, one third of all carbon revenue is used to meet local transaction costs and another third is paid to international brokers and commission agents who help sell carbon offsets. However, there are two interrelated issues here. One is that when the official Kyoto market does not accept forestry offsets and the voluntary market is highly disaggregated, hiring international brokers may be a necessary expense. In case of N'hambita, these brokers ensure that the project continues to sell its offsets at a premium. This is not easy considering how variable the carbon price is; even on a well established voluntary market such as the Chicago Climate Exchange, the price had reduced from a high of \$5 per tCO2 to less than \$0.50 per tCO2 within a short span of time. In contrast, local farmers would need assurance of steady payments in return for taking up carbon sequestration activities. How would community based projects manage to establish these contracts if the carbon price in the voluntary market is so uncertain? The second issue relates to high transaction costs when many small farmers are contracted, instead of a few large ones (Kerr *et al.*, 2006). When these costs are unavoidable, projects may again need additional funds until they are able to raise sufficient carbon revenue from the market. This raises serious concerns about the viability of community based carbon projects that are not subsidized by donor funds, at least in the initial stages of project development.

Another concern about the N'hambita project is the duration of the contract and the payment schedule. Monetizing carbon offsets over 100 years and disbursing payment over seven years has the advantage of taking care of farmers' upfront costs, but it locks them into very long term contracts leaving little room for renegotiating the contract if market prices for carbon offsets increase in the future. Also, after the last payment there is a real risk that farmers, particularly future generations, may have little incentive to care for their trees. Addressing this challenge poses a dilemma. Instead of monetizing carbon offsets over 100 years (long-term carbon offsets), the project could pay farmers on an annual basis for the number of offsets they produce in that year (temporary carbon offsets). Such a contract would be realistic but the value of the carbon payments might be too low to interest farmers.

Finally, in terms of payment mechanisms for REDD, this project distributes payment between wages for forest guards and a community fund. Judicious use of the fund is paramount in giving individual households an incentive to conserve the forest. However, forest use is dynamic and open to many conflicting claims. In the N'hambita project, migration into the area and new migrants' need to create farmlands places heavy pressure on forests, which cannot be addressed only through REDD payments. This is a national phenomenon which requires a country wide strategy.

Appendices

Table 3.1: Profile of project villages in Chicale *regulado*

Village	Distance to tar road	Total number of households*	Location of nearest		
			Primary School	Primary Health Center	Grocery shops
1. Bue Maria	20 km	42	2 km	20 km	27 km
2. N'hambita	12 km	64	In village	12 km	In village
3. Munhanganha	12 km	65	In village	12 km	12 km
4. Mutiambamba	8 km	56	In village	8 km	8 km
5. Mbulawa	6 km	414	In village	10 km	In village
6. Pungue	1-4 km	385	In village	In village	In village

Source: Authors' field work 2008. * Hegde and Bull (2008)

Table 3.2: Important components of the N'hambita project

I. PES Component	II. Development Component
1. **Payments for Carbon sequestration**	1. **Jobs in microenterprises (ME)**
• Agroforestry on HH farms • Payments to HH for 7 years (based on rates for 100 years) • Avg price $4.50/tCO2 • Payment: $400-$800/ha	• Various microenterprises promoted by the project • Carpentry shop • Tree nurseries • Salary $50 - $100 per month
2. **Payments for REDD**	2. **Project and extension staff**
• Protection of 11,000 ha forest block • Payment to community trust fund	• From local community • Salary $100 - $600 per month

Table 3.3: Carbon sequestration rates under the N'hambita Project

	(1) Carbon sequestered (tC)	(2) Baseline carbon stock (tC)	(3) Buffer carbon stock (tC)	(4) Net carbon offsets (tC) (1) – (2) – (3)	(5) Net carbon offsets (tCO_2)*
Boundary planting	3.23/100m	0	0.48/100m	2.75/100m	10.03/100m
Interplanting (*Gliricidia*)	10.00/ha	0	1.50/ha	8.50/ha	31.16/ha
Cashew orchards	40.14/ha	2.8/ha	5.60/ha	31.74/ha	116.38/ha
Mango orchards	34.00/ha	2.8/ha	4.68/ha	26.52/ha	97.24/ha
Homestead planting	42.05/ha	0	6.30/ha	35.75/ha	131.08/ha
Woodlots	61.30/ha	11.3/ha	7.50/ha	42.50/ha	155.83/ha
Interplanting (*Faidherbia*)	58.20/ha	0	8.73/ha	49.47/ha	181.05/ha

* 1tC = 3.67 tCO_2.
Estimates are based on projected tree growth under standard climatic and soil conditions, and assume that all farmers will follow a standard set of silvicultural practices. These sequestration rates may be affected by natural disasters such as prolonged drought or fire outbreaks.

Source: Tipper, 2008.

Table 3.4: Determinants of participation in agroforestry activities

	(1) Dependent variable = probability of participation Logit Model	(2) Dependent variable = number of contracts Tobit Model
Gender of household head (Male = 1)	-0.17 (0.43)	0.07 (0.17)
Migration into the area within past 5 years (dummy)	-1.32 (0.55)***	-0.53(0.27)**
Number of people in the household	0.29 (0.15)**	0.14(0.06)**
Number of literates in the household	0.12 (0.27)	0.07 (0.099)
Age of the household head	-0.002 (0.015)	-0.00 (0.006)
Number of *m'shambas* per household	0.15 (0.31)	0.14 (0.13)
Number of livestock per household	-0.03 (0.04)	0.002 (0.127)
Total annual cash income of the household	-0.0008*** (0.0002)	-0.0003** (0.0001)
Household Income from a regular job and/or a business	0.0009*** (0.0004)	0.0004*** (0.0002)
Bue Maria (Dummy = 1)	-17.85 (1.29)***	-0.19 (0.416)
Mbulawa (Dummy = 1)	-19.45 (0.81)***	0.56 (0.32)**
Munhanganha (Dummy =1)	-19.36 (0.79)***	0.07 (0.28)
Mutiambamba (Dummy = 1)	-18.64 (0.80)***	-0.07 (0.32)
Nhambita (Dummy = 1)	-19.76 (0.82)***	-0.46(0.35)
Constant	20.28	0.64 (0.36)*
LR Chi sq	32.68	42.41
Prob > Chi sq	0.0032	0.0001
Pseudo R sq	0.1532	0.1682
Log likelihood	-90.311	-334.1915

Notes: Figures in parentheses are standard errors
* Significant at 10% **Significant at 5% *** Significant at 1%

Table 3.5: Selected statistics for sampled households, 2001 and 2008 (n=270)

	(1) Before project in year 2001	(2) After project in year 2008	(3) Difference in mean (2) – (1) Paired t-statistics in parentheses
Household size	3.45 (1.77)	5.03 (2.19)	1.58 (15.9)***
Number of literates per household	0.9 (0.95)	1.6 (1.42)	0.7 (9.4)***
Household with no literates (%)	33 (47.2)	22 (41.7)	-11 (5.1)***
Number of *m'shambas* per household	1.4 (0.67)	1.9 (0.88)	0.5 (8.3)***
Household cultivating food crops (%)	95 (21.5)	99 (8.6)	4 (3.1) ***
Household cultivating horticultural crops (%)	87.4 (33.2)	93 (25.6)	5.6 (2.8)***
Household cultivating cash crops (%)	79.6 (40.3)	78 (41.7)	-1.6 (0.65)
Household bought food from outside (%)	80 (40)	82.6 (37.9)	2.6 (1.3)*
Number of months food bought per household	9.1 (3.9)	9.2 (3.8)	0.1 (0.7)
Household's annual expenditure on food (MTN)	1972.80 (1952.8)	2452.30 (2159.5)	484.6 (3.97)***
Household that own livestock (%)	63.3 (48.3)	53.3 (49.9)	-10 (3.01)***
Number of livestock per household	5.1 (7.44)	2.3 (3.3)	-2.8 (6.1)***
Household that own poultry birds (%)	91.9 (27.4)	91.5 (27.9)	-0.4 (0.18)
Number of poultry birds per household	13.3 (13.81)	10.7 (11.61)	-2.6 (3.1)***
Household with at least one permanent job or a small business (%)	24.8 (43.3)	37 (48.4)	12.2 (3.9)***
Household's annual cash income (MTN)	975.40 (1417.15)	1740.60(2076.64)	765.10 (6.9)***
Asset ownership per household (number)	2.34 (1.23)	2.44 (1.29)	0.1 (1.3)*

Notes: Standard deviations are in parentheses for columns (1) and (2)
Column (3) reports absolute value of t-statistics. *** Significant at 1%. * Significant at 10%

Table 3.6: Cross-sectional analysis of sampled households before-project (2001)

Variables	(1) Mean value for non-participating HH	(2) Mean value for HH with only carbon contracts	(3) Mean value for HH with both carbon contracts and ME employment	(4) F-value from one-way analysis of variance
Number of literates per household	0.85 (0.92)	0.99 (0.95)	1.09 (0.98)	0.82
Households with no literates (%)	41.3 (0.49)	34.1 (0.48)	24.1 (0.43)	1.73
Number of *m'shambas* per household	1.44 (0.67)	1.38 (0.56)	1.64 (0.92)	2.76*
Households that own livestock (%)	56.5 (0.50)	66.5 (0.47)	59.3 (0.49)	1.01
Number of livestock per household	3.72 (4.85)	5.5 (7.95)	5.24 (7.80)	0.99
Number of poultry birds per household	13.72 (15.14)	12.89 (13.13)	14.13 (14.63)	0.18
Household's annual expenditure on purchasing food (MTN)	939.66 (745.18)	2205.19 (2108.59)	2053.59 (1841.04)	6.23***
Households with access to wage labor in the village (%)	60.9 (0.49)	37.6 (0.49)	40.7 (0.49)	4.11**
Household with at least one permanent job or a small business (%)	26.1 (0.44)	26.5 (0.44)	18.5 (0.39)	0.71
Household's annual cash income (MTN)	1017.87 (945.33)	998.98 (1488.54)	865.28 (1534.03)	0.21
Asset ownership per household (number)	2.17 (1.32)	2.39 (1.20)	2.37 (1.25)	0.56
Number of sampled households	46	170	54	

Notes: HH Households.
Figures in parentheses are standard deviations.
* Significant at 10% ** Significant at 5% ***Significant at 1%

Table 3.7: Cross-sectional analysis of sampled households after-project (2008)

Impact variables	(1) Mean value for non-participating HH	(2) Mean value for HH with only carbon contracts	(3) Mean value for HH with both carbon contracts and ME employment	(4) F-value from one-way analysis of variance
Number of literates per household	1.26 (1.29)	1.66 (1.39)	1.89 (1.54)	2.52*
Households with no literates (%)	34.8 (48.1)	21.2 (40.9)	14.8 (35.86)	3.04**
Number of *m'shambas* per household	1.67 (0.83)	1.88 (0.81)	2.13(1.06)	3.57**
Households that own livestock (%)	52.2 (50.51)	51.8 (50.1)	59.3 (49.59)	0.47
Number of livestock per household	2.44 (3.15)	2.15 (3.37)	2.63(3.27)	0.45
Number of poultry birds per household	8.13 (8.34)	10.82 (12.02)	12.67 (12.61)	1.92
Household's annual expenditure on purchasing food (MTN)	1209.80 (1401.81)	2885.10 (2188.88)	2153.20 (2179.9)	10.52***
Households with access to wage labor in the village (%)	52.2 (50.51)	40.6 (49.3)	37.04 (48.74)	1.32
Household with at least one permanent job or a small business (%)	19.6 (40.11)	31.2 (46.46)	70.4 (46.09)	19.40***
Household's annual cash income (MTN)	1226.50 (1430.11)	1565.3 (1844.45)	2730.40 (2824.38)	8.61 ***
Asset ownership per household (number)	2.07 (1.29)	2.43 (1.33)	2.78 (1.11)	3.82 **
Number of sampled households	46	170	54	

Notes: HH Households.
Figures in parentheses are standard deviations.
* Significant at 10%   ** Significant at 5%   ***Significant at 1%

Table 3.8: Impacts of the N'hambita project
Difference in difference from 2001 and 2008 status

Impact variables	(1) Mean change for non-participating HH	(2) Mean change for HH with only carbon contracts	(3) Mean change for HH with both carbon contracts and ME employment	(4) F-value from one-way analysis of variance
Number of literates per household	0.41 (0.13)***	0.67 (0.09)***	0.79 (0.16)***	1.46
Households with no literates (%)	-6.5 (0.037)*	-12.9 (0.03)***	-9.3 (0.04)**	0.67
Number of *m'shambas* per household	0.35 (0.13)**	0.58 (0.059)***	0.70 (0.16)***	2.06*
Households that own livestock (%)	-4.3 (0.069)	-14.7 (0.04)***	0.0 (0.07)	1.79
Number of livestock per household	-1.28 (0.56)**	-3.3 (0.65)***	-2.61 (0.97)***	1.46
Number of poultry birds per household	-5.6 (1.93)**	-2.1 (1.08)**	-1.5 (1.91)	1.49
Household's annual expenditure on purchasing food (MTN)	310.8* (203.41)	550.97*** (140.86)	191.57 (306.73)	0.89
Households with access to wage labor in the village (%)	-8.7 (0.04)***	2.9 (0.027)	-3.7 (0.065)	2.07*
Household with at least one permanent job or a small business (%)	-6.5 (0.057)	4.7 (0.03)	51.85 (0.08)***	25.49***
Household's annual cash income (MTN)	208.61 (208.35)	566.28*** (111.26)	1865.11*** (356.13)	14.25***
Asset ownership per household (number)	-0.11 (0.18)	0.04 (0.08)	0.41 (0.17)***	2.94**
Number of sampled households	46	170	54	

Notes: HH Households.
Figures in parentheses are standard errors.
Columns 1, 2, and 3 represent intra-group differences between 2001 and 2008.
Column 4 represents F-values for difference-in-difference for each variable.
* Significant at 10%   ** Significant at 5%   ***Significant at 1%

Table 3.9: Comparison of the Project area with the Control area
Difference in difference between 2001 and 2008 status

	Project Villages			Control Villages			(7)*
	(1) Mean in 2001	(2) Mean in 2008	(3) Difference in Mean (2) – (1)	(4) Mean in 2001	(5) Mean in 2008	(6) Difference in Mean (5) – (1)	Difference in Difference (6) – (3)
Household size	3.4	5.0	1.6 (0.10)	4.2	6.1	1.9 (0.23)	0.3 (0.25)
Number of literates per Household	0.9	1.6	0.7 (0.07)	0.8	1.8	1.0 (0.24)	0.3 (0.25)
Households with no literates (%)	33.3	22.2	-11.1 (0.02)	40.6	23.4	-17.2 (0.05)	-6.1 (0.05)
Number of *m'shambas* per Household	1.4	1.9	0.5 (0.05)	1.3	2.0	0.7 (0.12)	0.2 (0.13)
Number of livestock per household	5.1	2.3	-2.8 (0.46)	12.6	7.4	-5.2 (2.07)	-2.4 (2.11)
Number of poultry birds per Household	13.3	10.7	-2.6 (0.85)	17.5	17.5	0 (2.62)	2.6 (2.76)
Sample Size		270			64		

Notes: Standard errors in parentheses
* None of the values in column 7 is different from zero at usual significance levels.

Figure 3.1: Major components of the N'hambita Community Carbon Project

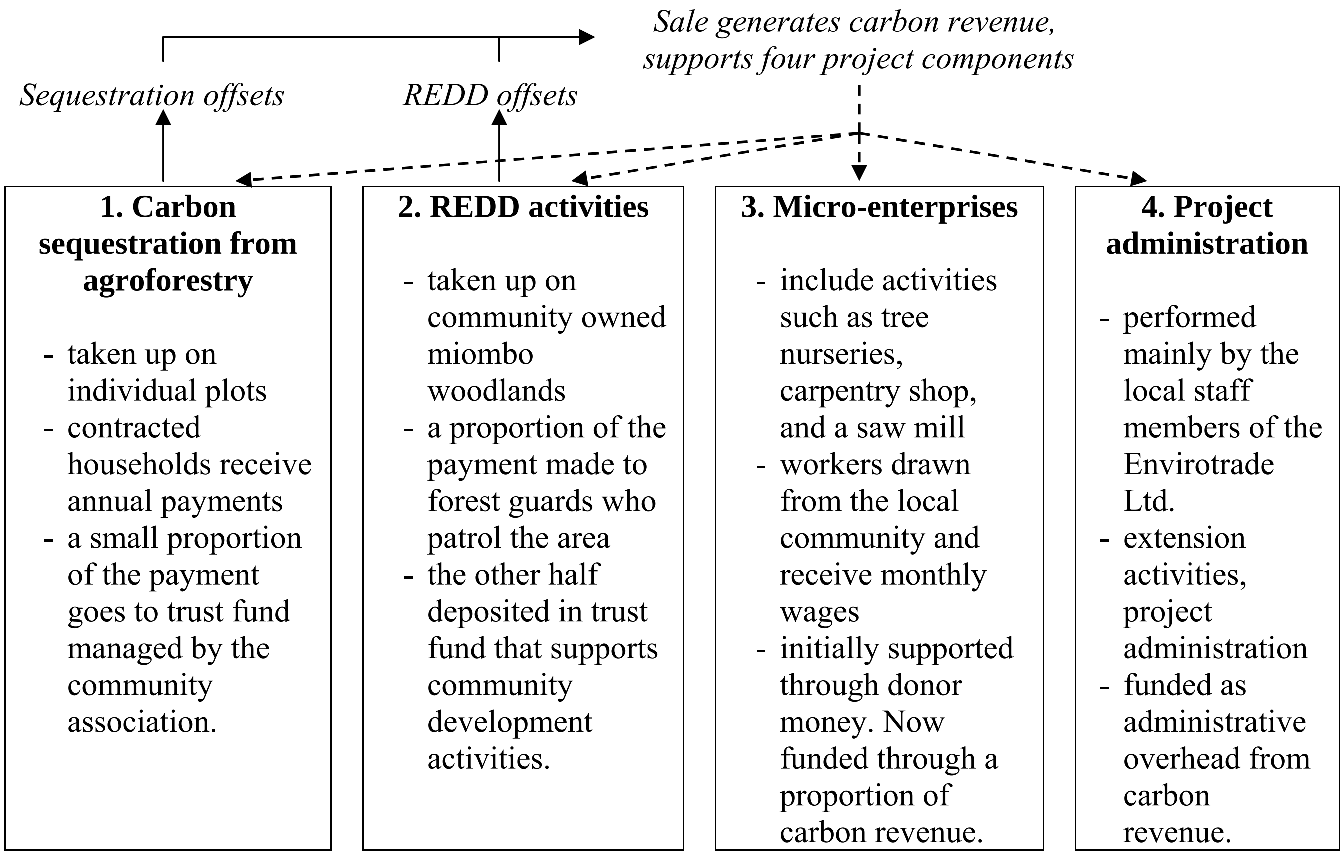
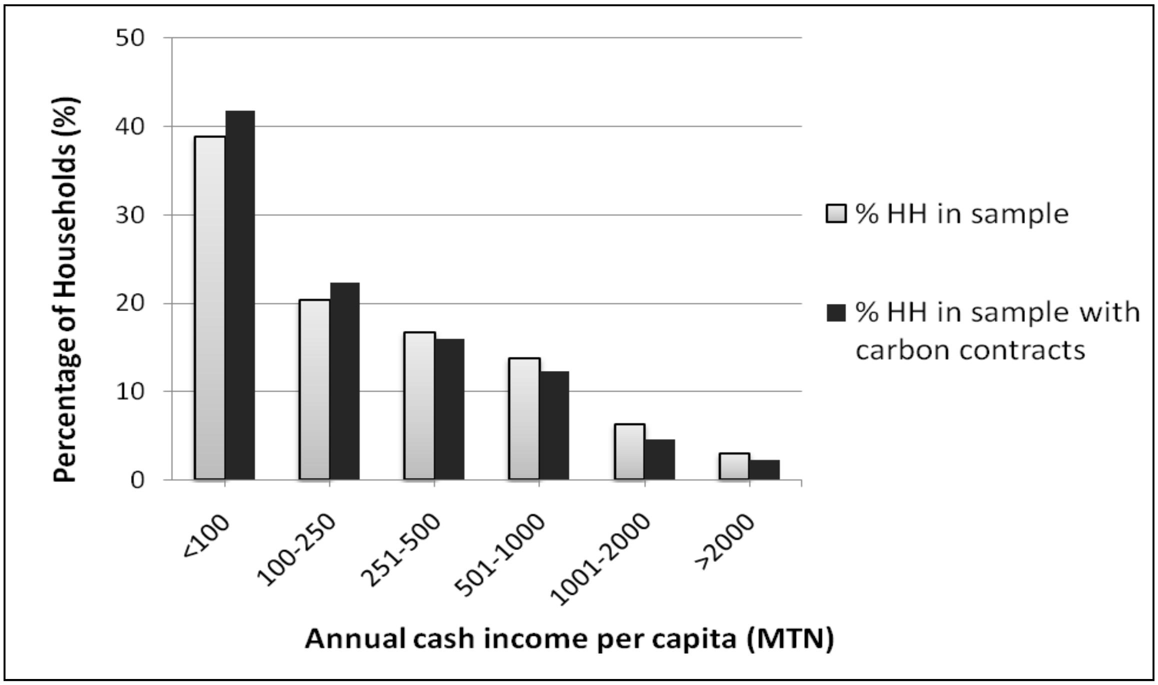
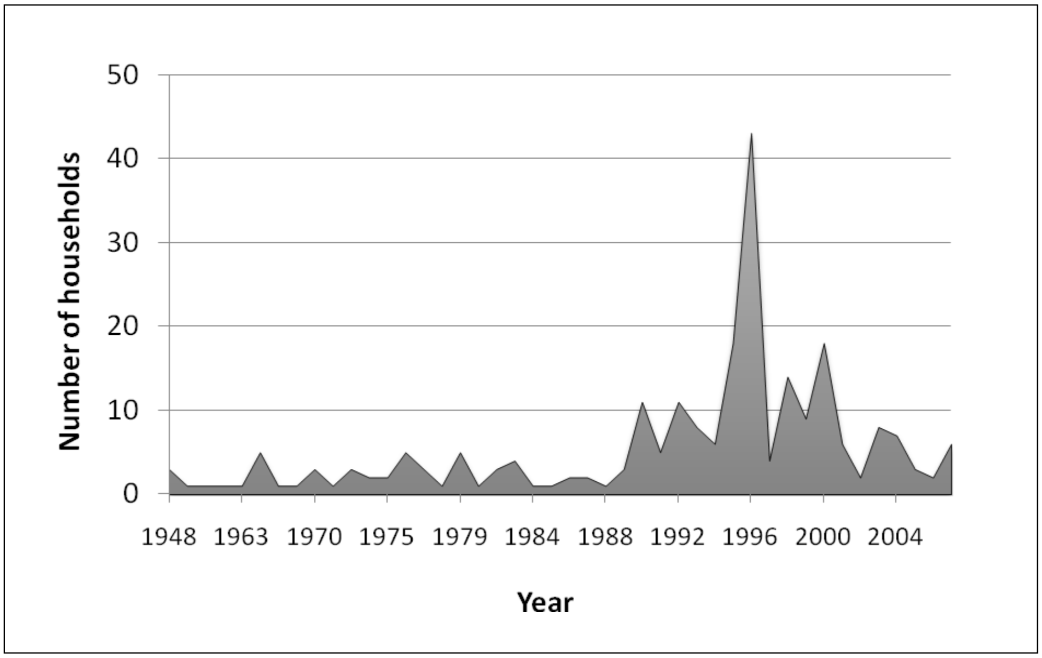


Figure 3.2: Distribution of sampled households: Proportion of households in different income categories (2001) and proportion of households with carbon contracts



Source: Authors' survey (2008)

Figure 3.3: Pattern of migration into Chicale Regulado, Mozambique



Source: Author's survey (2008).

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