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Tree Species, Purposes, and Determinants

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Household Tree Planting in Tigrai, Northern Ethiopia: Tree Species, Purposes, and Determinants

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Abstract

Trees have multiple purposes in rural Ethiopia, providing significant economic and ecological benefits. Planting trees supplies rural households with wood products for their own consumption, as well for sale, and decreases soil degradation. We used cross-sectional household-level data to analyze the determinants of household tree planting and explored the most important tree attributes or purpose(s) that enhance the propensity to plant trees. We set up a sample selection framework that simultaneously took into account the two decisions of tree growers (whether or not to plant trees and how many) to analyze the determinants of tree planting. We used logistic regression to analyze the most important tree attributes that contribute to households' tree-planting decisions. We found that land size, age, gender, tenure security, education, exogenous income, and agro-ecology increased both the propensity to plant trees and the amount of tree planting, while increased livestock holding impacted both decisions negatively. Our findings also suggested that households consider a number of attributes in making the decision to plant trees. These results can be used by policymakers to promote tree planting in the study area by strengthening tenure security and considering households' selection of specific tree species for their attributes.

Key Words: tree planting, tree species, tree attributes or purposes, sample selection, Tigrai, Ethiopia

JEL Classification: Q2, Q23, Q28

Contents

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Introduction

Trees have multiple roles in rural livelihoods, where they provide significant economic and ecological benefits (e.g., they decrease soil degradation). Trees can augment a household's income through sales of wood products and can contribute to risk management by diversifying agricultural outputs and spreading risks of agricultural production failure. Some studies have indicated that eucalyptus trees, which are relatively fast growing, are profitable. They found rates of return for farmers' investments in eucalyptus often above 20 percent (Jagger and Pender 2003). The economic benefits are greatest when unproductive community lands (generally low quality) are used for private tree planting. Similarly, the environmental benefits are more substantial when the trees are planted on degraded land.

Moreover, planting trees is currently seen as an alternative livelihood strategy, particularly in drier areas, such as our study area in Ethiopia, where drought is frequent, soils are very poor, and use of fertilizers and improved seeds is risky and less profitable (Pender et al. 2006). Tree planting has also significantly contributed to the production of non-timber forest products (NTFPs), such as honey and beeswax production. Harvesting honey and beeswax from forests has been a long-time, indigenous tradition in Ethiopia (Hartmann 2004). Ethiopia ranks fourth in the world in beeswax exports, and tenth in honey (Abebe et al. 2008), and tree planting could substantially enhance the production of these NTFPs and the country's role in the export market. Tree planting also provides food; construction materials for traditional farm implements, houses, and household furniture; medicine; and fodder for animals.

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Although some studies (e.g., Patel et al. 1995; Mekonnen 1998; Amacher et al. 2004) have analyzed the behavioral factors underlying tree planting decisions and linked tree planting to fuel issues, too few studies detail the extent and characteristics of on-farm tree cultivation and management practices, the proportion of households in different regions that have adopted these practices, and the households' rationales for doing so (Dewees 1995). Cooke et al. (2008) emphasized that more careful empirical analysis, particularly at the household level, is essential for the choice and targeting of fuelwood-related interventions.

In this paper, we address three questions. First, what factors affect the decision whether or not to plant trees? Second, how do these factors affect the quantity of tree planting, once households decide to plant trees? Third, what are the most important tree attributes or purposes that households consider when deciding to plant trees? We estimated the decisions to plant trees and at what quantity in a full information maximum likelihood (FIML) sample selection framework, where 1) a selection (probit) equation explains the decision to plant trees and, 2) a production function explains the intensity of tree planting. We also applied a logistic regression model on a species-by-species basis to analyze the most important tree attributes or purposes that contribute to the propensity of tree growing.

The paper is organized as follows. The next section presents a literature review of tree planting, tree resources, and rural livelihoods. The theoretical model is presented in section 2. Section 3 outlines the empirical model, and our empirical results are presented in section 4. The concluding section draws some policy implications of the study.

1. Tree Planting, Tree Resources, and Rural Livelihoods: A Review

When Patel et al. (1995) analyzed tree-growing and tree-planting decisions of households, they found that farmers do respond to incentives to plant trees and that tree planting is competitive with other production activities. They also attributed the differences among farm households in this regard to differences in factor costs, owing to different factor endowments and poorly functioning factor markets. Mekonnen (1998) also analyzed tree-growing and tree-planting decisions of households in Ethiopia. He distinguished between two broad categories of trees: all trees and eucalyptus trees. He found that family size, gender, education, and livestock holding are important factors influencing households' tree-plating behavior. He also found that households with relatively more male labor, relatively more income, and a higher proportion of off-farm income are more likely to plant trees. Amacher et al. (2004) examined tree planting in Tigrai, Ethiopia. They distinguished between two groups of species, eucalyptus and other trees, in the same way as Mekonnen; however, they emphasized two sites, tree planting on agricultural land versus microdam land.[1] They found both disease and microdams were important predictors of tree planting and also demonstrated a strong substitution effect between tree planting and agricultural residues, particularly on own land.

Hansen et al. (2005) investigated tree planting under customary tenure systems in Malawi. Specifically, they looked at how gender-specific variations in the transferability of land-tenure rights, as manifested by marriage and inheritance patterns, affected tree-planting behavior. They found that tree planting by married women is not necessarily promoted by matrilocal marriage patterns and that tree planting by men may indeed be discouraged by matrilocal marriage patterns. In fact, they argued that a high incidence of unmarried women is associated with increased tree planting by women.

Salam et al. (2000) analyzed why farmers plant trees in Bangladesh, emphasizing homestead agroforestry. They found that for tree planting economic factors play a larger role than ecological factors. They concluded that even fuelwood scarcity itself is not sufficient to induce decisions to plant trees, especially where substitute fuels, such as animal manure and agricultural residues, can be used in place of wood. Based on a historical analysis of the impact of economic and institutional changes on tree planting on the deforested farmlands of the Sewu hills in Java, Indonesia, Nibbering (1999) argued that the government-launched tree-planting campaign provided important incentives for establishing a critical mass of farmers who adopted tree growing. However, Dewees (1995) argued that the government's tree-planting bonus scheme in Malawi was costly to administer and had limited impact. Dewees also noted that household fuelwood demand and market prices for fuelwood are most important in influencing subsistence farmers' decisions to plant trees.

Based on the experience in western Kenya, Scherr (1995) made three generalizations: 1) agroforestry evolved historically in response to land-use intensification; 2) different livelihood strategies and resource constraints imply different choices of agroforestry practices on particular farms; and 3) associated risks affect farmers' adoption of agroforestry technologies, particularly in the case of new technologies. Emtage and Suh (2004) investigated the socioeconomic factors affecting smallholder tree-planting and management intentions in four communities of Leyte province, the Philippines. They found the primary purpose was to meet household needs for timber, house construction materials, and other household consumption. They argued that

[1] Microdam land is the catchment area or communal land around microdam sites where trees are planted.

household circumstances, rather than community circumstances, are more important influences on tree planting and management activities. However, their analysis was not species specific.

As regards the link between tree planting/tree resources and rural livelihoods, timber, fuelwood, fodder, and fruits directly satisfy household needs. In addition, while allowing more efficient use of labor, tree planting provides households with an alternative means of accumulating capital, adding to cash income and diversifying household economies and livelihoods (Nibbering 1999). Nibbering argued that the combined benefit of tree growing outweighs the gains that could have been obtained from further expansion of annual crop production in the deforested farmlands of the Sewu hills of Java.

Some studies have suggested that eucalyptus trees, which are relatively fast growing, are particularly profitable in northern Ethiopia. They often found rates of return for farmers' investments in eucalyptus above 20 percent (Jagger and Pender 2003). Kidanu (2004) showed that planting eucalyptus as field (plot) boundaries leads to stabilizing the livelihoods of resource-poor farmers and could help smallholder farmers increase their income and achieve food security. Kidanu also suggested that a short rotation of a eucalyptus-based agroforestry system could be practiced in the seasonally-waterlogged highland vertisols[2] of Ethiopia to meet wood demand, without inducing significant nutrient depletion and crop yield loss.

Holden et al. (2003) analyzed the potential of tree planting to improve household welfare in the poorer areas of the Amhara region of Ethiopia, using a bio-economic model. They particularly considered the potential of planting eucalyptus trees as a strategy to reduce poverty in a less-favored area of the Ethiopian highlands. They found that planting eucalyptus on private lands unsuitable for crop production can substantially contribute to poverty reduction in these areas. Salam et al. also linked tree planting, particularly homestead agroforestry, to improvement of overall household income and alleviation of rural poverty. In fact, they contended that tree planting on homesteads could increase overall household income twofold, relative to arable crops. Arnold et al. (2006) argued that fuelwood production, selling, and trading represents a significant part of household income for many people and can be the main source of income for others. They observed that commercial activity with wood fuels provides supplemental, transitional, or seasonal/occasional source of income for some and their main source of income

[2] Vertisols are black, clay soils that shrink and swell as the moisture content changes. During dry spells, the soil volume contracts and deep, wide cracks form. The soil expands as it gets wetter and the cracks close up to some extent.

for others. In some cases, it generates working capital to start up new agricultural or other business. Besides generating income, it also meets the subsistence requirement for fuelwood.

From this literature review, we drew a number of conclusions. First, far too little is known about rural afforestation or tree planting to provide much information for sound policies. There exists inadequate understanding and inability to make detailed characterizations about the extent of on-farm tree cultivation and management practices, the proportion of farmers and households in different regions who have adopted these practices, and their rationale for doing so. More careful economic and empirical analyses, particularly at the household level, are essential, especially when designing or choosing fuelwood-related interventions and their targets.

Second, because consideration of tree species tends to be vital for targeting forestry policy and interventions (Gebreegziabher 2007), most of these earlier works on tree planting (e.g., Patel et al. 1995; and Amacher et al. 2004) have either looked at tree planting in the aggregate or have only distinguished between two broad categories or groups of tree species (e.g., all trees versus eucalyptus trees or eucalyptus versus other trees) and, hence, are not specie specific.

Third, except for very few descriptive attempts to look at purposes, attributes, and principal uses, empirical knowledge about the reasons rural households plant trees and what type of trees they prefer for particular purposes or attributes is extremely scanty. Fourth, it is obvious that trees play multiple roles in rural livelihoods and provide significant economic and ecological benefits for poor farmers. Tremendous opportunities exist to increase family income and improve livelihoods, particularly for the rural poor, through tree growing. Nonetheless, the dimension that the trees contribute to livelihoods varies across species. All these issues call for further careful and rigorous scrutiny.

2. The Household Model

In developing countries, households face a number of constraints, such as endogenous prices due to market imperfections, liquidity problems, and labor-allocation decisions with non-profit motives.[3] In this situation, the relevance of a separable household model is often questioned (de Janvry et al. 1991). Therefore, the non-separable household model provides a

[3] For example, reciprocal labor-sharing arrangements among neighboring farmers or extended family during peak seasons.

suitable framework for analyzing household micro-economic behavior in a situation of market imperfection. This model considers that a market for some products does not exist or functions badly, indicating that production specification and consumption of subsistence households in most developing countries is interdependent and non-separable. The joint production and consumption of various non-timber forest and agricultural products suggest the use of a non-separable household model, rather than a pure demand model (Singh et al. 1986).

The theoretical model constructed in this study is based on a conventional utility-maximizing household, which derives the highest level of utility by consuming various goods. Specifically, consider a representative farm household that derives utility from consumption of goods and leisure. Let U be the utility of the household with respect to these goods:

$$U = U(c, F_c, T - L^S; \Phi), \qquad (1)$$

where c is a composite good or commodity and represents all other goods consumed by the household, F_C is fuel consumption, T is total time endowment, L^S is labor supply of household or time allocated for labor activities, and Φ stands for household demographic and other characteristics important to utility. $U(...)$ is an increasing function and concave in all of its arguments.

In farm household settings, like Ethiopia, food accounts for about 80 percent of the total household expenditure, with food grains constituting about half of the total. Therefore, the composite good or commodity c can be regarded as mainly food or agricultural staples.

If we designate H to be home time or leisure, then the household's time constraint can be specified as:

$$L^S = L_A + L_F + L_W \leq T - H, \qquad (2)$$

where L_A is labor allocated for farm work producing agricultural staples, L_F is the household labor allocation for production and collection of fuel, and L_W is labor allocated for wage-earning off-farm work.

The agricultural staples consumed by the household could be either self produced or market purchased, so that:

$$Q - c < 0, > 0, \text{ or } = 0; \qquad (3)$$

where Q is self produced and $Q - c$ is market purchased or the net marketed quantity of agricultural staples. Note that the net marketed quantity of agricultural staples could be negative, positive, or zero, depending on whether the household is a net buyer, a net seller, or self-sufficient in food.

The household's farm production of the agricultural staple is given by:

$$Q = Q(K_A, L_A, X_A, \Psi_A) , \tag{4}$$

where K_A is fixed farm capital inputs, including land and animals; L_A is labor inputs for production of agriculture staples (as above); X_A is additional variable farm inputs, other than labor (such as seeds); and Ψ_A represents other variables that affect production; with $Q(.)$ as a function relating the input levels to output and subscript A as above. The household's farm production function, equation (4), is assumed to be increasing and concave in all its arguments.

In addition to producing agricultural staples, households in the study area also collect fuels. Often households procure the fuels themselves from two primary sources, household holdings and village commons (plus natural forests). Let the subscripts O and E stand for household holdings and village commons, respectively. Then, we can specify R_O and R_E to denote tree resource stocks at the two sites, respectively. Note that the two resource stocks are enhanced by tree-planting efforts and are not necessarily equal. Hence, we can further represent that $R_O = R(t_O, Z_O)$, where t_O is planting effort on a household's holdings when the household chooses to plant trees and Z_O is a vector of non-tree qualities of the resource stock. Therefore, it turns out straight away that $\partial R_O/\partial t_O \geq 0$.

Hence, in light of the foregoing discussion, we can now specify the household's fuel-specific collection and production functions for fuelwood and dung as:

$$F^f = F^f(L_f, R_O, R_E, \Psi_F) \text{ , and} \tag{5}$$

$$F^d = F^d(L_d, M, R_O, R_E, \Psi_F) , \tag{6}$$

where F^f and F^d are quantities of fuel produced (the superscripts f and d stand for fuelwood and dung, respectively); L_i for $i = f, d$ (which stands for household time allocation to fuelwood and dung collection, respectively); Ψ_F represents other factors affecting fuel collection and production, and M is the livestock holding of the household in cattle equivalent, with $\partial F^d/\partial L_d > 0$, $\partial F^d/\partial M < 0$. The intuition is that it is needless to collect dung from the village commons if the livestock holding of a household is increasing. Equation (6) also suggests that the household's decision whether or not to collect dung is dependent upon the relative scarcity of fuelwood from both sources.

However, we assumed that the market for fuelwood exists and that the market for dung is missing. Therefore, the net marketed quantity of fuelwood can be specified as:

$$F^f - F^f_c > 0, < 0, or = 0 \; ; \tag{7}$$

depending on whether the farm household is a net seller, a net buyer, or self-sufficient in fuelwood. In the case of fuel types, like dung, for which the market is missing, consumption equals production, i.e., $F^d = F^d_c$, for the household's optimum.

The household's choice problem, therefore, is to maximize (equation 1), subject to resources/total time and income constraints. The cash constraint can be specified as:

$$p_A(Q - c) + p_f(F^f - F^f_c) + p_d(F^d - F^d_c) = wL_W + I \, , \tag{8}$$

where p_i is the price of ith good for $i = A, f, d$ (standing for agricultural staples, fuelwood, and dung, respectively), and I is exogenous income from all non-wage, non-farm, and non-fuelwood sources.

The majority of the fuels consumed in the study area is collected for free. The households in the study use family labor to collect fuel. Although fuelwood is traded in the towns in the vicinity of the study sites, only a small proportion of households buy fuelwood.[4] Almost none of the sample households buy dung. Moreover, hiring labor for fuel collection is not common practice. Hence, it is clear that hired labor and family labor are not perfect substitutes. Therefore, the market wage rate is not an appropriate measure of the opportunity cost of family labor used in fuel collection. For this reason, the value of the marginal product (VMP), also known as "virtual (shadow) wages" of household production activities, can be a suitable measure of this opportunity cost, assuming that households are optimizers (Jacoby 1993; Thornton 1994; Mekonnen 1999; Köhlin and Parks 2001; Amacher et al. 2004). The reasoning is that in the absence of hired labor a household attempts to equate the supply and demand of its own labor.

Virtual wage rate is a product of such an attempt and depends on household characteristics and resource endowments. This shadow wage rate is assumed to be household and

[4] See table 3 at the end of the text.

fuel specific. The VMPs are computed in two steps: first, the fuel collection functions, equations (5) and (6), are estimated, and then the marginal products specific to each fuel are computed.

On the other hand, as mentioned earlier, when a market does not exist for a good, market prices may not reflect the true scarcity value of that good. Hence, one must look for some other measures of price, that is, shadow or virtual prices. Cooke (1998) and Mekonnen (1999) developed a procedure for finding the shadow or virtual prices. We applied this procedure in our study. These shadow or virtual prices represent the scarcity values of the respective fuels considered and, hence, are assumed to affect tree planting decisions.

After some manipulation of the above equations, the optimal choices can be written as a function of all prices, income, resource stock, and production characteristics:

$$\Gamma^*(p_A, p_f, p_d, M, R_O, R_E, I, \Phi, \Psi_A, \Psi_F) \,. \qquad (9)$$

Note that in equation (9), Γ^* stands for a vector of optimal choices for labor in farm production of agricultural staples and fuel collection, labor in other activities, tree-planting effort, and the goods consumption decision.

3. Econometric Model

In this section, we outline the econometric models employed to answer our research questions. First, we set up an econometrically consistent framework that simultaneously takes into account the two decisions of tree growers (whether or not to plant tree and how many) to analyze the determinants of tree planting. Second, we specify the regression model that allows us to analyze the most important, specie-specific tree attributes that contribute to households' tree-planting decisions.

3.1 Household Tree-Planting Determinants

Because tree planting is only observed for a subset of the sample population, the potential exists for the sample selection to be referred to as incidental truncation; in other words, households with tree-planting observations are likely not to be a random subsample of the population. Unobservable variables (e.g., risk, managerial or entrepreneurial ability, family background) may affect participation in tree planting. When this is the case, simply regressing the intensity of tree planting on exogenous factors will result in biased parameters. To address this concern, we employed a sample selection model[5] and estimated two equations simultaneously: (1) a probit equation (or selection equation) explaining the decision whether or not to plant tree, and (2) an equation explaining the intensity of tree planting (outcome equation). The empirical model corrects for possible sample selection bias by accounting for the joint normal distribution between the error terms of the selection equation and the outcome equation. Formally, the equations are specified as follows.

The farmers' decision whether or not plant trees can be expressed with a latent variable:

$$\begin{aligned} &z_i^* = \alpha' w_i + \mu_i, \text{ where } z_i = 1 \text{ if } z_i^* > 0, \ 0 \text{ otherwise;} \\ &\text{Prob}(z_i = 1) = \Phi(\alpha' w_i), \ \text{Prob}(z_i = 0) = 1 - \Phi(\alpha' w_i), \end{aligned} \tag{10}$$

where w_i is a set of explanatory variables, α is a coefficient vector, μ_i is the error term, Prob(.) is a probability function, and $\Phi(.)$ is the cumulative distribution function (CDF) of the standard normal distribution. In the next step, the intensity of tree planting (y_i) is defined as:

$$y_i = \beta' x_i + \varepsilon_i, \quad \text{observed only if } z_i = 1, \tag{11}$$

where x_i is a vector of explanatory variables, β is a coefficient vector, and ε_i is the error term. We assume that $\rho = \text{corr}(\mu_i, \varepsilon_i)$, and thus the disturbance is $(\mu_i, \varepsilon_i) \sim$ bivariate normal $[0, 0, 1, \sigma_\varepsilon, \rho]$. In order to account for the selection bias, we had to reformulate equation (11) as follows:

$$E[y_i \mid x_i, z_i = 1] = \beta' x_i + E[\varepsilon_i \mid z_i = 1] = \beta' x_i + \rho\sigma_\varepsilon M_i, \tag{12}$$

where $M_i (\text{inverse Mills ratio}) = \dfrac{\phi(\alpha' w_i / \sigma_u)}{\Phi(\alpha' w_i / \sigma_u)}$ and $\phi(.)$ and $\Phi(.)$ are the PDF (probability distribution function) and CDF, respectively, of the standard normal distribution. Equation (12) indicates that omitting M_i would lead to omitted variable bias in estimating β. To get consistent

[5] We chose not to employ the tobit model, due to its restriction that whether or not to plant trees and the extent of planting trees are determined by the same set of covariates, and that a variable that increases the probability of the decision to plant trees also increases the extent of tree planting. It also assumes the same variables have same magnitude impact on both decisions.

and efficient estimates, equations (10) and (11) are estimated jointly by the maximum likelihood estimation technique.

3.2 Tree Species and Purposes or Attributes

Farmers have varying needs and preferences for planting different tree species. They consider their different attributes as criteria for planting a specific tree species. These attributes or purposes include income contribution, food, fodder, fuelwood production, construction materials (for fencing, housing, household utensils, and farm implements), watershed benefits (e.g., soil conservation), and shelter for animals. Farm households will also plant certain trees for such specific attributes as fast growth, ability to protect against winds, and so on.

We specify the following logistic regression model to identify the most important attribute(s) and purpose(s) of household tree growing:

$$prob(y=1)=\frac{e^{G'\alpha_i}}{1+e^{G'\alpha_i}} \ , \qquad (13)$$

where G is a vector of explanatory variables (i.e., in our case, elicited tree-planting attributes or purposes for a particular species) and α_i is vector parameters to be estimated.

4. Study Area and Data Description

Our data are from a survey of 200 rural households collected in 2000 in Tigrai, in northern Ethiopia. Two-stage sampling was used to select the sample households. The first 50 *tabias*—the smallest administrative unit in the region—were randomly selected from a total of 600 tabias, and then a random sample of 200 rural households was selected from these tabias. Both quantitative and qualitative data were collected on the households' tree planting, production (collection), and consumption of various biomass fuel types, as well as household characteristics, including age, gender, family size, and education of the household head. The dataset also included household physical assets, such as total land area, cultivated area, and livestock holdings. Information on tree planting was also gathered, such as number of trees grown by species, age of trees, and purpose(s) or attributes for which the trees were grown. Village-level factors (e.g., agro-ecological conditions: altitude and distance traveled (time spent) to collect different fuels) were also collected. In addition, the dataset included institutional variables, such as household's perception of security of land tenure, that is, whether the household felt secure about future use of current land holding(s). Table 1[6] shows summary statistics (means and standard deviation) of the variables used in regression.

Table 2 presents detailed characteristics of households involved in tree planting. Buying and adapting (transplanting) naturally grown (self-germinated) seedlings from the bush (forest) to the backyard or field constitute the main sources of seedlings in the area. Some farmers also raise their own seedlings. Government nurseries are the main sources of purchased seedlings. Most of the households are also involved in sale of tree products (mainly wooden poles).

Table 3 provides the mode of fuel acquisition of the sample households by fuel type. It is evident that free collection accounts for the majority of the fuels consumed in the study area. Although fuelwood is traded in the towns in the vicinity of the study sites, a small proportion of the households buy fuelwood. Own sources also account for a small share of fuel consumed by the sample households, either fuelwood or dung.

In rural settings, it is not uncommon to find a number of different tree species grown by farm households. In our dataset, we found a total of 112 tree species grown by sample households, of which 17 species were dominant and were specified in the analysis. Twelve are indigenous, while the rest are exotic species. The detailed scientific (botanical) and local names of these 17 tree species are presented in table A.1 in the appendices.

5. Results and Discussion

It is important to reiterate that the central issues of the problem at hand were analyzing the determinants of household tree planting and identifying the most important tree attributes or purposes that households consider when deciding to plant trees. In this section, we verify whether we followed the right procedure, ascertain the overall model validity (how well it fit), and present and discuss the results.

5.1 Household Tree Planting Determinants

The sample selection framework explores the factors that promote the propensity to plant trees, as well as the extent of tree growing. The full information maximum likelihood estimates of the sample selection model are shown in table 4. The good fit of the model we chose—

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[6] All tables are located at the end of the text.

likelihood ratio (LR) test (bottom section of table 4)—suggests that we cannot reject the alternative hypothesis that ρ is different from zero, implying that the two equations are not independent (or cannot be estimated independently) and that the Heckman selection model was the right procedure. This also justifies our use of an econometrically consistent framework to estimate the two aspects of household tree growing—a household's decision to grow trees and how many they plant.

In table 4, the estimated coefficients in the uppermost section of the results columns correspond to the outcome equation and the coefficients in the middle section of the table correspond to the selection equation. The dependent variable for selection equation equals 1 if the households plants trees and zero otherwise, while the number of trees grown by households form the dependent variable in the outcome equation. The estimated correlation coefficient (ρ) is statistically significant and the LR test does reject independence of the two error terms. This supports the joint estimation of both the selection and outcome equations. The LR test suggests that selection bias is a problem for the estimated model. Note that the model is estimated without exclusion restrictions; the same set of regressors appears in both equations. However, we have assumed that identification of the model relies on the non-linearity of the inverse Mills ratio.

Although the level of significance and the magnitude of regressors vary in both selection and outcome equations, most of the variables turned out to be statistically significant and positive in both equations. Land size, exogenous income, age, gender, and education all increased the propensity to plant tree and the quantity of trees planted. Given the fact that the benefits from investing in trees accrue over time, this inter-temporal aspect implies that secure land access or tenure will impact tree-planting decisions positively. Our results revealed that this particularly has a positive impact on the decision to plant trees and how many to plant, in line with Mekonnen's (1998) finding for the Amhara region of Ethiopia.

Location and/or village agro-ecology variables also have significant positive impact, which may reflect the role played by agro-ecology in promoting tree planting. The number of cattle turned out to be significant and negative, suggesting that households with relatively more cattle are less likely to be involved in tree planting. Shadow prices of fuelwood and dung, and the numbers of male adults and female adults in a household did not have any significant impact in either of the equations. Moreover, model results or findings are also interesting, in the sense that the same factors might not necessarily underlie the two aspects of tree planting (i.e., household's decision to plant trees and the extent of tree planting).

5.2 Tree Species and Purposes

To identify the species-specific, most important attributes and/or purposes for which the trees are grown, a logistic regression was run on a species-by-species basis for 17 tree species considered in the study. (The results are presented in table 5. The botanical and local names of the trees and whether they are indigenous considered in the study are presented in table A.1 in the appendix.) In general, these results are interesting because they depict the multiple roles of trees in rural livelihoods and the multiple purposes that a household will planting specific trees. For example, tree species, such as *Rhus natalensis*, *Shinus molle, Juniperus procera,* and *Ficus ingens,* can be designated as single purpose trees, the rest are essentially multipurpose trees. Table A.2 shows the primary (and secondary reasons) for planting each specific species in the study area: shade, farm implements, fuelwood, housing construction materials, fencing, soil conservation, fodder, and household utensils.

6. Conclusions and Implications

This paper analyses the determinants of household tree planting, using datasets from sample cross-sections of 200 households in the highlands of Tigrai, in northern Ethiopia. Three key questions asked what factor(s) enhance the likelihood of planting trees, what is the extent of tree planting, and what are the most important purposes or attributes that a household planted a specific tree(s).

Regarding the factors underlying a household's decisions to plant trees and in what quantity, household characteristics, characteristics of the household head, and village-level factors were the most important determinants. Our findings revealed a clear pattern, where the same factors do not necessarily affect these two decisions of tree planting. Moreover, our findings also suggested that intra-household or sex-age patterns of resource endowments, such as availability of male versus female labor, are irrelevant to the household's decision to grow trees or the extent of tree growing. Rather, institutional issues, such as perception of tenure security, tend to be more important in determining household tree planting. In addition, our results underscored the multiple roles of trees in rural livelihoods and the multiple purposes for planting most species of trees. (Three species, however, *Rhus natalensis*, *Shinus molle, Juniperus procera,* and *Ficus ingens,* had only one use.)

Results of the research have some broad policy implications. It highlighted certain factors that policies aiming to stimulate or encourage household tree planting should focus on or target. For example, policy measures or interventions that enhance the security of existing land tenure and support greater education of the household head would, at the same time, enhance household tree planting. In addition, these research results are relevant to forestry policy because they pinpoint which species might be more important, for example, to address the fuelwood problem or augment soil conservation.

Tables

Table 1. Summary Statistics of Variables Used in Regression (N = 200)

Variable	Mean	Std. dev.	Min.	Max
Family size	5	2	1	12
Adult males in household	1	1	0	5
Adult females in household	1	1	1	4
Exogenous income (ETB/month)	0.35	2.86	0	25
Number of cattle	4	3	0	14
Land area (hectares)	0.834	0.496	0	2.5
Age of household head	48	13	23	85
Education of household head (no. of years of schooling)	0.92	1.47	0	7
Sex of head				
Female	21%			
Male	79%			
Households involved in tree planting	93%			
Households not involved in tree planting	7%			
Total no. of trees (all trees)	74	172	0	1834

Table 2. Characteristics of Households Involved in Tree Planting (N = 186)

Variable	Mean	Std. dev.	Min.	Max.
Source of seedlings				
Purchased	60.75%			
Self raised	13.98%			
Tree nursery for free	26.88%			
Naturally grown	60.22%			
Neighboring farmer for free	1.68%			
Source of purchased seedlings				
Neighboring farmer	1.61%			
Government nursery	51.61%			
Community nursery	2.69%			
Both private and government nursery	0.54&			
Sex of household head				
Female (in percent)	18.82%			
Male (in percent)	81.18%			
Involvement in sale of tree products				
Yes	93%			
No	7%			
Income from sale of tree products (poles) (ETB/annum)	31.43	113.16	0	1050

ETB = Ethiopian birr

Table 3. Distribution of Sample Households by Method of Acquiring Fuel (N = 200)

Method of fuel acquisition	**Fuel type**	
	Fuelwood	***Dung***
Free collection	85.2%	72.3%
Buying	11.2%	0.6%
Own source (tree/cattle manure)	3.6%	27.1%
Total	***100.0%***	***100.0%***

Table 4. Results of Full Information Maximum Likelihood Estimates of the Sample Selection Model of the Determinants of Tree Planting (Dependent Variable, Total Number of Tree Planted) and the Decision to Plant Trees

Explanatory variable	Estimation results	
	***Coefficient*[a]**	***t-statistic***
Outcome equation		
Adult males in household	-0.004	-0..04
Adult females in household	0.219	1.28
Land size (hectares)	0.482**	2.23
Number of cattle	-0.093*	-1.89
Exogenous income (ETB/month)[c]	0.168	0.69
Age of household head	0.055***	6.44
Education of household head	0.186**	2.29
Sex of household head[d]	1.129***	3.68
Tenure security	0.521**	2.34
Wood price/shadow	0.052	0.57
Dung price/shadow	0.011	0.81
Middle highland	0.720***	3.00
Upper highland	0.998***	3.12
Constant	-5.489***	-14.18
Selection equation		
Adult males in household	-0.001	-0.04
Adult females in household	0.040	1.28
Land size (hectare)	0.088**	2.25
Number of cattle	-0.017*	-1.90
Exogenous income (ETB/month)	0.015***	2.49
Age of household head	0.010***	7.17
Education of household head	0.034**	2.33
Sex of household head	0.205***	3.80
Tenure security	0.095**	2.37
Wood price/shadow	0.009	0.57
Dung price/shadow	0.002	0.81
Middle highland	0.131***	3.08
Upper highland	0.182***	3.20
Statistic		
ρ	1	7.39e-12[b]
σ	0.182	0.013[b]

λ	0.182	0.013[b]
N	200	
Log likelihood	23.862	
Wald Chi2(13)	3008.01***	
LR test of independent equations (rho=0): chi2(1) = 50.81 Prob > chi2 = 0.000		

[a] *** and * indicate statistically significant at 1% and 10% levels, respectively.

[b] Standard error rather than t-statistic.

[c] ETB is Ethiopian birr. US$ 1 = ETB 8.3044 during the survey period.

[d] Sex of household head was captured as male = 1, otherwise 0.

Table 5. Logistic Regression Results (standard error in parenthesis) of Purpose(s) of Tree Growing by Tree Species

Explanatory variable	Tree species [a] 1	2	3	4	5	6	7	8	9
Market (=1; 0 otherwise)					8.143*** (1.038)				
Fuel wood (=1; 0 otherwise)	2.509*** (0.609)	5.570*** (0.8493)	0.782 (0.602)	4.956*** (1.214)	3.087*** (0.353)	2.610*** (0.7005)	0.532 (0.499)	0.771 (0.759)	2.222** (1.111)
Soil conservation (=1; 0 otherwise)		6.079*** (1.8819)							6.562*** (1.734)
House construction (=1; 0 otherwise)	0.939 (0.620)	-1.602** (0.715)	-1.040* (0.617)	-0.526 (0.842)		1.026* (0.604)	0.174 (0.545)	0.472 (0.879)	
Fodder (=1; 0 otherwise)		-2.441* (1.410)	-0.530 (0.674)			-0.769 (0.768)	0.287 (0.438)	0.574 (0.549)	
Farm implements (=1; 0 otherwise)	0.182 (0.684)	-1.128 (0.807)	5.012*** (0.770)	-0.206 (0.895)	1.324*** (0.376)	-0.225 (0.620)	2.541*** (0.496)	1.638** (0.780)	-1.129 (1.271)
Fencing (=1; 0 otherwise)	-0.199 (1.089)					2.756*** (0.555)	2.540*** (0.505)	1.305 (0.930)	4.480*** (1.280)
Shade (=1; 0 otherwise)	1.684** (0.726)					-0.572 (1.131)	1.575*** (0.599)	3.070*** (0.739)	
House utensils (=1; 0 otherwise)			4.304* (2.4107)						
Constant	-6.502*** (0.4299)	-7.484*** (0.7273)	-7.076*** (0.5844)	-8.104*** (1.000)	-5.052*** (0.215)	-6.444*** (0.417)	-5.933*** (0.323)	-7.100*** (0.569)	-8.494*** (1.096)
n	3568	3573	3573	3553	3573	3571	3571	3571	3573
Loglikelihood	-78.811	-54.055	-67.081	-36.074	-213.541	-88.297	-110.374	-45.486	-20.240
LR chi2(k)[b]	47.34	75.01	102.73	29.05	702.75	81.00	96.82	34.71	35.23
Prob>chi2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pseudo R2	0.231	0.409	0.434	0.287	0.622	0.314	0.305	0.276	0.465

Table 5 (continued)

Explanatory variable	Tree species [a] 10	11	12	13	14	15	16	17
Market (=1; 0 otherwise)								
Fuel wood (=1; 0 otherwise)	-1.412 (0.944)	-0.618 (0.881)	-0.624 (0.883)	-0.506 (0.833)	0.347 (0.576)	0.150 (0.704)	0.096 (0.747)	0.397 (1.517)
Soil conservation (=1; 0 otherwise)								
House construction (=1; 0 otherwise)				3.932*** (0.983)	2.345*** (0.590)	1.345 (0.868)	4.541*** (0.919)	
Fodder (=1; 0 otherwise)	1.992*** (0.793)	0.973 (0.917)	0.946 (0.982)		1.146* (0.659)			4.343*** (1.520)
Farm implements (=1; 0 otherwise)	-0. 382 (0.6882)	1.557** (0.9022)	1.547** (0.803)		1.325*** (0.544)			
Fencing (=1; 0 otherwise)			0.149 (1.397)	2.899*** (0.878)	-0.380 (1.112)			
Shade (=1; 0 otherwise)	5.636*** (0.633)	5.067*** (0.6632)	5.059*** (0.888)		1.633** (0.691)	5.747*** (0.708)		
House utensils (=1; 0 otherwise)								
Constant	-6.777*** (0.514)	-7.556*** (0.723)	-7.555*** (0.722)	-7.433*** (0.709)	-6.098*** (0.353)	-7.148*** (0.592)	-7.388*** (0.707)	-3.183*** (1.292)
N	3521	3571	3571	3391	3570	3417	3371	26
Loglikelihood	-55.390	-36.412	-36.406	-37.283	-100.490	-48.095	-47.313	-6.488
LR chi2(k)[b]	71.93	52.85	52.87	38.21	56.60	85.68	41.75	12.48
Prob>chi2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
Pseudo R2	0.394	0.420	0.421	0.339	0.220	0.471	0.306	0.490

[a] ***, **, and * indicate statistically significant at 1%, 5% and 10% level (or better), respectively. See table A1 for specie associated with each number.

[b] k stands for the number of explanatory variables considered in each regression.

References

Abebe, W., R. Puskur, and R.J. Karippai. 2008. Adopting an Improved Box Hive in the Atsbi Wenberta District of Eastern Tigrai Zone, Tigrai Region: Determinants and Financial Benefits. IPMS Working Paper, no. 10. Addis Ababa, Ethiopia: ILRI

Amacher, G. S., L. Ersado, W.F. Hyde, and A. Osario. 2004. Tree planting in Tigrai, Ethiopia: The Importance of Human Disease and Water Microdams. *Agricultural Systems* 60: 211–25.

Arnold, J.E.M., G. Köhlin, and R. Persson. 2006. Woodfuels, Livelihoods, and Policy Interventions: Changing Perspectives. *World Development* 34(3): 596–611.

Chambers, R.G., and W.E. Foster. 1983. Participation in the Farmer-Owned Reserve Program: A Discrete Choice Model. *American Journal of Agricultural Economics* 65(1): 120–24.

Cooke, P. 1998. The Effect of Environmental Good Scarcity on Own-Farm Labor Allocation: The Case of Agricultural Households in Rural Nepal. *Development and Environment Economics* 3: 443–469.

Cooke St. Clair, P., W.F. Hyde, and G. Köhlin. 2001. A Fuelwood Crisis: Where and for Whom? In *Fuelwood: Crisis or Balance–Workshop Proceedings*, edited by G. Köhlin, Gothenburg University for CIFOR, Marstrand, Sweden, June 6–9, 2001, 18–53.

Cooke, P., G. Köhlin, and W.F. Hyde. 2008. Fuelwood, Forests, and Community Management: Evidence from Household Studies. *Environment and Development Economics* 13: 103–136.

de Janvry, A., M. Fafchamps, and E. Sadoulet, 1991. Peasant Household Behaviour with Missing Markets: Some Paradoxes Explained. *Economic Journal* 101: 1400–1417.

Dewees, P.A. 1995. Trees on Farms in Malawi: Private Investment, Public Policy, and Farmer Choice. *World Development* 23(7): 1085–1102.

Emtage, N., and J. Suh. 2004. Socio-economic Factors Affecting Smallholder Tree Planting and Management Intensions in Leyte Province, the Philippines. *Small-Scale Forest Economics, Management and Policy* 3(2): 257–71.

Ethiopian Forestry Action Program (EFAP). 1994. The Challenges for Development. Vol. 2. Addis Ababa: EFAP Secretariat, Ministry of Natural Resources Development and Environmental Protection.

Fichtl, R., and A. Adi. 1994. *Honeybee Flora of Ethiopia*. Weikersheim, Germany: Wargraf Verlag.

Filius, A.M. 1982. Economic Aspects of Agroforestry. *Agroforestry Systems* 1: 29–39.

Gebreegziabher, Z. 2007. Household Fuel Consumption and Resource Use in Rural-Urban Ethiopia. PhD diss., Department of Social Sciences, Wageningen University, the Netherlands.

Gebremedhin, B., J. Pender, and G. Tesfay. 2003. Community Resources Management: The Case of Woodlots in Northern Ethiopia. *Environment and Development Economics* 8: 129–48.

Gindaba, J. 2006. Overview of Water and Nutrient Relations of Eucalyptus and Deciduous Tree Species and Implications for Their Use in Land Rehabilitation. *Journal of the Drylands* 1(1): 15–25.

Hansen, J.D., M.K. Luckert, S. Minae, and F. Place. 2005. Tree Planting under Customary Tenure Systems in Malawi: Impact of Marriage and Inheritance Patterns. *Agricultural Systems* 84: 99–118.

Hartmann, I. 2004. "No Tree, No Bee–No Honey, No Money": The Management of Resources and Marginalization in Beekeeping Societies of Southwest Ethiopia. Paper presented at the Millennium Ecosystem Assessment conference, "Bridging Scales and Epistemologies: Linking Local Knowledge and Global Science in Multi-Scale Assessments," Alexandria, Egypt, March 17–22, 2004.

Heckman, J.J. 1979. Sample Selection Bias as a Specification Error. *Econometrica* 47(1): 153–62.

Holden, S., S. Benin, B. Shiferaw, and J. Pender. 2003. Tree Planting for Poverty Reduction in Less-Favored Areas of the Ethiopian Highlands. *Small-Scale Forest Economics, Management and Policy* 2(1): 63–80.

Jagger, P., and J. Pender. 2003. The Role of Trees for Sustainable Management of Less-Favored Lands: The Case of Eucalyptus in Ethiopia. *Forest Policy and Economics* 5(1): 83–95.

Jagger, P., J. Pender, and B. Gebremedhin. 2003. Woodlot Devolution in Northern Ethiopia: Opportunities for Empowerment, Smallholder Income Diversification, and Sustainable Land Use. EPTD Discussion Paper, no. 107. Washington, DC: IFPRI.

Kidanu, S. 2004 Using Eucalyptus for Soil and Water Conservation on the Highland Vertisols of Ethiopia. PhD diss., Department of Environmental Sciences, Wageningen University, the Netherlands.

Köhlin, G., and P.J. Parks. 2001. Spatial Variability and Disincentives to Harvest: Deforestation and Fuelwood Collection in South Asia. *Land Economics* 77(2): 206–218.

Mekonnen, A. 1999. Rural Household Biomass Fuel Production and Consumption in Ethiopia: A Case Study. *Journal of Forest Economics* 5(1): 69–97.

———. 1998. Rural Energy and Afforestation: Case Studies from Ethiopia. PhD diss., Department of Economics, Gothenberg University, Sweden.

Nibbering, J.W. 1999. Tree Planting on Deforested Farmlands, Sewu Hills, Java, Indonesia: Impact of Economic and Institutional Changes. *Agricultural Systems* 46: 65–82.

Patel, S.H., T.C. Pinckney, and W.K. Jaeger. 1995. Smallholder Wood Production and Population Pressure in East Africa: Evidences of an Environmental Kuznets Curve? *Land Economics* 71(4): 516–30.

Pender, J., F. Place, and S. Ehui. 2006. Strategies for Sustainable Land Management in the East African Highlands. Washington, DC: IFPRI.

Salam, M.A., T. Noguchi, and M. Koike. 2000. Understanding Why Farmers Plant Trees in the Homestead Agroforestry in Bangladesh. *Agricultural Systems* 50: 77–93.

Scherr, S. J. 1995. Economic Factors in Farmer Adoption of Agroforestry: Patterns Observed in Western Kenya. *World Development* 23(5): 787–804.

Thacher, T., D.R. Lee, and J.W. Schelhas. 1997. Farmer Participation in Reforestation Incentive Programs in Costa Rica. *Agroforestry Systems* 35: 269–89.

Verbeek, M. 2004. A Guide to Modern Econometrics, 2nd ed. West Sussex, UK: John Wiley & Sons Ltd.

Appendix

Table A1. Description of Tree Species Considered in the Study

	Scientific name	Local name	Key
1	*Acacia ethbaica*	Seraw	Indigenous
2	*Euclea shimperi*	Kliow	Indigenous
3	*Olea europaea*	Awlie	Indigenous
4	*Rhus natalensis*	Tetaelo	Indigenous
5	*Eucalyptus spp*	Kelanitos	Exotic
6	*Acacia lehay*	Lehay	Indigenous
7	*Acacia seyal*	Cha'a	Indigenous
8	*Balanites aegyptiaca*	Mekie	Indigenous
9	*Mytenus senegalensis*	Argudi	Indigenous
10	*Faidherbia albida*	Mommona	Indigenous
11	*Melia azedarach*	Nim	Exotic
12	*Acacia saligna*	Akacha	Exotic
13	*Euphorbia candelabrum*	Kolenkual	Indigenous
14	*Croton macrostachys*	Tambukh	Indigenous
15	*Shinus molle*	Tikur berbre	Exotic
16	*Juniperus procera*	Tsihdi Habesha	Indigenous
17	*Ficus ingens*	Shibakha	Exotic

Table A2. Primary Reasons for Planting Specific Tree Species

	Tree species	Primary uses (√), secondary uses (√)							
		Fuel-wood	Shade	Soil conser-vation	House construc-tion materials	Farm imple-ments	House-hold utensils	Fencing	Fodder
1	*Acacia ethbaica*	√	√						
2	*Euclea shimperi*	√		√	√				
3	*Olea europaea*					√	√		
4	*Rhus natalensis*	√							
5	*Eucalyptus spp*	√ *				√			
6	*Acacia lehay*	√			√			√	
7	*Acacia seyal*		√			√		√	
8	*Balanites aegyptiaca*		√			√			
9	*Mytenus senegalensis*			√				√	
10	*Faidherbia albida*	√	√						√
11	*Melia azedarach*		√			√			
12	*Acacia saligna*		√			√			
13	*Euphorbia candelabrum*				√			√	
14	*Croton macrostachys*		√		√	√			
15	*Shinus molle*		√						
16	*Juniperus procera*				√				
17	*Ficus ingens*								√
No. of species for each use		6	8	2	5	7	1	4	2

* Fuelwood for both market and household use

Modelling Technology Adoption/ Tree Planting

The adoption decision is modeled as the decision to plant trees or not plant trees. In making decisions about whether to plant trees, we assume that a farmer will evaluate the tree planting in terms of its expected incremental benefit. Let $(\pi\ )$ be the expected incremental benefit or payoff; then, if the expected utility gains (benefit) of planting trees (π_1) is higher than without planting trees (π_0), the preference or utility for planting trees will be higher than without planting trees. We assume that there is an unobserved or latent variable, y^*, that generates the observed variable y, which represents a farmer's decision to adopt tree planting or not. The latent variable y^* equals $E[U(\pi_1)] - E[U(\pi_0)]$, the net benefit or payoffs from adoption. The farmer will adopt tree planting, if the expected utility gains with adoption are greater than the expected utility of non-adoption. That is, when $y^* > 0$, the household adopts tree planting and $y = 1$ is observed, and when $y^* \leq 0$, the households do not adopt tree planting and $y = 0$ is observed.

For farmer i, the latent variable y^* is related to observed farmer and other characteristics through a structural model as follows:

$$y_i^* = \beta' X_i + \varepsilon_i, (i = 1,..., N) \ ,$$

where X_i represents a set of explanatory variables, which influence adoption decision of the farmers; β' is a coefficient vector; and ε_i is random disturbances associated with the adoption and non-adoption of tree planting. Then, y_i^* is linked to y_i, as follows, using indicator function:

$$y_i = 1\,[\, y_i^* > 0\,]\ .$$

Farmer i adopts or gets involves in tree planting. If $y_i^* > 0.$ The probability that $y_i = 1$ is:

$$\Pr[y_i = 1] = \Pr[y_i^* > 0] = \Pr[\beta' X_i + \varepsilon_i > 0] = 1 - F(-\beta' X_i) = F(\beta' X_i),$$

where $\Pr[.]$ is a probability function and $F(.)$ is the cumulative distribution function. The function $F(\beta' X_i)$ cannot be estimated directly without knowing the form of *F.* The exact distribution of *F* depends on the distribution of the random term ε. A probit model was used in this paper, assuming the disturbance term is normally distributed with mean zero and variance 1.