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Coping with Fuelwood Scarcity

Household Responses in Rural Ethiopia

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Abstract

This study uses survey data from randomly selected rural households in Ethiopia to examine the coping mechanisms employed by rural households to deal with fuelwood scarcity. The determinants of collecting other biomass energy sources were also examined. The results of the empirical analysis show that rural households in forest-degraded areas respond to fuelwood shortages by increasing their labor input for fuelwood collection. However, for households in high forest cover regions, forest stock and forest access may be more important factors than scarcity of fuelwood in determining household's labor input to collect it. The study also finds that there is limited evidence of substitution between fuelwood and dung, or fuelwood and crop residue. Therefore, supply-side strategies alone may not be effective in addressing the problem of forest degradation and biodiversity loss. Any policy on natural resource management, especially related to rural energy, should distinguish regions with different levels of forest degradation.

Key Words: fuelwood, labor allocation, biomass, rural Ethiopia

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Contents

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Introduction

Many people in developing countries rely on biomass energy sources, primarily fuelwood, dung, and crop residue, for their energy needs.[1] Widespread poverty in many rural areas of developing countries, especially sub-Saharan Africa, is a critical factor in continued dependency on biomass energy sources and persistent traditional and inefficient means of using them. It can be observed across developing countries by the ongoing forest degradation and deforestation, particularly in Asia and sub-Saharan Africa, which has resulted in fuelwood scarcity.

Ethiopia is a typical example, where nearly all its rural population depends on biomass energy sources for cooking and other energy requirements. Of the different biomass energy sources, fuelwood accounts for around 78 percent of the total energy demand, while animal dung and crop residue account for 12 percent and 9 percent, respectively (WBISPP 2004). Because these resources must be collected from common areas, such high dependence has a fundamentally negative impact on the availability of forest resources.

A 2007 forest policy of the Ethiopian government noted that fuelwood collection, together with land clearing for agriculture, illegal settlement within forests, logging, and illegal trade, has resulted in the deterioration of forests and forest resources. According to the Food and Agriculture Organization (FAO 2009), Ethiopia loses about 141,000 hectares of forest each year. Cognizant of these problems, the Forest Development, Conservation, and Utilization Policy and

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[1] According to the International Energy Agency (IEA 2002), 2.4 billion people in developing countries use biomass as a source of energy for cooking, heating, and lighting needs.

Strategy was approved by the Council of Ministers in April 2007—the first forestry policy developed and passed by the Ethiopian government.

Although there is considerable policy interest within the government, the link between socioeconomic, environmental, and institutional factors and biomass use is not well documented in Ethiopia. A better understanding of the interaction between rural people and biomass use, under different environmental conditions, may help policymakers design better, more effective strategies to conserve rural Ethiopia's forests and forest resources.

Fuelwood scarcity, especially in rural areas, has attracted the attention of many researchers and policymakers since the mid-1970s because it has serious, negative socioeconomic consequences for rural livelihoods (Arnold et al. 2003; Mekonnen 1999). For example, Dewees (1989) and Arnold et al. (2003) argued that scarcity increases the burden on women and children, who are the primarily collectors of biomass, significantly decreasing the amount of time they have for other tasks and activities. Furthermore, in the absence of sufficient fuelwood, increasing quantities of crop residue and animal dung are used as fuel, reducing their availability as livestock feed, soil conditioner, and fertilizer. Fuelwood scarcity can increase deforestation, change cooking and eating habits, and promote fuelwood markets.[2] However, each of these changes may also occur for other reasons unrelated to the physical or the economic scarcity of fuelwood (Dewees 1989).

Given the potential negative impacts of fuelwood scarcity, understanding its effects and households' responses to (increasing) fuelwood scarcity represents an important research agenda, with the potential to impact behavior and develop better forest policies. Early studies examined responses to scarce fuelwood within the context of fuelwood production and consumption. Although there are a number of studies of fuel-wood production and consumption in Asia and Africa, the empirical evidence is still limited.

Kumar and Hotchkiss (1988) found that households in Nepal cope with fuelwood scarcity by increasing the amount of time spent on collection. Similarly, Cooke (1998a;1998b) showed that, when Nepalese households face shortages of environmental goods (as measured by shadow prices), they spend more time collecting these environmental goods without affecting agricultural productivity, concluding that such reallocated time must come from other activities, e.g., leisure. Brouwer et al. (1997) showed that Malawian households switch to lower-quality wood,

[2] See Cooke et al. (2008) for further implications of fuelwood scarcity on rural household welfare.

economize on wood use, and increase the number of collectors. Heltberg et al. (2000) found that households in forest-degraded areas increase their collection time. Similarly, Palmer and Macgregor (2009)'s study demonstrated that fuelwood scarcity has a positive effect on labor inputs in fuelwood collection.

Both Heltberg et al. (2000) and Palmer and Macgregor (2009) examined the relationship between fuelwood scarcity and forest degradation, using collection time per unit of fuelwood as an indicator for fuelwood scarcity. In contrast, van `t Veld et al. (2006) found that households in India do not spend more time searching for fuelwood when biomass availability from common areas decreases. Instead, households are less likely to collect from common areas at all and more likely to use privately produced fuel. Cooke et al. (2008), in their review, argued that more evidence on the collection and consumption of fuel wood is needed from African countries.

In addition to examining the direct household response to fuelwood scarcity, in terms of fuelwood collection efforts, the literature has also examined indirect responses, such as substitution of other biomass energy sources. Both Heltberg et al. (2000) and Palmer and Macgregor (2009) found limited evidence of substitution of fuelwood from common areas for private fuels in India, and fuelwood for dung in Namibia. Mekonnen (1999), using virtual prices, demonstrated that dung and fuelwood are complements. Amacher et al. (1993) showed that crop residue and fuelwood are complements in one region of Nepal, but are substitutes in another district of their study area. A review by Cooke et al. (2008) summarized the cross-price evidence (substitution or complementation) between fuelwood and dung, and fuelwood and crop residue, as mixed.

As the research suggests, fuelwood scarcity results in increased fuelwood collection efforts. However the literature has not settled upon the appropriate indicator of fuelwood scarcity. In particular, Brouwer et al. (1997) made the case that the distance to the collection place and the collection time are not reliable indicators of fuelwood shortages, as so often postulated in the literature, because households from the same village often use considerably different collection strategies. In addition, the literature does not generally relate household responses to forest status, a more appropriate indicator of scarcity, with the exception of Bandyopadhyay et al. (2006) and van `t Veld et al. (2006). As discussed by Dewees (1989) and Arnold et al. (2003), early analyses failed to distinguish between physical and economic measures of scarcity and abundance.

In our study, although we follow the literature in using collection time as an economic measure of scarcity, we also control for physical measures of scarcity based on spatial data. Because few studies combine spatial information with household-level data (Dasgupta 2005), one contribution of our research is to account for differences in household responses to fuelwood scarcity under different environmental conditions. Moreover, the spatial data enable us to separately analyze households' fuel-use behavior by status of forest cover.

Our study includes spatial data, incorporates biomass availability related to the level of forest degradation, and uses household-specific measures of fuelwood scarcity. With this mixed data, we can consider 1) whether or not households increase their fuelwood collection time when faced with fuelwood scarcity, 2) whether or not households respond differently to fuelwood scarcity in different forest conditions, and 3) what the relationship is between fuelwood scarcity and the consumption of other traditional fuel sources, such as dung and crop residue. We consider these issues by empirically analyzing the links between the socioeconomic, environmental, and institutional factors that affect household coping mechanisms in the face of fuelwood scarcity, with special attention to the level of forest degradation.

The remainder of the paper is organized as follows. In section 1, we outline the theoretical frameworks. Given the nature of rural households in this study area in particular, and other developing countries in general, the theoretical framework is based on the farm household model. In section 2, we present the empirical methodology. Section 3 describes the study area, the nature and sources of the data, and the statistics of that data. Section 4 discusses the empirical results and relates them to the context of the literature, while section 5 concludes and adds some implications for policy.

1. Analytical Framework: The Farm Household Model

Rural Ethiopian households are both producers and consumers of fuelwood and other biomass energy sources, suggesting that markets for biomass energy sources are missing or incomplete. Moreover, collection activities in rural Ethiopia do not involve hired labor, which is further evidence of missing markets. Given this lack of markets, the appropriate analytical framework is a nonseparable household model incorporating the consumption and production decisions of the farm household.[3]

The main implication of the household model is the need for household-specific shadow prices, in order to examine rural household behavior toward consumption and production of fuelwood and other biomass collection, as well as labor allocation to it. Because the market price

[3] For further details on agricultural household models, refer to Singh et al. (1986).

has a limited role for households that produce and consume all their fuelwood, Mekonnen (1999) and Cooke (1998a; 1998b) derived the household opportunity cost for collecting fuelwood and used it to estimate the shadow price of fuelwood. The model developed for this study follows a similar strategy, although it abstracts from a number of interesting details.

Consider a farm household with concave utility over net income, energy, and leisure. In other words, $U = U(\pi, E, \ell;\ \Omega_U)$, where the first argument denotes net income, the second denotes energy, and the third, leisure; these are all conditioned on household preferences. Energy is assumed to be the sum of energy from all sources, firewood, dung, and crop residue, respectively, such that $E = F_E + D_E + R_E$. Leisure is total time net of all labor supplied in all activities, such as labor supplied to the market and in the collection of fuelwood, dung, and crop residue; therefore, $\ell = T - L - F_L - D_L - R_L$.

Income arises from the sale of agricultural goods and fuelwood, although fuelwood can also be purchased from wage earnings. Furthermore, agricultural production is assumed to depend on nonenergy dung and crop residue, which are determined by their respective labor inputs, as well as technology. Fuelwood production is also determined by its labor input and the technology affecting production. Allowing *a*, *f*, and *w* to represent the prices of agricultural goods, fuelwood, and labor, respectively, net income is written as equation (1), while the conditioning technology information Ω_j in each production function is product specific.

$$\pi = a[A(D(D_L; \Omega_D) - D_E, R(R_L; \Omega_R) - R_E; \Omega_A)] + wL + \ f(F(F_L; \Omega_F) - F_E) \qquad (1)$$

The preceding specification assumes 1) all energy sources are perfectly substitutable, 2) the trade-off for using dung or crop residue for energy is a reduction in agricultural output, 3) the use of labor for any activity reduces leisure, and 4) $A(0,0; \Omega_A) > 0$; in other words, if no fuelwood is available, households can still produce agricultural goods, while using all dung and crop residue for energy.

Maximizing household utility, subject to the energy, leisure, and profit constraints, as well as non-negativity constraints for each of the energy and labor choice variables, yields a series of conditions specifying optimal household behavior. The conditions yield a set of household-level “market” equilibriums for each labor and energy type. Generally, households will equate the marginal utility of leisure with the marginal utility of profits times the value of the marginal product of labor in each of the three energy collection activities. Similarly, households will equate the marginal utility of energy with the marginal utility of profits times the marginal profit associated with that energy source. Importantly, the equilibriums are only a function of the exogenous information Ω_j and the prices *a, f,* and *w*.[4]

Once these equilibriums have been determined, it is possible to place the model within the context of this research. Although it was subsumed in the model specification, energy substitution does not necessarily arise in the model, since substitution away from fuelwood toward either dung or crop residue reduces agricultural productivity. For example, if the value of agricultural goods is high enough, relative to fuelwood, households could prefer to focus on agricultural production, while purchasing their fuelwood from the market.

Regarding household level responses to fuelwood scarcity, which would imply an increase in the market and shadow prices of fuelwood, households could choose to either work harder to reduce their expenditure on fuelwood (raise the market value of their sales) or cut their energy use to maintain their leisure and/or focus their efforts on agricultural production. Given the many possible household level responses, even within this simple theoretical construct, the impact of fuelwood scarcity on household behavior is an empirical question, the methodology for which is considered, below.

2. Empirical Methodology

In the preceding subsection, we briefly described a simple model of household behavior in the face of fuelwood scarcity, with separate equations for each type of labor and energy included. However, the focus of the empirical research is only on a subset of these equations (labor devoted to collecting fuelwood, dung, and crop residue) the initial equations are intuitively subsumed in the three that are estimated.[5]

Guided by theory, but constrained by data limitations, the goal of our empirical analysis is to describe the household-level equilibrium allocation of labor to collecting fuelwood, dung, and crop residue. In the sample, only 42.5 percent and 35 percent of the sample collect dung and crop residue, respectively. Theory suggests that each of these equilibria is determined by

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[4] A more complex model would include a number of other factors and markets, such as home-produced goods and market-purchased goods, which would expand the set of exogenous information, but not change the general conclusions derived in the model.

[5] Unfortunately, the data do not allow us to separate dung used as fertilizer from dung used for energy, or crop residue used for livestock feed from crop residue used for energy. Although the available data detract from our ability to correctly quantify substitution across energy use, it is still possible to consider substitution across energy sources, although dung and crop residue collection in this data are not only collected for energy use.

preferences, technology, prices, and other exogenous information, and that these equilibria are interrelated. Therefore, the empirical strategy is based on the estimation of the following equations related to energy production and consumption by the household:

$$y = G_y\left(X_y, P\right) \tag{2}$$

In equation (2), $y = \{F_L, Q_D, Q_R\}$, where F_L (labor allocation for fuelwood collection) was described earlier, Q_D represents the quantity of dung collected; Q_R denotes the quantity of crop residue collected; X_y represents a vector of observable controls related to preferences and technology, for the outcome considered; while P represents prices, which might be shadow prices or market prices, depending upon the type of energy considered. In principle, equation (2) could be estimated as a system of equations; however, missing data problems, specifically data that is not missing at random, require a circuitous route.

In the sample used (described more fully below), price information is scant. For example, agricultural prices are not available, so we ignored those prices in the analysis. Similarly, labor is provided outside the household for only a subset of households: thus, wage data is missing for some households. Furthermore, a number of households do not collect fuelwood from the common areas, such that fuelwood collection time—our measure of fuelwood scarcity—is not available for all households.[6] To accommodate missing data and missing prices, we follow methodology similar to that proposed by Heckman (1979). We estimate and predict them via selection methods based on equations (3) and (4):

$$\text{prob}(P > 0) = \Phi(X_P, Z_P) \tag{3}$$

$$P_{P>0} = P(X_P, \lambda_P) \tag{4}$$

In equation (3), Φ represents the cumulative normal distribution and, thus, is estimated via a probit specification; X_P is a vector of control variables; while Z_P is a variable that affects participation, but is assumed to not affect the actual price, except through participation. From equation (3), it is possible to calculate the inverse Mills ratio λ_P, which is included in equation (4) to correct for selection bias. Predicted values for the entire sample, based on equation (4), are incorporated into equation (2) for estimation, using all of the available observations:

$$y = G_y\left(X_y, \hat{P}\right) \tag{5}$$

[6] By assumption, based on observation of the study areas, there are no markets for either dung or crop residue.

Equation (5) includes two generated regressors and, therefore, the complete estimation process—the estimation of equation (3) and prediction of equation (4) for both wages and fuelwood collection time, as well as the estimation of equation (5)—is bootstrapped to generate appropriate standard errors. The nonseparability property of the household model implies that the functional form of the reduced-form equation (5) cannot be derived analytically (Singh et al. 1986). Therefore, all functions are assumed to be linear in their arguments.

2.1 Prices and Exclusion Restrictions

In empirical work on fuelwood scarcity, there are two types of scarcity measures: physical measures and economic measures. Physical measures, such as the distance from the forest or village-level biomass availability (as applied by van `t Veld et al. 2006), control for the household's ability to directly access forests. Dewees (1989) and Cooke et al. (2008), however, pointed out that physical measures may not be a reliable indicator, since labor shortages are often more important for household fuel-use decisions than physical scarcity of fuelwood. Therefore, the opportunity cost of the time spent collecting may be a better measure, although it is often unobservable.

Two common proxies for the opportunity cost are demonstrated by Cooke (1998a; 1998b), who used the wage rate multiplied by the time spent per unit of environmental good collection, as a measure of scarcity, and Mekonnen (1999), who used the marginal product of labor in energy collection multiplied by the shadow wage. In the absence of markets, household responses to fuelwood scarcity can be assessed by the impact of nonprice variables on fuel consumption (Heltberg et al. 2000). Therefore, in line with Heltberg et al.'s argument, we use the time spent per unit of fuelwood collected (measured as hours/kilogram of fuelwood collected), as our measure of fuelwood scarcity. This better reflects the time cost of gathering fuelwood from the forest.

For households collecting from the common areas, it is possible to observe our measure of the fuelwood shadow price. On the other hand, for those who do not collect from the common areas, it is necessary to predict those values, since they depend on either own sources or market sources. However, it is not possible to calculate the shadow price of dung and crop residue collection because most households in the sample collect these energy sources from their own fields and a market for these goods does not exist.

Fuel substitution possibilities among fuelwood, dung, and crop residue are examined via the magnitude and sign of the shadow price of fuelwood (as measured by hours/kilogram of fuelwood collected from the common areas) on the production and consumption of both dung and crop residue, as measured by participation in collection activities. However, estimation of the economic scarcity, due to missing data, requires an exclusion restriction. We use a physical indicator of scarcity, a GIS survey showing available biomass, as our exclusion restriction.[7]

Also, per the data, only a limited number of households earn income from off-farm activities, such that market wages are not observed for the entire sample. Therefore, we also estimate and predict the opportunity cost of labor, following selection methods (Heckman 1979).[8] The primary exclusion restrictions for participation in off-farm labor activities include measures of farming activities, such as livestock and land holdings, as well as nonlabor income, such as remittances. Larger farms are expected to require greater labor inputs and, thus, reduce the likelihood that any member of the household works off the farm.[9] Furthermore, actual farm size should not affect wages in the labor market. Finally, less than half the sample collects either crop residue or dung; therefore, the quantities collected are also estimated via sample selection methods. The primary exclusion restriction for these quantities is household knowledge of the rules governing forest use.

2.2 Analysis Variables and Expected Effects

Although the main interest in the analysis is the effect of fuelwood scarcity on household behavior, we include other household- and community-level variables that are can affect behavior. As already discussed, the off-farm wage rate measures the opportunity cost of household time, although the marginal product of agricultural labor is also common in the literature (Skoufias 1994; Jacoby 1993). It is expected that higher opportunity costs reduce household fuelwood and other energy source collection.

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[7] Households located farther from town are more likely to collect fuelwood from communal forests, while households heads with more education, and households with greater forest access and locations farther from markets are less likely to collect from communal forests. Time spent collecting, on the other hand, is higher for households located farther from markets, but is lower for households with knowledge related to the rules governing forest use, and for households, whose head has ever been a member of an organization. Although there is a negative selection effect, the effect is insignificant. The results are in appendixes B and C.

[8] For more information on the estimation of Heckman's sample selection model and the marginal effects, see Greene (2003, 780–87).

[9] Off-farm labor is negatively associated with land size and livestock ownership, although it is positively associated with the Amhara and Tigray regions. Education also increases the probability of participating in off-farm labor activities. The number of children in the household under 5 years of age reduces participation, although not significantly. Furthermore, average schooling (positive), distance to town (negative), and the number of male members of the family (negative) are significantly related to the off-farm wage rate. Participation and wage regression results are in appendix A.

The other price, collection time per unit of fuelwood, is an additional measure of the opportunity cost of time (in fuelwood collection activities) and is also expected to affect behavior. Higher opportunity costs should reduce fuelwood collection efforts; however, higher costs of fuelwood collection could either increase or decrease efforts related to collecting other energy sources, depending on the degree of substitutability. Van `t Veld et al. (2006) found that higher opportunity costs lead to households substituting lower-quality energy sources, while Mekonnen (1999) showed that fuel, wood, and dung are complements.

In an effort to control for preferences and technology, a number of household characteristics are also included, such as the age, sex, and education of the household head, which are expected to reduce household collection activities. Households with younger heads are more inclined to participate in other activities and, hence, have less time for fuel collection. Increased education is expected to increase the opportunity cost of time, also reducing collection efforts. Educated households have greater access to private sources and are observed to purchase from the market. Similarly, educated households are more likely to understand the importance of dung and crop residue as fertilizer in agricultural production.

Children in the household, measured by the number of children younger than five years, are expected to reduce all labor inputs, since it is more difficult to leave young children unattended. However, a greater number of older household members increases labor supply and, thus, is likely to increase all labor inputs. Similarly, older children are able to watch over younger children, allowing other household members to work. However, it is also true that larger households are expected to require more energy for household activities, such as cooking and heating.

As indicators for household wealth, we also include livestock ownership, land holdings, and nonlabor income. Relatively wealthy households are expected to consume smaller quantities of traditional biomass fuels. According to the energy ladder hypothesis, as income increases, households will shift to better energy sources, such as kerosene, liquefied petroleum gas, and electricity. However, given the limited availability of these alternative sources, the energy ladder hypothesis does not have much traction in the rural Ethiopian context; instead, fuel stacking (multiple fuel use) may be more relevant.[10] However, it should also be noted that livestock holdings should increase the availability of dung. Similarly, land holdings are likely to increase

[10] The discussion of the fuel-stacking behavior of rural households is not the focus of this study. Masera et al. (2000) critiqued and provided an alternative to the energy ladder hypothesis.

the availability of crop residue, although households with large land holdings have more agricultural production and require more dung and crop residue for fertilizer.

The impact of variables related to forest stock, level of biomass, forest access, and local institutions are also assessed in the analysis. Forest stock measures the number of people per hectare of forest and accounts for forest quality. Population density measures the number of people per hectare of the village to account for local area demand.

Biomass availability is a more accurate combination of forest stock and population density, measured as the amount of biomass per hectare of forest per capita. It is more accurate because the numerator is taken from a GIS survey. Reduced forest stock and increased density are expected to decrease the marginal product of labor inputs for fuelwood collection, which could increase or decrease collection efforts. This depends upon whether or not households need to satisfy a minimum energy requirement and the ability of households to substitute across energy sources.

Finally, local-level institutions are included to account for the level of protection accorded to the common areas used by the community. Although the data is not complete, we create a dummy variable indicating household awareness of government rules related to forest use. Greater awareness is expected to reduce fuelwood collection labor inputs and, assuming substitutability across energy sources, increase collection of dung and crop residue.

3. Study Area and Data

The data arise from a survey conducted under the auspices of the "Household Forest Values under Varying Management Regimes in Rural Ethiopia" project.[11] Data was collected from four regions in the country, namely, Amhara; Oromiya; Tigray; and Southern Nations, Nationalities, and People's (SNNP) regions. Within those regions, ten *woredas* were purposefully chosen: three from Amhara, three from Oromiya, three from SNNP, and one from Tigray.[12]

[11] Individuals with extensive fieldwork experience were chosen to supervise the data collection efforts, while the enumerators were selected based on their experience in a similar survey. Enumerators received three days of training before entering the field. The entire process was monitored.

[12] *Woreda* is an administrative division of Ethiopia managed by a local government, which is equivalent to a district. *Kebele*, or peasant association, is the lowest administrative unit. A woreda is composed of a number of kebeles.

The current sustainable land management (SLM) program in Ethiopia informed our site selection.[13] One of the goals of site selection was variation in forest cover, agroecology, and local-level institutions. We selected four kebeles from each woreda, two participating in the SLM program and two not, for a total of 40 sample sites. The households surveyed were obtained from household lists available from the kebele administration offices: 15 households were selected from each kebele, totaling 600 households to be interviewed.[14]

The survey data includes information on household characteristics; health and social capital; consumption and production of various agricultural products and market-purchased goods; labor allocation for various agricultural products and market-purchased goods; labor allocation related to various agricultural and nonagricultural activities; information on credit markets; the household's perception of forest values, rules, and regulations; forestry programs and questions related to valuations; and household time preferences.

In addition to the household-level survey, focus group discussions were held at each sample site to gather villagers' attitudes and perceptions regarding forest management rules and regulations, use of technology, and other relevant information. In addition to the primary (survey) sources, we made field visits to collect information about the study sites at the grassroots level, including information on local forest types, watershed area, area of woredas and kebeles, woreda and kebele populations, location of farms, type of farming systems, and other related information.

3.1 GIS Data

One of the major advantages of our study is the availability of GIS information. Specialist foresters—experts who can correlate aerial photographs with ground-level forest and vegetation information to create a measure of forest cover—collected the GIS data. Information from the GIS survey, such as forest cover, total area of each sample site, and total biomass availability in each site, are incorporated in the analysis.[15]

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[13] The Ministry of Agriculture and Rural Development of Ethiopia runs the SLM program, which is funded by international donors, such as the World Bank and the Global Environment Facility Trust Fund.

[14] The first household in the kebele was selected randomly from the list and the remaining households were chosen systematically. For example, if there were 150 households in the kebele, the first household was chosen randomly; after that the 4th household on the list was randomly selected, the 14th, the 24th, and so on, until 15 households were included.

[15] One of the project team members undertook the biomass estimation. The regression equations for estimating the biomass of tropical trees are based on Brown et al. (1989).

From the forest cover data, we were able to identify and classify study sites into two groups: those with relatively high forest cover (HFC) and relatively low forest cover (LFC); the latter is often referred to as a degraded area in the following discussion. Households living in areas where the forest cover is less than 30 percent of the total area are classified as LFC (62.1 percent of the sample), while households living in areas where forest cover exceeds 30 percent are classified as HFC (37.9 percent of the sample).[16] Unfortunately, forest cover data was not available in Mustembuay, Yelen, Gosh Beret, and Debretsehay kebeles, due to the lack of satellite imagery. However, that information gap was filled from community survey estimates.

3.2 Energy Use

Modern fuels, including electricity, are not common sources of household energy in the study regions. Instead, most energy sources (dung, crop residue, and fuelwood) are obtained from own fields, natural forests, and state or government forests. Very few households, only 4.5 percent of the sample, purchase fuelwood. However, nearly all households collect either dung or crop residue for own consumption, while all households collect and consume some fuelwood, as part of their energy requirement. Approximately 48 percent of the sample households collect their fuelwood from common areas, while 42.6 percent and 35 percent of the sample households collect/use dung and crop residue for energy, respectively.

Energy in Ethiopia is primarily used for cooking, heating, and lighting. Baking *injera*, traditional pancake-like bread, is the most energy-consuming activity in both urban and rural areas of Ethiopia. The energy for this baking primarily comes from burning fuelwood. Other biomass energy sources, such as dung and crop residue, are less preferred sources of energy for household cooking (Zenebe 2007).

However, the relationship between fuelwood and dung and crop residue is still an empirical issue. These biomass energy sources have alternative uses. Households primarily use dung as fertilizer and crop residue as livestock feed. Biomass is also used for construction: crop residue is a common roofing material and dung is commonly used for floors and walls.

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[16] Sample-site forestry cover ranges from 65 hectares to 4,613.74 hectares, while the forest coverage proportion ranges from 3.9% to 77.4%. On average, sample sites are 26.9% forest. Although there are many ways to classify forests (for example, low, medium, and high forest cover), we prefer to divide the sample into two parts. As the sample size decreases, it reduces the statistical power of a test. We arbitrarily chose 30% because our objective is to see whether households behave differently in different forest conditions.

We expect that increased availability of fuelwood would release dung and crop residue for these other nonenergy purposes. However, about 48 percent of the sample households responded that they would not reduce their dung consumption, even if more fuelwood became available, while others reported that they would increase their usage of dung, if more fuelwood became available. Survey responses of this nature provide some indication of the difficulty faced by policymakers, since the responses suggest that supply-side strategies alone are not likely to effectively address rural energy shortages or reverse the decline in agricultural productivity resulting from the diversion of dung and crop residue for energy needs (IFPRI 2010).

Until there is an increase in alternative energy sources or improvements in the efficiency of cooking technology, especially, the dominance of biomass energy sources will continue into the foreseeable future in Ethiopia. Therefore, it is necessary to understand the manner in which households use the available energy sources, and design ways to sustainably manage the available resources.

3.3 Descriptive Statistics

Table 1 summarizes the descriptive statistics of the explanatory variables used in the empirical analysis, presented in two categories (based on forest cover status). A simple comparison of these statistics suggests large differences between the two groups across a number of variables. For example, average land size and livestock holdings are higher in the HFC areas, while nonlabor income (in the form of gifts, remittances, and aid) is higher in the LFC areas of the sample.

Table 1. Summary of Descriptive Statistics by Forest Status

Description of Variables	LFC (N=368) Mean (μ_0)	LFC (N=368) Std. dev.	HFC (N=224) Mean (μ_1)	HFC (N=224) Std. dev.	TOTAL (N=592) Mean	TOTAL (N=592) Std. dev.	Difference in means $(\mu_0 - \mu_1)$
Household-level variables							
Age of household head	45.43	11.98	46.08	13.87	45.68	12.72	-0.650
Sex of household head (1 = male; 0 = female)	0.91	0.29	0.91	0.29	0.91	0.29	0.004
Educhead: education of household head (1 = head can read and write; 0 otherwise)	0.48	0.50	0.53	0.50	0.50	0.50	-0.047
Livestock: livestock ownership (in tropical livestock units, TLU)	4.45	2.80	6.24	4.83	5.13	3.80	-1.786***
Landha: land size in hectares	1.37	0.97	2.62	2.11	1.84	1.62	-1.249***
Family_adeq: family size in adult equivalent	5.70	1.97	5.80	2.29	5.74	2.10	-0.107
Male10: no. of male household members age ≥ 10 years	2.31	1.29	2.31	1.40	2.31	1.33	0.000
Female10: no. of female members of household members age ≥ 10 years	2.15	1.08	2.20	1.28	2.17	1.16	-0.050
Child 5: no. of children in household ≤ 5years)	1.08	0.93	1.24	1.12	1.14	1.01	-0.155**
Nonlabor: amount of nonlabor income in ETB‡	311.05	1044.8	168.85	726.9	257.2	939.2	142.20**
Avschooling: average schooling level of household (years of schooling divided by no. of family members ≥ 6 years)	3.88	2.28	3.57	2.01	3.77	2.19	0.309**
Village-level variables							
Forest_acess: no. of people/hectare in kebele‡‡	2.81	2.79	1.35	1.16	2.26	2.42	1.46***
Forest_stock: no. of people/hectare of forest	24.82	24.67	2.78	1.72	16.48	22.22	22.04***
Bio-hh: biomass availability per household (kg/hectare per household)	12.18	13.65	49.56	70.87	26.32	48.37	-37.37***
govt_rules: aware of government rules (dummy =1, if household is aware of government rules; 0 otherwise)	0.48	0.50	0.53	0.50	0.50	0.50	-0.05

** = significant at 5%; *** = significant at 1%. ‡ ETB = Ethiopian birr. ‡‡ Information for four sample sites (Mustembuay, Yelen, Gosh Beret and Debretsehay kebeles) was obtained from villagers' estimations. No information from spatial data was available.

The forest stock, measured as the total number of people per hectare of forest, is 2.78 and 24.82 persons per hectare of forest for the HFC and LFC areas, respectively. By definition, our measure of forest access, the number of people in the community per hectare of the kebele area, is higher in the LFC. Similarly, there is a significant difference between LFC and HFC areas in terms of biomass availability. The mean values of forest stock, forest access, and the level of biomass for the LFC clearly indicates that it is highly degraded compared to HFC.

Other individual and household characteristics, such as age, gender, and education level of household head; family size; and number of male and female household members 10 years or older, are more or less the same in the two groups. This suggests that the sampling strategy was reasonable and that the analysis should be able to detect differences in household behavior that can be attributed to biomass availability.

The primary outcome variables of interest in this analysis—labor inputs and the total collection of three types of biomass energy—are summarized in table 2. In order to calculate the values in the table, data on conversion factors were collected from each district for each type of fuel and for each type of forest product. The quantities of fuelwood, dung, and crop residue were recorded using local units and later converted into a standard weight (kilograms). The data is based on annual figures, since all biomass energy sources are collected throughout the year. In particular, each member of the household was asked how many trips they made per week to collect each type of biomass fuel.

A follow-up question related to the amount of biomass fuel collected per trip was also asked. Since the amount of biomass collected may vary by seasons for some households, the same questions were asked for both the summer season and the winter season. The total quantity (per season) was calculated as the product of the number of trips per week and the amount of biomass collected per trip, while the sum across the seasons yields the total quantity. Given that no labor is hired for collection and that family members collect all the biomass, a household-based summation is an appropriate measure of total collection.

Table 2. Descriptive Statistics of Labor Supply and Production of Biomass Energy Sources

	No.	Mean	Std. dev.	Min.	Max.
Annual time spent collecting (hours/year)					
Total time for fuelwood	577	302.58	342.59	6.07	3796
Total time for dung	252	107.31	170.47	2.60	1534
Total time for crop residue	206	152.37	196.23	1.73	1560
Annual quantity collected (kgs/year)					
Quantity of fuelwood collected	577	2303.39	1542.01	273.00	10920
Quantity of dung collected	252	1919.61	1967.68	145.60	15600
Quantity of crop residue collected	206	1315.07	1320.08	22.75	10400

***** The number of observations (No.) refers to those households who participated in collection of the fuel.

4. Regression Results

The main objective of the study is to analyze rural household responses to fuelwood scarcity, as measured by collection time per unit of fuelwood collected (in hours/kilogram). The study emphasizes the time-allocation decision of rural households, testing whether or not households shift toward other traditional biomass energy sources and/or increase their time allocation for fuelwood collection, when faced with firewood shortages. The analysis is based on the estimation of labor allocated to fuelwood collection, the quantity of dung produced, and the quantity of crop-based biomass residue produced.

Each of these equations is estimated as a function of the quality of the local forest cover available to the households, as well as a number of household-level controls, including the off-farm wage. However, since many households do not have members working outside the household, the wage must be estimated for these households. Furthermore, since many households also do not collect firewood from the common areas, the shadow cost of fuelwood collection was also estimated for these households.

4.1 Labor Allocated to Fuelwood Collection

Unlike other studies related to rural energy, we were able to classify study areas based on forest cover using GIS information, which allowed us to consider the possibility that forest cover affects the quantity of labor allocated to fuelwood collection. The household labor allocation for fuelwood collection was estimated separately for degraded forest areas (LFC) and less degraded forest areas (HFC). A Chow test for pooling across this measure of forest cover was also applied and the results rejected the hypothesis that the estimates could be pooled, at a 1 percent confidence level ($F_{(16, 545)} = 2.04$, p-value = 0.0001).

Table 3 presents the regression results of fuelwood collection labor inputs for the LFC, HFC, and pooled samples, where the labor input is measured as the natural log of total household time in hours allocated to fuelwood collection. In line with many similar studies, the shadow price (collection time per kilogram of fuelwood collected) in the pooled regression is positive and statistically significant at the 5 percent level.[17] For households in close proximity to degraded forests, the shadow price is positive and significant at the 10 percent level; however, for households living near higher quality forests, the shadow price is not a significant determinant of total collection time. Therefore, as forest resources become increasingly scarce in an already degraded area, rural households respond by increasing total fuelwood collection time. Any attempt to generalize the responsiveness of demand or production of fuelwood to increasing forest scarcity, without taking into account the forest status of the study area, would be misleading.

Table 3. Regression of Labor Input to Fuelwood Collection (from all sources)

Variable	**Pooled**	**HFC**	**LFC**
	Coeff.	***Coeff.***	***Coeff.***
Collection time	3.963**	3.817	5.704*
	(2.25)	(5.97)	(3.57)
Wage rate (predicted)	-0.652**	-0.005	-0.422
	(0.35)	(0.76)	(0.36)
Age of household head	-0.152	-0.384	0.114
	(0.24)	(0.34)	(0.31)
Sex of household head	-0.050	0.045	-0.093
	(0.17)	(0.26)	(0.21)
Education of household head	-0.081	-0.272*	0.029
	(0.11)	(0.21)	(0.18)
Land size in hectare	0.429***	-0.107	0.702***
	(0.15)	(0.26)	(0.25)
Livestock ownership in TLU	-0.144	-0.104	-0.093
	(0.12)	(0.16)	(0.15)

[17] The results for the participation regression equations for predicting the time spent collecting fuelwood are in appendixes B and C.

Government rules	0.261***	-0.008	0.257
	(0.11)	(0.72)	(0.24)
Amount of nonlabor income	0.000**	0.000*	0.000
	(0.00)	(0.00)	(0.00)
Number of children in household under 5	0.104**	0.067	0.079
	(0.05)	(0.08)	(0.07)
Number of male members in household ≥ 10 years	-0.056	0.034	-0.104*
	(0.06)	(0.07)	(0.07)
Number of female members in household ≥ 10 years	0.013	0.029	-0.021
	(0.05)	(0.07)	(0.06)
Forest access	0.112***	0.056	0.103***
	(0.03)	(0.26)	(0.04)
Forest stock	-0.009***	-0.173*	-0.004
	(0.00)	(0.11)	(0.00)
Biomass availability	0.002**	0.003**	0.015**
	(0.00)	(0.00)	(0.01)
Constant	6.266***	6.516***	4.001***
	(1.18)	(2.64)	(1.54)

*, **, and *** represent significance level at 10%, 5%, and 1%, respectively.

Notes: The numbers in brackets are bootstrapped standard errors The dependent variable is the log of the total household annual labor time (in hours) allocated to fuelwood collection.

Livestock (in TLU), land (in hectares), and age (in years) are in log form.

Variance inflation factors were considered for multicollinearity; all were under 5 and deemed acceptable.

HFC and LFC represent the relatively high forest cover and low forest cover regions, respectively.

The impact of community-level variables related to forest stock, forest access, and local institutions is also included in order to examine their influence on fuelwood collection. In the analysis, forest access, as measured by population density, is positively and significantly correlated with fuelwood collection time in LFC areas, but the correlation is insignificant for HFC areas. This result is similar to Heltberg et al. (2000), in that households respond by increasing their collection time in areas where population density is relatively high.

Similar to both Heltberg et al. (2000) and Palmer and MacGregor (2009), we find that forest stock, measured by the number of people per hectare of forest, is negatively correlated with the time spent collecting fuelwood in the pooled regression. We find a similar result in the HFC regression, but there is no significant influence on LFC households. In terms of the community level knowledge dummy variable, we find that households that are aware of forestry rules and regulations undertake significantly more hours to collect fuelwood in the pooled regression, although it is not significant in either the HFC or LFC regions.

Household characteristics, such as age, sex, and the education level (except for the HFC) of the household head, have no impact on fuelwood collection labor inputs, irrespective of the status of forest cover. In contrast to Heltberg et al. (2000), the number of female household members aged 10 years and older was an insignificant determinant of fuelwood collection time. The number of children is also insignificant in both the HFC and LFC regions, although it is positive and significant for the pooled regression. In contrast, the number of male household members negatively impacts collection time in LFC regions, although the relationship is insignificant within HFC regions and for the pooled sample.

The impact of wealth indicators, such as land and livestock, on time use and the impact of non-labor income on time use were also considered. Contrary to Heltberg et al. (2000), but similar to Chen et al. (2006), land holdings are positively related to labor inputs in both LFC and pooled regressions (but not in HFC regions). Since the dependent variable (total annual time spent for fuelwood collection) and land size are in log-log form, the estimated coefficient can be interpreted as an elasticity. As such, a 10 percent increase in land size is associated with a 7 percent increase in total collection time for LFC households.

Similar to Heltberg et al. (2000), livestock ownership has no significant impact on fuelwood collection time. The effect of nonlabor income is positive and significant for HFC households. The effect of the opportunity cost of time is also examined by considering the effect of the predicted wage rate on the fuelwood collection time. As expected, higher wages, or higher opportunity costs of time, result in reduced fuelwood collection time in the pooled regression. However, the results are statistically insignificant when we consider the level of forest degradation.

The elasticity estimates show that an hour increase in collection time per kilogram of fuelwood results in a 5.7 percent increase in total household fuelwood collection time in LFC areas, while the pooled result implies an increases of about 4 percent. Heltberg et al. (2000) found that a 10 percent increase in collection time per unit of fuelwood results in an 8.9 percent increase in labor time for fuelwood collection in rural India. The pooled results are also in line with those of Kumar and Hotchkiss (1988), Amacher et al. (1993), and Palmer and MacGregor

(2009).[18] However, none of the previous studies is able to describe the difference between households living in close proximity to either highly degraded or less degraded forests. Intuitively, labor input is expected to be less elastic when considering the production of basic commodities; however, in the face of increased degradation, some substitutes become more plausible, raising the observed elasticity.[19]

Our study is also different from other studies, with the exception of those by van `t Veld et al. (2006) and Bandyopadhyay et al. (2006), in that it incorporates information on biomass availability obtained from GIS data. According to van `t Veld et al. (2006), per capita biomass availability is an exogenous physical measure of fuelwood availability. This, however, may not truly reflect the physical scarcity of fuelwood because a few large trees may yield significant biomass. In contrast to van `t Veld et al. (2006), our estimation results show that biomass availability is positively correlated to total fuelwood collection time. Van `t Veld et al. (2006) find that higher biomass availability in a village increases the use of commons resources, but does not affect the time spent collecting.

4.2 Other Biomass Production and Consumption Activities

As previously uncovered, the fuelwood labor input elasticity is affected by the quality of the forest cover accessible by these households, and the results suggest that households in highly degraded forests must increase their labor input further, cut their fuelwood consumption, or turn to other sources of energy. In table 4, we report the total production function of dung and crop residue because the Chow test fails to reject the null hypothesis that the coefficients are the same in both equations (LFC versus HFC areas) for dung, though it is different for crop residue. Note also that only 27 households participated in the fuelwood market. Of these, 12 households collect fuelwood from private or common sources, while the rest depend on purchased fuelwood only. Because of the small numbers of market participants, we do not distinguish between collecting

[18] We cannot calculate elasticity directly. However, the value of the elasticity based on Heckman estimates without bootstrapping yields an elasticity estimate that is smaller than that of Heltberg et al. (2000).

[19] A simple descriptive analysis of the responses of surveyed households with regard to their coping mechanisms for fuelwood scarcity supports this finding. More than 44% of the sample households responded that they increase their collection time when there is a shortage of fuel wood. Others (21%) reduce consumption. The literature also confirms the negative and small own-price elasticities, implying that households respond to increases in shadow prices by reducing their consumption. (See, for example, Cooke 1998a and 1998b; Mekonnen 1999; Heltberg et al. 2000; and Palmer and MacGregor 2009).

and purchasing households, as was the case in Palmer and MacGregor's (2009) Namibian study.[20]

Table 4. Heckman Estimates of Dung and Crop Residue Collection

Variable	**Dung** ***Coeff.***	**Crop residue** ***Coeff.***
Collection time	1.359	-2.808
	(3.37)	(4.43)
Wage rate (predicted)	0.236	0.126
	(0.43)	(0.41)
Education of household head	0.253**	-0.029
	(0.13)	(0.20)
Sex of household head	-0.333**	-0.173
	(0.20)	(0.33)
Amount of nonlabor income	0.000**	0.000**
	(0.00)	(0.00)
Livestock ownership (in TLU)	0.081	0.137
	(0.13)	(0.17)
Land size (in hectares)	0.201	-0.007
	(0.19)	(0.24)
Family size (in adult equivalent)	0.069**	-0.006
	(0.04)	(0.05)
Forest stock	-0.002	0.013*
	(0.00)	(0.01)
Forest access	-0.009	-0.189***
	(0.04)	(0.07)
Average schooling level of household	-0.066**	-0.051*
	(0.03)	(0.04)
Inverse Mills ratio	0.023	-1.027***
	(0.19)	(0.37)
Constant	6.163***	8.426***
	(1.32)	(1.53)

*, **, and *** represents significance level at 10, 5 and 1%, respectively.

[20] Substitution from private trees, dung and residue consumption, and market purchase accounts for only a small proportion of coping mechanisms for fuelwood shortages in our surveyed households and, thus, these are ignored in the analysis.

Notes: The numbers in brackets are the bootstrapped standard errors.

The dependent variables of the regression equation are collection of dung and crop residue in kg per annum (in log form), land size and livestock are also in log form.

In order to examine the effect of fuelwood scarcity on the consumption of other biomass energy sources (dung and crop residue), selection regressions of dung collection and crop residue collection activities were also estimated.[21] The sign and significance of the fuelwood shadow price in the dung and crop residue functions suggest the nature of the relationship (substitutability or complementarity) between these two types of biomass energy sources and fuelwood. Here the results are not statistically significant.

Based on intuition, we expect that biomass availability will affect participation, but have no independent effect on the total quantity. Furthermore, a variable indicating awareness of government rules related to forest use should determine participation, but not the total quantity of collected biomass, so this variable represents another exclusion restriction. Based on simple Heckman estimates, the Wald test of independent equations rejects the null hypothesis of no correlation between the two disturbance terms (in the outcome equation and selection equation) at a 1 percent level of significance. Hence, the selection model is appropriate and should be used to avoid inconsistency in the parameter estimation.

As suggested earlier, degradation could affect substitutability and, hence, influence either the participation elasticity or the production elasticity, given participation. We consider these possibilities by including various measures of forest accessibility in the regressions. Our results suggest that increased forest stocks (people per hectare of forest) are associated with reduced participation in crop residue collection activities, but positively and significantly affect the amount of crop residue collected, given participation. However, there is no influence on either dung collection participation or collection, given participation.[22]

We further find that an increase in forest access (people per hectare of kebele area) increases the probability of participating in crop residue collection, but is negatively correlated

[21] Results for the participation component of the selection regressions are in appendixes D (dung) and E (crop residue). Higher wages and larger family sizes increase the probability of dung collection, while greater land holdings, greater forest access, greater biomass availability and higher average schooling levels in the household reduce the dung collection participation probability. The crop residue participation probability is higher for male-headed households with greater land holdings and greater forest access, but it is lower for larger livestock holdings, greater forest stock, and better knowledge of the rules governing forest access.

[22] Heltberg et al. (2000) found a negative relationship between forest stock and private fuel consumption, while Palmer and MacGreger (2009) showed a negative relationship between forest stock and dung collection.

with the amount of crop residue collected, given participation. Finally, participation in dung collection is reduced when forest access (people per hectare in the kebele) rises, while the total dung collection quantity, given participation, is not affected by population density in the area.

Given that approximately 50 percent of households use dung and fuelwood at the same time, it is not all that surprising that forest degradation is not strongly correlated with dung participation or total collection. Furthermore, the small and highly fragmented nature of per capita land size in highly populated regions explains the relationship between forest access and crop residue collection activities. Intuitively, agricultural production, which provides crop residue as a by-product, in these areas is also small; thus, although more households participate, there is less opportunity to collect.

Since larger family size implies greater demand for energy sources, we find that it does increase the likelihood of participating in dung collection activities, as well as the quantity of dung collected. However, it does not have a significant effect on either the participation decision or the quantity of crop residue collected. Unexpectedly, the education level of the household head is significantly and positively related the amount of dung collected for fuel. However, the average education level of the whole family is negatively related to the probability of collecting dung and the amount of dung collected.

Land holdings are negatively related to the decision to collect dung, but positively related to the decision to collect crop residue. The quantities of dung and crop residue collected are not affected by the size of land holdings. Amacher et al (1999), using land holding as a proxy for income, finds that larger (and wealthier) households consume less crop residue, leading them to conclude that crop residue is inferior goods for the rich. On the contrary, we find an insignificant relationship between livestock ownership and the quantity of both dung and crop residue collected, given participation. In other words, as opposed to the energy ladder hypothesis, dung and crop residue are not perceived as inferior goods in this sample of Ethiopian households.[23] We also included the predicted wage rate in the dung and crop residue collection regression and found no significant influence on the amount of either dung or crop residue collected.

The literature on the relationship between fuelwood use and dung use, as well as fuelwood use and crop residue use, is mixed. Cooke et al. (2008) surveyed a number of papers in

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[23] The energy ladder hypothesis states that high-income households reduce consumption of lower quality energy sources (Leach 1992).

the literature finding evidence of substitution, as well as complementation. For example, Amacher et al. (1993) found evidence of substitution between fuelwood and agricultural residue in one of their survey districts in Nepal. On the other hand, Mekonnen (1999) showed that dung and fuelwood are complements in the northern highlands of Ethiopia.

According to our results, the effect of collection time on the production and consumption of dung and crop residue is insignificant. In other words, when fuelwood is scarce, households in this area of rural Ethiopia do not readily switch to other biomass energy sources. Our results are consistent with analyses from Nepal (Kumar and Hotchkiss 1988; Amacher et al. 1993), India (Heltberg et al. 2000), and Namibia (Palmer and MacGregor 2009).

In this analysis, no direct substitution between fuelwood and other biomass energy sources was uncovered, although forest cover and forest access effects do suggest indirect substitution patterns. Furthermore, the availability of more fuelwood (in the form of increased biomass per household) does not necessarily reduce consumption of other biomass energy sources, although it decreases the likelihood of participating in dung collection. This supplements Mekonnen's (1999) findings that rural households in northern Ethiopia do not use less dung for cooking when more forest biomass is available, due to the complementarity between dung and forest biomass.

For policymakers, the implication of this result is that the development of plantations and other measures to increase the supply of fuelwood may not have a significant impact on reducing the demand for alternative energy sources, which—at least from a policy perspective—have higher values in maintaining soil fertility. However, it should be noted that we are not able to separate using dung and crop residue for energy from using them for fertilizer.

5. Conclusion and Policy Implications

This paper reports results from an analysis of household survey data collected in rural Ethiopia. The survey examined rural household coping mechanisms for fuelwood shortages. The study aimed to address whether households in rural Ethiopia respond to fuelwood shortages by increasing their labor input to fuelwood collection or switching to other biomass sources (which are considered inferior goods by some scholars). By using information from a GIS survey, we classified our study area into two regions: low and high forest cover areas. Rural household behavior toward fuelwood was examined separately for LFC and HFC areas, while pooled regressions were considered for the collection or production of other biomass sources (i.e., dung and crop residue).

The results of the analysis suggest that household responses to fuelwood scarcity depend on the status of forest degradation. Households living in a degraded environment (low forest cover area, LFC) respond to fuelwood scarcity (measured by collection time per kilogram) by increasing their labor input to fuelwood collection. However, this is not the case for those living in high forest cover areas (HFC). Households in HFC areas respond neither to the physical measure nor economic measure of fuelwood scarcity. For households in HFC regions, forest stock (negative) and biomass availability (positive) may be more important factors than scarcity of fuelwood in determining household labor input allocation.

The analysis also uncovers no evidence of substitution between fuelwood and dung and crop residue. Ethiopian households do not switch to dung and crop residue when faced with fuelwood shortages. Similar to what has been found in Nepal and Namibia, consumption of other biomass energy sources may not necessarily decrease, when more biomass is available. The implication of our finding is that supply-side strategies alone may not be effective, if the aim is to reduce forest degradation and biodiversity losses, and simultaneously increase the supply of dung and crop residue for soil management.

Population pressure in all regions in general, and in LFC regions in particular, contribute to forest degradation and a loss of biodiversity, as is easily observed in rural Ethiopia, where encroachments for agriculture and grazing are common. As explained by Heltberg et al. (2000), the underlying factors responsible for forest degradation or deforestation need to be addressed if specific forest policies, such as afforestation and area enclosure establishments, are to be effective at the local level.

Finally, a distinction needs to be made between forest degraded regions and relatively good forest cover regions, when planning for natural resource management and use by the surrounding people. Further investigation could consider whether the increase in labor input for fuelwood collection, when fuelwood becomes scarcer, comes at the expense of other productive activities, such as agricultural production in forest-degraded regions (Cooke 1998a and 1998b; Bandyopadhyay et al. 2006). Moreover, it is necessary to identify which members of the household are most affected by fuelwood scarcity in environmentally degraded regions. This will help in the design and implementation of targeted policies once we identify which group is more vulnerable to fuel wood collection due to scarcity.

Appendices

Appendix A

Heckman Wage Regression Estimates

Participation equation		Wage regression equation	
Variables	***Coeff.***	***Variables***	***Coeff.***
Age	-0.371 (0.31)	Average schooling level of the family	0.062** (0.03)
Sex of household head	-0.213 (0.21)	Distance to town (in km)	-0.020** (0.01)
Distance to town (in km)	0.097 (0.11)	Location dummy (1 = Amhara and Tigray; 0 = other)	0.232 (0.15)
Livestock ownership (in TLU)	-0.322*** (0.13)	Whether any member of the family has attended any type of training or not	-0.112 (0.13)
Land size (in hectares)	-0.569*** (0.18)	Number of male members of the family	-0.093** (0.04)
Location dummy (1 = Amhara and Tigray; 0 = other)	0.368*** (0.13)	Inverse Mills ratio	2.18** (0.99)
Number of children in household < five years	-0.108 (0.07)	Constant	1.35* (0.70)
Average schooling level of household	0.090*** (0.03)		
Amount of nonlabor income	-0.005 (0.02)		
Number of male members in household	0.016 (0.04)		
Constant	1.023 (1.12)		

Note: The dependent variable (wage rate), age, land size, distance to town (in the participation equation), and nonlabor income are in log form.

Appendix B

Participation in Collection from Communal Forests

Variable	**Coeff.**
Predicted wage	-0.360 (0.43)
Distance to town (in km)	0.103*** (0.02)
Land size (in hectares)	-0.071 (0.16)
Education of household head	-0.222** (0.12)
Government rules	0.114 (0.11)
Household size (in adult equivalent)	-0.029 (0.03)
Distance to market (in km)	-0.081*** (0.02)
A dummy variable if household head is a member of any organization	0.137 (0.12)
Forest access	-0.053** (0.03)
Biomass availability	0.001 (0.00)
Constant	0.820 (1.18)

Appendix C

Selection Regression of Time Spent per Unit of Fuelwood Collected in Communal Forests

Variable	**Coeff.**
Predicted wage	0.014 (0.06)
Land size (in hectares)	0.017 (0.02)
Education of household head	0.026 (0.03)
Distance to town (in km)	-0.008 (0.01)
Government rules	-0.026* (0.02)
Household size (in adult equivalent)	0.002 (0.01)
Distance to market (in km)	0.008* (0.00)
A dummy variable if house-head is a member of any organization	-0.034* (0.02)
Forest access	0.002 (0.01)
Inverse Mills ratio	-0.181 (0.45)
Constant	0.253 (0.22)

Appendix D

Participation in Dung Collection

Variable	Coeff.
Collection time	1.598 (4.77)
Wage rate (predicted)	1.602** (0.76)
Education of household head	-0.095 (0.17)
Sex of household head	-0.275 (0.26)
Amount of nonlabor income	0.000 (0.00)
Livestock ownership (in TLU)	-0.154 (0.15)
Land size (in hectares)	-0.786*** (0.30)
Household size (in adult equivalent)	0.123** (0.05)
Government rules	0.062 (0.20)
Forest stock	0.002 (0.01)
Biomass availability	-0.023* (0.02)
Forest access	-0.067* (0.05)
Average schooling level of household	-0.082* (0.06)
Constant	-3.210* (2.12)

Appendix E

Participation in Crop Residue Collection

Variable	Coeff.
Collection time	-0.079 (3.53)
Wage rate (predicted)	0.012 (0.32)
Education of household head	-0.185* (0.14)
Sex of household head	0.314* (0.23)
Amount of nonlabor income	0.000 (0.00)
Livestock ownership (in TLU)	-0.214** (0.12)
Land size (in hectares)	0.263* (0.17)
Household size (in adult equivalent)	0.040 (0.04)
Government rules	-0.739*** (0.14)
Forest stock	-0.020*** (0.01)
Biomass availability	0.001 (0.00)
Forest access	0.201*** (0.05)
Average schooling level of household	0.017 (0.03)
Constant	-0.597 (1.03)

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