RURAL HOUSEHOLD BIOMASS FUEL PRODUCTION AND CONSUMPTION IN ETHIOPIA: A CASE STUDY

ALEMU MEKONNEN*

ABSTRACT

Over 90 percent of energy consumption in Ethiopia comes from biomass fuels and this pattern is a major cause of land degradation and deforestation in the country. This paper examines biomass fuel collection and consumption behaviour of a sample of rural households in Ethiopia. We use a non-separable agricultural household model to take into account imperfections in, or absence of, markets for fuel and labour used in collection. The method of instrumental variables (2SLS) is used in the estimation of demand functions to take care of endogeneity of virtual (shadow) fuel prices and wages. Negative own-price elasticities indicate advantages of forest policies that can reduce fuel collection time and make more time available for other activities. The results also suggest that fuel choice and mix are influenced by scarcity which indicate a possibility of policy interventions directed at reducing the relative price of wood and encouraging increased dung use as fertilizer and hence reduced land degradation. While income elasticities of demand give indications of increasing viability of such interventions with growth, the absence of evidence of substitutability and the effects of household resource endowment indicate the importance of cooking habits and culture.

Keywords: Biomass fuels, deforestation, Ethiopia, household fuel collection and demand, land degradation, virtual prices.

~

INTRODUCTION

Biomass fuels are the most important source of energy in developing countries in general and Sub-Saharan Africa in particular. A large number of fuelwood and forest projects and policies in these countries have been based on recommendations of the results of what are called "fuelwood gap" models. These models usually start with (rough) estimates of fuel demand and supply to project future excess demand and recommend such programs as

---

* Alemu Mekonnen, Department of Economics, Addis Ababa University and Goteborg University.

An earlier version of this paper was presented at an International Symposium on Forest Resource Economics held in Umeå, Sweden, September 1997. I thank participants for useful comments. I also thank Tekie Alemu, Fredrik Carlsson, Priscilla Cooke, William F. Hyde, Olof Johansson-Stenman, Gunnar Köhlin, Ramon Lopez, Thomas Sterner and an anonymous referee for useful comments.

afforestation and improved stove dissemination to fill teh "gap" (Leach & Mearns, 1988). Typically such studies do not consider household responses to scarcity. And these responses could depend on specific household and regional characteristics (Dewees, 1989). There are many testable hypotheses about household behaviour and responses regarding scarcity of biomass fuels (see Hyde, 1991). Empirical studies of rural household fuel production and consumption behaviour particularly on Sub-Saharan Africa are however very limited.[1]

The percentage of biomass fuels in total energy consumption in Ethiopia is one of the highest in the world. They constitute over 90 percent of total energy consumption in the country, and about 99 percent in the rural areas; and their shortage is one major cause of deforestation and land degradation (EFAP, 1993).

Recent estimates of land area under forest cover are below 3 percent of the total (EFAP, 1993). Moreover, due to the significant use of dung and crop residues as energy sources, rural energy is closely linked with land degradation which is considered to be one of the most important environmental and economic problems. Some estimates of the gross annual immediate financial losses due to land degradation show that it is about 3 percent of the agricultural GDP or about 2 percent of the GDP. Out of this about 98 percent is estimated to be caused by nutrient losses due to removal of dung and crop residues from crop land for use as energy sources which could have been used as fertilizer (Bojö & Cassells, 1995).

The use of imported chemical fertilizers with high prices, particularly after the recent removal of subsidies, does not seem to be the only solution to soil nutrient losses for a majority of Ethiopian peasants who are poor and have to rely on risky rain-fed agriculture. In spite of significant improvements in the supply of chemical fertilizers in recent years through the government's Agricultural Development Led Industrialization (ADLI) strategy, only about 33 percent of the rural households used chemical

---

[1] Empirical studies of rural household biomass fuel production and consumption behaviour on Sub-Saharan Africa include Hosier (1985,1988), Jama (1995) and Barnes *et al.* (1984) while those on Asia include Amacher *et al.* (1993, 1996a,b) and Cooke (1996).

fertilizers in 1995 and the average quantity of chemical fertilizers purchased by a peasant was still much below the recommended level (Mulat *et al.*, 1996). Moreover, only two types of chemical fertilizer are used in Ethiopia, which mainly contain nitrogen and phosphate, implying that their use would make faster the depletion of elements in the soil that are not provided by these chemical fertilizers.[2] On top of these, we should also mention the burden on the balance of payments added due to import of chemical fertilizers and the possible negative externalities of chemical fertilizer use on health.

The arguments above suggest that introducing policies that encourage tree planting and the use of dung as fertilizer could lead to a balanced improvement in soil nutrients and organic matter, and hence more sustainable agricultural productivity. A potential to increase the use of dung as fertilizer exists particularly in the northern half of the country where a considerable share of total rural household fuel consumption comes from dung.[3] But this assumes or requires knowledge of, among others, substitution possibilities between different household fuel sources. As Dewees (1989) observes, "there is only limited evidence which suggests that if woodfuels were more available, the use of animal dung for fuel will decline" (p. 1165).

While fuelwood and dung are the two most important household fuel types in (rural) Ethiopia, some argue that they are to a significant extent complements particularly for the baking of *injera*,[4] which consumes about half of cooking fuels, using the traditional three-stone fire. For example, a report on the most comprehensive country wide energy survey of 7617 households in the first half of

---

[2] Di-ammonium phosphate (DAP) and urea are virtually the only commercial fertilizers (which are imported) in use in Ethiopia. DAP contains 18 percent nitrogen and 46 percent phosphate, while urea contains 46 percent nitrogen (Sutcliffe, 1993).

[3] The data collected for this study show that the share of dung in total rural household fuel consumption is over 30 percent. Similar figures are found even at the national level, see for example World Bank (1984). However, there are other estimates at the national level which give figures below 30 percent, but do not indicate the percentage for the northern part of Ethiopia separately. The average at the national level given by EFAP (1993) is 20 percent.

[4] *Injera* is a pancake like bread consumed as a staple food in Ethiopia in general and northern and central Ethiopia in particular.

the 1980s (ENEC, 1986: 3) states that "...the principal reason for dung and crop residue consumption [as cooking fuels] does not appear to be so much the scarcity of woodfuels as the fact that they provide higher quality cooking for traditional culinary culture: slow fire for dung and lively flames for agriresidues." It also states that "in fact, [...] the first stage of the household's response to fuelwood depletion is not substitution with dung and agriresidue, but a drastic reduction in use through both greater thrift and improvements in technology" (ENEC, 1986:3). On the other hand, others argue or assume that fuelwood and dung are substitutes and hence increased availability of fuelwood could lead to increased use of dung as fertilizer to improve agricultural productivity (World Bank, 1984; Newcombe, 1989). A study using village level data from the survey mentioned above also concludes that the two fuel types are substitutes (Asmerom, 1991).[5]

In addition to the issue of substitution possibilities, knowledge of peasants' behaviour towards scarcity of biomass fuels is useful in the formulation of rural development policy in general, and energy and forest policy in particular. Some of the other important economic parameters in this respect include price and income elasticities of demand for biomass fuels and of supply of (demand for) labour for their collection. Examination of these elasticities by fuel type would help identify the degree of peasants' response to scarcity, availability of substitutes and whether or not a fuel type is inferior. Collection of woody biomass and dung and the related gender division of labour is another interesting issue to look into. The usual hypothesis is that in general women and children in the developing world are the main collectors of biomass fuels who are also responsible for child care and cooking. Thus, if households are sensitive to the cost of time spent to collect a fuel type, policies that reduce labour time spent to collect fuel could have a positive contribution to child care, nutrition and perhaps agricultural production.

[5] We use the concepts of uncompensated or gross substitutes and complements in this paper.

The two main objectives of this paper are therefore to: (1) look into the possibility of substitution (or complementarity) in household consumption between woody biomass and dung and its implications for land degradation[6], and (2) estimate price and income elasticities of demand for woody biomass and dung and discuss its implications for poverty and forestry issues. Moreover, we will also try to examine the effect of household composition in biomass fuel collection and its implications.

This paper is different from most empirical studies of rural household fuel production and consumption behaviour which (1) use market prices of biomass fuels and market wages based on assumptions of the existence of perfect markets for fuel types and labour for fuel collection and (2) are based on aggregation of fuel types and labour used. We use the concepts of virtual fuel prices and wages to take into account non-market activities in fuel collection and consumption, which is common in rural Ethiopia in general and our study sites in particular.[7]

The rest of the paper is organized as follows. In section two we present the theoretical model where we discuss the reasons for using virtual (shadow) fuel prices and wages instead of using the respective market values. In section three the data used is briefly described followed by a discussion of the empirical strategy. Section four presents estimation issues and empirical results. Section five concludes the paper.

A THEORETICAL MODEL OF AGRICULTURAL HOUSEHOLD BEHAVIOUR

The theoretical model used in this paper is a version of agricultural household models, with a focus on fuel collection and consumption, as the households in our sample are producers and consumers at the same time. We

[6] In this paper woody biomass includes firewood, twigs, branches and leaves. Also note that we use the terms woody biomass, fuelwood and wood interchangeably.

[7] To our knowledge, in the empirical literature on rural household fuel demand, only Amacher *et al.* (1996a, b) used the concept of virtual (shadow) wages and Cooke (1996) used the concept of virtual (shadow) fuel prices. These concepts are discussed later in this paper.

will employ a non-separable (non-recursive)[8] agricultural household model since the recursive (separable) one requires, among others, the assumptions that (1) hired and family labour are perfect substitutes and (2) perfect markets exist for goods. These assumptions are not fulfilled in our study areas because (1) hiring labour for biomass fuel collection is not common and (2) while fuelwood is traded mainly in the closest towns to each of our survey sites and some of our respondents have either sold or purchased fuelwood, dung is traded only in two out of the four peasant associations (PAs) surveyed and virtually all households are not involved in the market for dung.

The household is assumed to maximize a twice continuously differentiable quasi-concave utility function given by

$$U\left(X, F_c, T - L_s; A, R\right) \tag{1}$$

where X is a composite commodity representing non-fuel goods consumed by a household; F_c is quantity of fuels consumed[9]; $T - L_s$ is leisure, where T is total household time available and L_s is total household labour supply which is the sum of labour supply to different activities including fuel collection; and A and K stand, respectively, for household characteristics and resource endowment.

The constraints to the maximization problem are:

$$F_p = F_p\left(L_{df}, A, R\right) \tag{2}$$

$$P_x X + P_f F_c = W_f L_{sf} + \left(P_f F_p - W_f L_{df}\right) + V \tag{3}$$

$$F_c - F_p \geq 0 \tag{4}$$

$$L_{df} - L_{sf} \geq 0 \tag{5}$$

$$X \geq 0; T - L_s \geq 0; L_i \geq 0; F_c \geq 0, i = s, sf, df. \tag{6}$$

---

[8] In this paper we use the terms non-separable and non-recursive interchangeably which is a common practice in the literature on agricultural household models. In this context separability (or recursion) or its absence is related to whether or not production decisions depend on consumption ones. With separability only production decisions are assumed to influence consumption ones, while with non-separability production decisions are also assumed to depend on consumption decisions.

[9] In the theoretical part of this paper we assume only one fuel type for simplicity. We can, however, think of the variable as a vector to accommodate more than one fuel type without any major change in the arguments.

Equation (2) represents a monotonic, twice continuously differentiable well-behaved fuel production (collection) function where F_p denotes quantity of fuel produced (collected) and L_{df} is labour demand for its collection. Equation (3) is the budget constraint where P_x is the price of X; P_f is the price of fuel; W_f is wage rate for labour collecting fuel; L_{sf} is labour supply for fuel collection; and V accumulates all non-fuel income. The expression in parentheses on the right hand side of Equation (3) represents non-labour income from fuel collection.[10] Equations (4) and (5) are what are called market environment constraints (Thornton & Eakin, 1992), the former for quantities of fuel collected and consumed and the latter for labour (demand and supply) for fuel collection. Equation (4) refers to households that are either net buyers of a fuel type (when the strict inequality holds) or self-sufficient (when the equality holds). Similarly, Equation (5) refers to households self-sufficient in labour for fuel collection when the equality holds and those that hire labour when it does not hold.[11] The implication of binding market environment constraints is discussed below. Equation (6) represents constraints for non-negativity of leisure, consumption of X and F_c, and demand for and supply of labour.

After substituting the production function (2) into the budget constraint (3), the Lagrangian function for the problem would be

$$\begin{aligned} L = {} & U\left(X, F_c, T - L_s; A, R\right) + \\ & \lambda\left[W_f L_{sf} + \left(P_f F_p\left(L_{df}, A, R\right) - W_f L_{df}\right) + V - P_x X - P_f F_c\right] \\ & + \sigma\left[F_c - F_p\right] + \phi\left[L_{df} - L_{df}\right]. \end{aligned} \qquad (7)$$

where λ, σ and ϕ are Lagrangian multipliers attached to constraints (3), (4) and (5), respectively.

---

[10] Note that, as opposed to the standard presentation of the budget constraint in agricultural household models, we have left out the value of leisure from both sides of Equation (3) for clarity of exposition.

[11] In principle, sellers of fuel or labour for fuel collection could also be accommodated in the model without changing the basic results.

Assuming interior solutions, we will have the following first order conditions:

$$\partial U \big/ \partial F_c = \lambda \left(P_f - \sigma / \lambda \right) \tag{8a}$$

$$\partial U \big/ \partial L_{sf} = \lambda \left(W_f - \phi / \lambda \right) \tag{8b}$$

$$P_f \partial F_p \big/ \partial L_{df} = W_f - \phi / \lambda \tag{8c}$$

along with constraints (3), (4) and (5).[12]

Interpreting P_f and W_f as market prices, we see from the first order conditions that as long as the market environment constraints are binding, the relevant prices for decision making by the household concerning fuels will be the expressions in parentheses in (8a) and (8b) and not just the market prices P_f and W_f. We also see from (8c) that the value of the marginal product of labour (which is the left hand side) is different from the market wage rate, W_f, which gives a justification for not using the latter as a measure of the relevant wage rate. The prices in parentheses in (8a) and (8b) are referred to in the literature as virtual (shadow) prices[13]. Virtual prices would reflect the relevant opportunity costs and benefits when making utility-maximizing choices and hence the household would respond directly to them rather than market prices (Thornton & Eakin, 1992, 1997; de Janvry *et al.*, 1991; Singh *et al.*, 1986a,b). Depending on the signs of σ/λ and ϕ/λ, virtual prices would be smaller or larger than the respective market prices of fuel or wages for fuel collection.[14] In general, there would be three different wages or fuel prices depending on whether the household is self-sufficient in, a net seller or buyer of labour or a fuel type (Sadoulet *et al.*, 1996). The reasons for different prices or

[12] We can think of X, the composite commodity, as the numeraire, in which case its price, P_x, equals one. Moreover, we should note that we used L_{sf} (labour supply for fuel collection) instead of leisure in equation (8b) assuming the use of a transformation of leisure into labour supply. For details see, e.g., Lopez (1984).

[13] Following the general practice in the literature we use the terms shadow price and virtual price interchangeably. Some authors (e.g., Thornton & Eakin, 1992) make a distinction between the two where the first is used to refer to the values of Lagrangian multipliers and the second for the price of the relevant input or output.

[14] For details see Thornton & Eakin (1992).

wages include transaction costs in buying and selling, and cultural values. Household preference for family labour for efficiency reasons or limited employment opportunities could be additional reasons for the existence of different wage rates for an activity. In our case, given the formulation of the market environment constraints (4) and (5), when the equalities hold the relevant virtual prices (wages) would be those that equate household supply to household demand. Note that the Lagrangian multipliers λ, σ and ϕ, which are determined by the solution to the constrained maximization problem, determine virtual prices and hence the latter are endogenous variables. Moreover, if the relevant commodity is both produced and consumed by the household, the shadow price will be a function of both preferences and technology (Singh *et al.*, 1986b).

The formulation of the model above is similar to that for recursive (separable) agricultural household models except that Equations (4) and (5) are added and, by implication, the budget constraint (3) would be non-linear, due to non-linearity in the conditional profit function. In our case non-linearity arises at least partly because hired and family labour are not perfect substitutes in fuel collection and there is a missing market for dung. One solution proposed by Jacoby (1993) is to linearize the budget constraint at the optimum values of the relevant variables, assuming a convex budget set. This budget constraint will include shadow (virtual) prices instead of market prices for those inputs and outputs whose markets are imperfect. Once this is done, the optimization problem will be very similar to that for separable agricultural household models, the main exception being the presence of shadow(virtual) prices instead of market prices and inclusion of production and consumption variables on both the production and consumption sides of the model. In particular, once virtual prices and wages are used, the constraint to the maximization problem will look like the following:

$$P_x X + P_f^* F_c = W_f^* L_{sf} + \left(P_f^* F_p - W_f^* L_{df}\right) + V, \tag{9}$$

where P_f^* and $\ _f^*$ denote virtual fuel price and virtual wage for fuel collection, respectively.

Assuming second order conditions for utility maximization are satisfied, the first order conditions from maximization of Equation (1) subject to Equation (9) would give sufficient information to derive the relevant demand and supply functions. Thus, the structural fuel demand functions would take the following general form

$$F_c = F_c\left(P_f^*, W_f^*, V, A, R\right). \tag{10}$$

DATA AND EMPIRICAL STRATEGY

Data Description

The data used is from a survey of a random sample of rural households interviewed in February 1996. The descriptive statistics, for 419 households, for most of the variables used in this paper are presented in Table 1. Average annual income per household was Birr 1565 (about USD 247). Most of the income came from farm work, the share of non-labour income in the form of returns from rented out land and remittances being very small.[15] The figure for the number of cattle refers to the number cared for as opposed to the number owned since what we need is a measure of household capital in the collection (production) of dung for which the former is the relevant measure. The number of wood trees owned by households is used as a measure of household capital in woody biomass collection (production) and for that reason the value of the variable for those households who do not have trees older than 3 years is zero.

Descriptive statistics are also presented for consumption, production and time spent collecting biomass fuels. The data reported for consumption and production were obtained as direct responses of households to questions on average monthly consumption and production, while those for time spent for collection were responses to questions on averages per week which we then converted into monthly figures.[16] The statistics presented in Table 1 refer

[15] In the case of own-farm activities what we called labour income includes the contribution of land because of lack of (reliable) measures of prices of labour and land inputs.

[16] The unit of measurement we used for quantities of woody biomass and dung is kilocalories. The conversion factors we used are: For woody biomass 1kg = 3500 kilocalories, and for dung 1kg = 3300 kilocalories (ENEC 1986).

TABLE 1. DESCRIPTIVE STATISTICS.

The Table presents descriptive statistics of the main variables from the sample of rural households used in this study.

VARIABLE	MEAN	STD. DEV.	MIN.	MAX.
Number of adult males[a]	1.38	0.89	0	6
Number of adult females[a]	1.26	0.62	0	4
Number of male youth[a]	0.62	0.79	0	3
Number of female youth[a]	0.61	0.77	0	3
Number of children[a]	0.94	0.96	0	4
Household size	4.80	2.13	1	12
Household labour income in Birr per year[b]	1495	1342	0	10482
Household non-labour income in Birr per year[b]	70	209	0	1764
Number of cattle cared for	1.92	1.54	0	11
Number of private wood trees older than 3 years	115	267	0	2000
Time spent collecting dung (minutes/month)				
From private sources	633	711	0	6720
From communal areas	624	777	0	5880
Total	1257	1065	0	7140
Time spent collecting woody biomass (minutes/month)				
From private sources	595	860	0	5600
From communal areas	1273	1574	0	9840
Total	1868	1618	0	9840
Dung collected (thousands of kilocalories/month)				
From private sources	387	430	0	2586
From communal areas	157	248	0	2228
Total	544	453	0	2586
Woody biomass collected (thousands of kilocalories/month)				
From private sources	407	568	0	2988
From communal areas	335	465	0	2627
Total	742	601	0	3039
Dung consumed (thousands of kilocalories/month)	556	455	0	2586
Woody biomass consumed (thousands of kilocalories/month)	851	596	0	2988

[a] Adults are defined as those over 15 while the youth and children are, respectively, between 7 and 15, and below 7.

[b] The exchange rate at the time of the survey was 1USD = Birr 6.34. Sample size = 419.

to all observations used and hence include non-collectors and/or non-consumers of a fuel type which implies that the time, production and consumption averages will be larger without the non-collectors and/or non-consumers. Out of a total of 419 households, 387 (92.4%) collected woody biomass during the period considered while 400 (95.5%) collected dung.

The data on production and time spent for collection give details regarding sources of collection in addition to the total. Households in the sample collect woody biomass and dung from two main sources: private sources and communal areas (commons). The collection time from private sources per unit of biomass fuels was lower than that for communal areas. The main reasons for this include that the private sources are usually close to the households' homestead and that the search time is lower even if they were at some distance from their homestead. As can be seen from Table 1, the total production(collection) figure for dung was not very different from total consumption since virtually all the households collect for their own consumption. On the other hand, the difference between consumption and production figures for woody biomass was relatively more as there were some households who purchased and others who sold, the total quantity for the purchasers being much larger.

Empirial Strategy

An earlier, perhaps the earliest, work on estimation of nonseparable agricultural household models that is in some sense similar to the one presented in section 2 is in Lopez (1984,1986). The reason for nonseparability in that study was imperfect substitution between on- and off-farm labour. In order to get a profit function that is homogeneous of degree one in the quantity of on-farm labour used, Lopez used the assumptions that the production technology exhibits constant returns to scale and there are no fixed inputs. More recent studies (Amacher *et al.*, 1996a,b; Jacoby, 1993; Skoufias, 1994; Thornton, 1994) employed the concept of virtual (shadow) wage which they estimate from a production function that does not necessarily exhibit constant returns to scale. Once the virtual (shadow) wages and prices are estimated, the budget constraint (Equation (3)) in section two can be linearized at the optimum values of the relevant variables, and demand and/

or supply functions derived and estimated. These demand and supply functions will include virtual (shadow) prices and wages, which are endogenous, as explanatory variables and hence the functions have to be estimated using instrumental variable or simultaneous equation methods. In this paper we use instrumental variables where instruments are used for virtual wages and prices.

Production (collection) and demand functions for woody biomass and dung are estimated in this paper. Non-separability implies that the demand functions should include all virtual (shadow) prices and wages as well as exogenous (production and consumption) variables as explanatory variables. Thus, we first estimate and discuss production functions for woody biomass and dung. From these functions we derive the marginal product of labour which are then used as measures of virtual (shadow) wages in the subsequent estimation of demand functions.

In the data set used in this paper, there were some households not involved in an activity. For example, about 8 percent of the households did not collect woody biomass and about 35 percent did not collect dung from communal areas. Thus, whenever there is a need to analyze only the case of those involved in an activity, we first check for sample selection bias that may be caused by exclusion of those not involved in the activity. For this we use a version of generalized tobit to check for sample selection bias and get efficient estimates using maximum likelihood (Greene, 1995; Maddala, 1983).[17] Thus, in the event that

---

[17] The basic formulation of the model we use is:

$$z^* = \mathbf{V}\alpha + u, \tag{1}$$

$$z = 1 \quad \text{if} \quad z^* > 0 \quad \text{and} \quad z = 0 \quad \text{if} \quad z^* \leq 0,$$

$$y = \mathbf{X}\beta + \varepsilon, \tag{2}$$

$$\varepsilon, u \sim N\left[0,0,\sigma_\varepsilon^2,1,\rho\right], \tag{3}$$

where y and z^* are vectors of dependent variables, the former denoting quantities of fuel collected (or consumed) and the latter is a latent (unobserved) binary variable whose observed counterpart is z which is 1 for those who collect (or consume) a certain fuel type and 0 for those who do not; $\mathbf{X}$ and $\mathbf{V}$ are matrices of explanatory variables; α and β are vectors of parameters to be estimated; and ε and u are vectors of error terms assumed to have a bivariate normal distribution which may be correlated (with correlation coefficient ρ) as specified in Equation (3). Values of y and $\mathbf{X}$ are only observed when z equals 1. Both Equations (1) and (2) are estimated using maximum likelihood (Greene, 1995).

a significant sample selection bias is found, generalized tobit results are reported.

To account for the effect of differences in the study areas on production and consumption behaviour, we use site dummies whenever these are found significant. We also use household composition and size variables whenever they are found significant. The likelihood ratio test is used to decide on the inclusion or exclusion of these variables; and whenever the decision is ambiguous we use t-test and Akaike's information criterion (AIC).

Estimation Issues and Empirical Results

This section, which is divided into two sub-sections, is mainly devoted to a presentation and discussion of estimation issues and empirical results. The first one is on production and virtual wages and the second on demand.

Biomass Fuel Production (Collection) and Virtual (Shadow) Wages

Production (collection) functions are estimated separately for woody biomass and dung. The theoretical counterpart of these production functions is Equation (2) in section two of this paper. For each fuel type, we estimate functions for collection from communal areas in addition to total collection.[18]

As fuel collection in our study areas is a labour intensive activity, labour is one main explanatory variable used in the collection functions as measured by time spent to collect. We also include number of private wood trees over three years of age (for wood collection) and number of cattle cared for by the household (for dung collection) as measures of household capital which facilitate collection. However, these variables are included in the estimations for total collection and not for collection from communal areas as the latter depends not on the number of trees and/

[18] A main reason for estimating total collection functions is to obtain marginal product of labour which is used in the estimation of demand functions. Collection functions from the commons are estimated to look at their implications for such variables as household composition. Separate estimates for collection from private sources did not indicate any significant effect of household composition on collection.

or cattle a household has but on their availability on common lands which should be reflected through such variables as time spent and site dummies, once the decision is made to collect from these sources.[19] In the absence of data on biomass fuel availability on communal lands of our study sites, we used site dummies which might capture inter-site differences. We should note however that these dummies may also measure differences other than availability. The names of the four sites for which dummy variables are used are given in Table 2 which have to be compared with *Amber*, the reference site.[20] Moreover, to examine the effect of household composition on collection, we include the number of adults and the youth separated into males and females in addition to the number of children. While household composition variables correspond to the household characteristics variable A in Equation (2) of the theoretical model, trees and cattle owned, and site dummies are, respectively, household and site specific resource endowment variables that correspond to variable R. We also include interactions between site dummies and the time variable to capture the possible effect of inter-site differences on the slope in addition to the intercept.[21]

The production (collection) function estimates for both fuel types are presented in Table 2. As indicated in the table, the first two columns are estimates for woody biomass while the last two are for dung. Estimates for total collection of woody biomass and dung are presented in the first and third columns of results, respectively. For these we excluded non-collectors since one objective of estimating the total collection functions is to compute

[19] We included number of private wood trees and cattle cared for in the commons regressions for woody biomass and dung, respectively, to examine whether they influence collection perhaps because households that own trees and/or cattle could collect from the commons, if they ever do, when it is easier to do so. The number of trees was not significant while the number of cattle was an important variable for the probit in the generalized tobit estimates for dung collection from the commons reported in Table 2.

[20] Although the total number of peasant associations (PAs) covered in the survey is four, we divided one of these into two to account for differences in topography since they are separated by a gorge and there is a noticeable difference in source of fuelwood.

[21] It may also be argued that the quantity collected of one fuel type may influence that of the other. While this is not supported by the empirical results, it may be argued that such effects should be captured by variables such as time spent to collect a fuel type.

marginal product of the collectors. We run a version of generalized tobit to check for any sample selection bias that may arise from such an exclusion and found no evidence of selection bias in both cases; similar conclusions were reached regarding selection bias for wood collection from communal areas. A significant selection bias was found, however, for dung collection from communal areas. We therefore estimated a version of generalized tobit for this function (Greene, 1995); the results are presented in the last column of Table 2. Standard errors of parameter estimates for the first three columns of results in Table 2, which are estimated using OLS, were corrected for heteroscedasticity using White's (1980) heteroscedasticity-consistent covariance estimator.

The results indicate that the time variable is significant and has the expected positive sign in all cases. Among household composition variables, the number of adult males was significant only in the total wood collection function while the number of adult and/or youth females was significant in most cases. A comparison of the results for household composition by source indicates that the number of youth females is more important in collection from the commons than from the total. These results may be consumption effects. However, since we have tried to control for such variables as time spent and availability, they may also be interpreted as indicators of the advantages of specialization in collection as the coefficients for these groups are positive; and the more frequent significance of the number of adult and/or youth females indicates the importance of females in fuel collection. The slightly significant negative effect of number of children for wood collection from the commons may be because of inconvenience created by kids due to the joint nature of child care and fuel collection in our study areas. On the other hand, the slightly significant positive effect of number of children in total collection of wood may be a consumption effect.

The parameter estimates for the number of trees and cattle were significant and positive, as expected, indicating the collection time minimizing effect of these variables for those households who have trees and/or cattle. Site dummies were significant in most cases which indicate the presence of significant differences between the reference site, *Amber*, and other sites. All site dummies were positive and significant for total wood and total dung collection. We cannot, however, conclude about the implications of these results at least partly because they are also used as interaction terms with the time spent variable. On the other hand, almost all estimated coefficients for site dummies for collection from the commons were negative and all of these were significant for wood collection. This suggests easier access particularly for wood collection from the commons in the reference site, *Amber*, which is generally closer to a larger area of common woodlands than other sites.

We conclude this sub-section by noting how the marginal product of labour is computed, which is used in the next section, from the total production functions for each fuel type. As noted at the bottom of Table 2, the dependent variables and the time spent variable are expressed in logarithms. Thus, given the functional form used in the estimation, the marginal product of labour was computed as the product of output elasticity with respect to labour and the ratio of predicted quantity produced to time spent. In particular, we used the following:

$$MP_{ih} = \left[b_i + \sum_j \left(d_j \times b_{ij} \right) \right] \times \left(F'_{pih} \,/\, L_{dih} \right),$$
$$i = w, d; \quad h = 1,2,3,\ldots n. \tag{11}$$

where i denotes a fuel type, with w for woody biomass and d for dung; h denotes a household; MP_{ih} is marginal product of labour in collecting fuel type i for household h; L_{dih} is labour time spent to collect fuel type i by household h; b_i is the parameter estimate for the variable L_{dih}; d_j is dummy for site j; b_{ij} is the parameter estimate for the variable (site dummy×time spent, or $d_j \times L_{dih}$); and F'_{pih} is predicted quantity of fuel type i collected by household h (Jacoby, 1993; Skoufias, 1994).

Biomass Fuel Demand

In this sub-section demand functions are discussed for woody biomass and dung separately. The theoretical model discussed in section two suggests inclusion of,

TABLE 2. WOODY BIOMASS AND DUNG PRODUCTION (COLLECTION) FUNCTION ESTIMATES.

	Dependent variable			
	Woody Biomass Collected		Dung Collected	
	Total	Commons	Total	Commons[A]
Number of adult males[b]	0.136*** (0.037)			
Number of adult females[b]	0.11** (0.046)	0.09 (0.082)		0.147** (0.074)
Number of female youth[b]		0.17*** (0.06)	0.066 (0.043)	0.17*** (0.064)
Number of children[b]	0.053* (0.032)	−0.088* (0.049)		
Number of trees	0.073*** (0.018)			
Number of cattle			0.098*** (0.022)	
Time spent	0.68*** (0.06)	0.67*** (0.06)	0.88*** (0.18)	0.463*** (0.055)
Geltima site*Time spent	−0.48*** (0.104)		−0.62*** (0.2)	
Zemetin site*Time spent	−0.37*** (0.095)		−0.48** (0.21)	
Bulbulo site*Time spent	−0.23** (0.11)		−0.75*** (0.21)	
Filagober site*Time spent	−0.56*** (0.08)		−0.48** (0.2)	
Geltima[c]	3.54*** (0.8)	−0.84*** (0.13)	4.8*** (1.3)	−0.037 (0.167)
Zemetin[c]	2.5*** (0.7)	−0.22* (0.13)	3.5*** (1.4)	0.11 (0.35)
Bulbulo[c]	1.4* (0.8)	−0.54*** (0.13)	5.6*** (1.4)	−0.305* (0.166)
Filagober[c]	3.7*** (0.61)	−0.74*** (0.097)	3.34*** (1.32)	−0.71*** (0.17)
Constant	8*** (0.4)	8.3*** (0.43)	6.43*** (1.19)	9.2*** (0.38)
Sigma				0.93***
Rho				−0.759***
No. of observations	387	257	400	419
Log likelihood function	−370.7	−257.3	−423.9	−571.1
Chi−squared	145.2	200	170	
Adj. R^2	0.29	0.53	0.33	

[a] Generalized tobit estimates (see footnote number 17 for empirical model specification).

[b] Adults are defined as those over 15 while the youth and children are, respectively, between 7 and 15, and below 7.

[c] The reference site is Amber.

***, ** and * indicate significance at 1%, 5% and 10% levels respectively. Figures in parentheses are standard errors. The dependent variables, number of trees and time spent are in logarithms.

among others, virtual fuel prices, virtual wage rates and income as explanatory variables. Before presenting the empirical results, we discuss the following four issues related to estimation of the demand functions: virtual fuel prices and virtual wages, endogeneity, sample selection bias and the treatment of non-fuel income, in that order.

As indicated earlier, given that households in our sample use family labour in fuel collection, the market wage rate is not an appropriate measure since hired and family labour are not perfect substitutes. Thus, we use the value of the marginal product of labour estimated in the previous sub-section as a measure of virtual (shadow) wages. This measure is household specific since it is expected that in the absence of hiring of labour, the shadow wage rate would be a result of a household's attempt to equate supply of and demand for its own labour. Moreover, since dung is almost exclusively collected by females while woody biomass is collected by both males and females, we estimate fuel specific shadow wages which implies imperfect substitution between labour used to collect the two fuel types.

Regarding the price of fuel we indicated earlier that in our sample, dung was collected almost exclusively for own consumption and all those who consumed dung did not purchase it. In two of our study sites dung was not traded even in the respective closest towns. Moreover, although fuelwood is traded in all the closest towns to our study sites, a large majority of the households are not involved in the market. These arguments suggest that market prices may not reflect the degree of scarcity faced by the household, at least to those not involved in the market. In terms of the theoretical model this implies that, depending on the fuel type considered, for all or a large majority of the households in the sample, the equality holds for Equation (4) and hence the relevant fuel price is different from the market price since σ would not be zero in Equation (8a). But obviously saying that market prices may not reflect scarcity of fuels for a household does not mean that woody biomass and dung are not economically scarce. It means that we should look for some other measures of price (shadow or virtual price) that are more specific to the household.

What we used as a measure of virtual fuel price in this study is one which relies on a combination of time spent to collect a unit of a fuel type and the shadow wage. We argue that time is a main resource peasants have and its availability is the main variable that they use in their decision to collect or not. Thus, the time they spend to collect a unit of fuel would be an indicator of how difficult it is for the household to get it and hence it is an essential ingredient in the computation of shadow price of wood and dung (Dasgupta & Mäler, 1995).[22] In the case of households that collect from both private and communal fuel sources, we used time spent to collect a unit of fuel for collection from communal areas only, which may be an approximation to the marginal unit. On the other hand, it is important to consider the value of labour time for the household in addition to the collection time per unit of fuel collected since the former is expected to influence the shadow price of biomass fuels collected. We therefore use the shadow wage multiplied by the time spent to collect a unit of a fuel type as a measure of shadow price of that fuel type (Cooke, 1996).[23] This implies the expectation that, other things remaining the same, the longer it takes to collect a unit of fuel and/or the higher the opportunity cost of labour used, the higher the cost of collecting a unit of fuel. Note that these measures of virtual price are household and fuel type specific since we expect differences across households in terms of shadow wages and time spent to collect a unit of fuel for various reasons including differences in household composition and resource endowment.

A problem with non-collecting consumers is that we do not have measures of shadow prices and wages that are comparable to the ones used for collectors. As there were no households who purchased dung in our sample, this issue is relevant only for few households who purchased woody biomass and did not collect. Regarding shadow

[22] Dasgupta & Mäler (1995) suggest the energy cost of collecting a unit of fuel as an approximation to the shadow price of fuelwood. To the extent that time spent to collect a unit of fuel is highly correlated to the energy cost of collecting a unit of fuel the two measures are similar.

[23] Using a slightly modified version of the theoretical model we presented in section 2 of this paper, Cooke (1996) shows a similar result.

wages we expect the non-collecting consumers to have an opportunity cost of labour higher than those of collectors, for which reason we used the maximum shadow wages for the sample as a measure of shadow wages for the former group. The expectation of higher opportunity cost of labour is based on the argument that they would have collected if it had not been so. For shadow fuel prices we used average shadow fuel prices based on the argument that if those prices are missing, it is safer to assume that they take on the average values in the absence of better measures.

The marginal product of labour per hour used in the collection of woody biomass and dung, computed using Equation (11), was on average about 2.7 kg of wood and 3 kg of dung, respectively. If we convert these physical marginal products into money using average fuel prices, the average wages per hour for woody biomass and dung would be Birr 0.58 and Birr 0.55 respectively. Virtual (shadow) fuel prices per 10 kg of woody biomass and dung were found to be Birr 1.04 and Birr 1.33 respectively. These shadow prices are less than 80 percent of average fuel prices in our study sites.

As we noted earlier in the theoretical section, shadow fuel prices and shadow wages are endogenous variables. Moreover, since we expect the two fuel types to be related in the sense that they may be substitutes or complements, the demand equations to be estimated will form a system of (simultaneous) equations. In particular, the econometric model to be used in the estimation of the two demand equations will take the following form

$$y_m = X_m \beta_m + \varepsilon_m, \quad m = 1,2, \tag{12}$$

where m is the equation number for the two demand equations, y_m is a vector representing the dependent variable for equation m (i.e. either quantities of woody biomass or dung consumed), $\mathbf{X}_m$ is a matrix of explanatory variables for equation m, β_m is the parameter vector for equation m and ε_m is a vector that denotes the classical disturbance term for equation m. To correct for inconsistency that may be caused by endogeneity of virtual fuel prices and virtual wages, which are included as explanatory variables in the demand equations, we apply instrumental variable estimation (2SLS).[24] It may be argued that such an estimation strategy would lead to inefficient estimates since the error terms may be correlated across equations. However, this would not be a problem if the equations have identical explanatory variables (Greene, 1993), which is the case in this study. Standard errors are corrected for heteroscedasticity using White's (1980) heteroscedasticity-consistent covariance estimator.

A related issue is selectivity bias. Deaton (1986) discusses problems related to application of (standard) tobit models to the analysis of consumer behaviour and suggests the use of non-zero values for the dependent variable(s) after allowing for any possible sample selection bias that may be caused by exclusion of zero values. Since there are some households in our sample who do not consume a fuel type, we run a version of generalized tobit with simultaneous equations (Greene, 1995) to check for sample selection bias and found no evidence in favour of the existence of selection bias. Only positive quantities of fuel consumed are therefore used in the instrumental variable estimation.

The non-fuel income variable used in the theoretical model consists of labour and non-labour income. Since this distinction may indicate differences in labour availability and returns to labour in activities not related to fuel collection, we use these two types of income as separate variables in the regressions. Note also that in addition to fuel prices, wages and income variables, the theoretical model suggests inclusion of other production and consumption variables in the demand functions. For this reason, we included measures of household and regional character-

[24] The following variables were used as instruments: Number of adult males and females (over 15 years of age); number of male and female youth (between 7 and 15 years of age); number of children (below 7 years of age); household size; number of trees owned; number of persons educated above grade 3; age, education and sex of household head; number of cattle, sheep, goats and equines; non-labour income; distance between homestead and the forest; distance between homestead and communal area where dung is collected; whether or not the household has borrowed money; area of land owned; and site dummies. In addition to the values of these variables we also used squares and interactions of some of them. The correlation coefficients for virtual (shadow) wages and the corresponding predicted values (i.e., the instruments) are 0.87–0.89 while those for virtual (shadow) fuel prices are 0.66−0.67.

istics, and resource endowment such as household size, trees, cattle cared for, and site dummies.

The empirical results are presented in Table 3. The first column of results in Table 3 is for woody biomass, while the second is for dung. As indicated at the bottom of Table 3, the dependent variables, price, wage and income variables are in logarithms and hence we interpret the respective parameter estimates as elasticities. The results indicate that all own-price elasticities are significantly negative suggesting that households respond to increased cost of time spent to collect a unit of biomass fuels by reducing the amount consumed. Cross-price elasticities are either negative and significant or insignificant suggesting that the two fuel types are either complements or independent. There is no evidence of substitution.

Non-labour income elasticities are insignificant in most cases with a positive value for woody biomass and negative for dung. Labour income elasticities are similar in terms of sign and those for woody biomass were significant. These results give an indication that dung is an inferior good and richer households tend to consume less dung and more woody biomass. Own-wage elasticities are negative and significant for dung consumption suggesting that households respond to increased shadow wages by cutting on consumption. Cross-wage elasticities are generally insignificant .

The number of trees owned by a household has a significant positive effect on consumption of both fuel types. The number of cattle has a positive and significant effect on both wood and dung consumption. Household size is a significant variable positively affecting fuel consumption in all cases, as expected. All site dummies are negative and most of them are significant, suggesting that biomass fuel consumption in the reference site, *Amber*, is significantly higher than in other sites. Since the reference site is warmer than all others, this result suggests that the higher frequency of cooking partly explains the difference and outweighs the heating fuel demand increasing effect of colder sites.[26]

[26]. Households would be forced to cook more frequently if the weather is (too) warm since facilities such as refrigerators are nonexistent in our study areas.

TABLE 3. BIOMASS FUEL DEMAND FUNCTION ESTIMATES[A].

	DEPENDENT VARIABLE	
	WOODY BIOMASS CONSUMED (CONSUMERS OF BOTH)	DUNG CONSUMED (CONSUMERS OF BOTH)
Household size	0.07*** (0.017)	0.038*** (0.014)
Virtual price of wood	−0.4*** (0.053)	0.03 (0.09)
Virtual price of dung	−0.3*** (0.1)	−0.72*** (0.11)
Virtual wage for wood collection	−0.1 (0.14)	−0.21* (0.12)
Virtual wage for dung collection	−0.18 (0.11)	−0.72*** (0.12)
Labour income	0.056*** (0.02)	−0.017 (0.02)
Non-labour income	0.029 (0.019)	−0.02 (0.016)
Number of trees	0.05** (0.023)	0.04** (0.02)
Number of cattle	0.066** (0.03)	0.19*** (0.029)
Geltima site[b]	−0.77*** (0.28)	−0.58* (0.32)
Zemetin site[b]	−1.12*** (0.18)	−0.6*** (0.21)
Bulbulo site[b]	−1.6*** (0.35)	−1.8*** (0.39)
Filagober site[b]	−1.54*** (0.33)	−0.91*** (0.35)
Constant	13.6*** (0.72)	15.6*** (0.64)
Log likelihood function	−315.3	−316.5
Chi−squared	231	351

[a] Instrumental variable estimation (2SLS)

[b] Amber is the reference site.

***, ** and * indicate significance at 1%, 5% and 10% levels respectively.

Figures in parentheses are standard errors. Sample size = 392.

The dependent variables, prices, wages, income and number of trees are in logarithms.

CONCLUSIONS

We used a non-separable agricultural household model to examine fuel production and consumption behaviour of a random sample of rural households. Fuel production (collection) functions were estimated for both total collection and collection from communal areas for each of the two major biomass fuels consumed in our study areas, namely, woody biomass and dung. The results indicate that in addition to the labour time variable which was significant in all cases, site dummies and some of the household composition variables were significant explanatory variables. Among household composition variables, the more frequent significance of parameter estimates for the number of adult and/or youth females particularly for collection from the commons indicates the importance of females in biomass fuel collection.

Demand functions were also estimated for woody biomass and dung. Because of non-separability between production and consumption decisions caused by imperfection in, or absence of, markets for fuel and labour used for its collection, we used virtual (shadow) fuel prices and virtual (shadow) wages as explanatory variables instead of market prices. The results showed significant household responsiveness to own prices with negative parameter estimates. Since we used the cost of time spent to collect a unit of fuel as a measure of virtual fuel prices, these significantly negative own-price elasticities indicate advantages of forest policies that can reduce fuel collection time and possibly make more time available for child care, cooking and perhaps agricultural production.

Cross-price elasticities were either negative and significant or insignificant suggesting that woody biomass and dung are either complements or independent; substitution is not supported by the empirical results and hence may not be automatic as has been assumed or implied by some (e.g., World Bank, 1984; Newcombe, 1989). The significance of own price elasticities combined with the effects of household resource endowment variables suggests that fuel choice and mix are significantly influenced by scarcity. This indicates a possibility of policy interventions directed at reducing the relative price of wood and encouraging increased dung use as fertilizer and hence reduced land degradation. Estimated income elasticities of demand for dung and woody biomass also give indications of increasing viability of such interventions with growth. However, the absence of evidence of substitutability and the positive effects of number of cattle on wood consumption and number of trees on dung consumption suggest the importance of cooking habits and culture which in turn indicates the importance of policies that could affect the demand side such as education and dissemination of improved stoves, if these are deemed necessary.

REFERENCES[27]

Amacher, G. S., Hyde, W. F. & Joshee, B. R., 1993. Joint Production and Consumption in Traditional Households: Fuelwood and Crop Residues in Two Districts in Nepal. *Journal of Development Studies,*30(1), 206–25.

Amacher, G. S., Hyde, W. F. & Kanel, K. R., 1996a. Forest Policy when Some Households Collect and Others Purchase Fuelwood. *Journal of Forest Economics*, 2(3).

Amacher, G. S., Hyde, W. F. & Kanel, K. R., 1996b. Household Fuelwood Demand and Supply in Nepal's Tarai and Mid-hills: Choice between Cash Outlays and Labour Opportunity. *World Development*, 24(11), 1725–1736.

Asmerom Kidane, 1991. Demand for Energy in Rural and Urban Centres of Ethiopia: An Econometric Analysis. *Energy Economics*, 13(2), 130–134.

Barnes, C., Ensminger, J. & O'Keefe, P., eds., 1984. *Wood, Energy and Households: Perspectives on Rural Kenya,* Energy. Environment and Development in Africa 6, The Beijer Institute, Stockholm and the Scandinavian Institute of African Studis, Uppsala.

Bojö, J. & Cassells, D., 1995. Land Degradation and Rehabilitation in Ethiopia: A Re-assessment. *AFTES Working Paper* No. 17, Washington, D. C.: World Bank.

Cooke, P. A., 1996. The Effect of Environmental Degradation and Seasonality on the Collection and Consumption of Environmental Goods by Rural Nepali Households. *Studies in Environmental Economics and Development* 1996:11, Environmental Economics Unit, Department of Economics, Göteborg University.

Dasgupta, P. & Mäler, K.-G., 1995. Poverty, Institutions, and the Environmental Resource-base. In *Handbook of Development Eco-*

[27] Ethiopian names are listed alphabetically by first name.

nomics, Vol. III, edited by J. Behrman. and T.N. Srinivasan (Elsevier Science Publishers B.V.).

Deaton, A., 1986. Demand analysis. In *Handbook of Econometrics*, Vol. III, edited by Z. Griliches and M.D. Intriligator, (Elsevier Science Publishers B.V.).

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

Dewees, P. A., 1989. The Woodfuel Crisis Reconsidered: Observations on the Dynamics of Abundance and Scarcity. *World Development*, 17(8), 1159–1172.

EFAP (Ethiopian Forestry Action Programme), 1993. The Challenge for Development, Volume II, Addis Ababa: Ministry of Natural Resource Development and Environmental Protection, Transitional Government of Ethiopia, March 30.

ENEC (Ethiopian National Energy Committee), 1986. Cooperation Agreement in the Energy Sector: Main Report, The Ministry of Mines and Energy of Ethiopia and CESEN-ANSALDO / FINMECCANICA Group.

Greene, W. H., 1993. *Econometric Analysis*, Second edition (New York: Macmillan Publishing Company).

Greene, W. H., 1995. *LIMDEP: User's Manual, Version 7.0* (New York: Econometric Software, Inc.).

Hosier, R., ed., 1988. *Energy for Rural Development in Zimbabwe*. Energy, Environment and Development in Africa 11, The Beijer Institute, Stockholm and the Scandinavian Institute of African Studies, Uppsala.

Hosier, R., ed., 1985. *Energy Use in Rural Kenya: Household Demand and Rural Transformation*. Energy, Environment and Development in Africa 7, The Beijer Institute, Stockholm and the Scandinavian Institute of African Studies, Uppsala.

Hyde, W. F., 1991. Social Forestry: A Working Definition and 21 Testable Hypotheses. *Journal of Business Administration*, 11, 430–52.

Jacoby, H. G., 1993. Shadow Wages and Peasant Family Labour Supply: An Econometric Application to the Peruvian Sierra. *Review of Economic Studies*, 60, 901–923.

Jama, M., 1995. Impacts of Rural Energy Availability in Kenya: The Case of Kiambu District. *Studies in Environmental Economics and Development* 1995: 2, Environmental Economics Unit, Department of Economics, Göteborg University.

Leach, G. & Mearns, R., 1988. *Beyond the Woodfuel Crisis: People, Land and Trees in Africa* (London: Earthscan Publications Ltd.).

Lopez, R. E., 1984. Estimating Labor Supply and Production Decisions of Self-employed Farm Producers. *European Economic Review*, 24, 61–82.

Lopez, R. E., 1986. Structural Models of the Farm Household that Allow for Interdependent Utility and Profit Maximization Decisions. In *Agricultural Household Models*, edited by I. Singh , L. Squire and J. Strauss (Baltimore: The John Hopkins University Press).

Maddala, G. S., 1983. *Limited-dependent and Qualitative Variables in Econometrics* (Cambridge: Cambridge University Press).

Mulat Demeke, Ali Said & Jayne, T. S., 1996. The Relationships between Grain Market Performance and Fertilizer Markets and Profitability. Paper presented at the Grain Market Research Project Discussion Forum sponsored by the Ministry of Economic Development and Cooperation, November 8-9, Sodere, Ethiopia.

Newcombe, K. J., 1989. An Economic Justification for Rural Afforestation: The Case of Ethiopia. In *Environmental Management and Economic Development*, edited by G. Schramm, G. and J. J. Warford (Baltimore and London: The Johns Hopkins University Press).

Sadoulet, E., de Janvry, A. & Benjamin, C., 1996. Household Behaviour with Imperfect Labour Markets. Department of Agricultural and Resource Economics, Division of Agriculture and Natural Resources, University of California at Berkeley, Working Paper No. 786.

Singh, I., Squire, L. & Strauss, J., 1986a. The Basic Model: Theory, Empirical Results, and Policy Conclusions. In *Agricultural Household Models*, edited by I. Singh, L. Squire and J. Strauss (Baltimore: The Johns Hopkins University Press).

Singh, I., Squire, L. & Strauss, J., 1986b. Methodological Issues. In *Agricultural Household Models*, edited by I. Singh , L. Squire and J. Strauss (Baltimore: The Johns Hopkins University Press).

Skoufias, E., 1994. Using Shadow Wages to Estimate Labour Supply of Agricultural Households. *American Journal of Agricultural Economics*, 76, 215–227.

Sutcliffe, J. P., 1993. Economic Assessment of Land Degradation in the Ethiopian Highlands: A Case study. Addis Ababa: National Conservation Strategy Secretariat, Ministry of Planning and Economic Development, December, mimeo.

Thornton, J. & Eakin, B. K., 1992. Virtual Prices and a General Theory of the Owner Operated Firm. *Southern Economic Journal*, 58(4), 1015–29.

Thornton, J., 1994. Estimating the Choice Behaviour of Self-employed Business Proprietors: An Application to Dairy Farmers. *Southern Economic Journal*, 60(3), 579–96.

Thornton, J. & Eakin, B. K., 1997. The Utility-maximizing Self-employed Physician. *The Journal of Human Resources*, XXXII(1).

White, H., 1980. A Heteroskedasticity-consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity. *Econometrica*, 48, 817–838.

World Bank, 1984. Ethiopia: Issues and Options in the Energy Sector. Report No. 4741-ET, Washington, D.C.