Modeling choice of fuelwood source among rural households in Malawi: A multinomial probit analysis

Charles B.L. Jumbe [a,b,*], Arild Angelsen [b]

[a] Centre for Agricultural Research and Development, Bunda College of Agriculture, P.O. Box 219, Lilongwe, Malawi
[b] Department of Economics and Resource Management, Norwegian University of Life Science, PB 5003, 1432 Aas, Norway

ARTICLE INFO

Article history:
Received 26 January 2010
Received in revised form 11 December 2010
Accepted 12 December 2010
Available online xxxx

Keywords:
Local forest management
Biomass
Multinomial probit analysis
Fuelwood
Malawi

ABSTRACT

This paper addresses two questions: what determines household's choice of fuelwood source and, what are the environmental consequences of fuelwood collection from the forest reserves? We address these questions by estimating the multinomial probit model using survey data for households surrounding Chimaliro and Liwonde forest reserves in Malawi. After controlling for heterogeneity among households, we find strong substitution opportunities across fuelwood collection sources. Attributes of the fuelwood sources (size and species composition) and distance to the sources are the most important determinants of fuelwood choice. Further results show that customary managed forests generate environmental benefits by reducing pressure on both plantation forests and forest reserves. These findings support the need to strengthen community-based institutions to manage local forest resources.

1. Introduction

This paper aims to provide empirical evidence to answer the following questions: (i) what determines household's choice of fuelwood collection source, and (ii) what are its environmental consequences? These are pertinent questions due to the importance of fuelwood to rural and urban livelihoods in Malawi, and the fact that fuelwood extraction for energy is one of the leading causes of deforestation and environmental degradation (Malawi Government, 2006a,b) besides permanent land conversion for agriculture, settlement and infrastructural development (FAO, 2010; Zulu, 2009). Although the contribution of fuelwood collection to forest degradation is much debated in literature, wood harvesting for charcoal production is estimated to contribute about one-third of Malawi's total deforestation (Kambewa et al., 2007).

In Malawi, biomass energy accounts for more than 90% of the total primary energy consumption, and forests contribute nearly 75% of the total biomass supply. With only 5% of the country's population having access to electricity (MARGE, 2009), fuelwood remains the primary source of energy for heating and cooking. Even among households with electricity in urban areas, much of it is mainly used for lighting due to high cost of appliances and electricity charges. The main sources of fuelwood in Malawi are forest reserves, customary forests,[1] and plantation forests. Forest reserves are the most important source of fuelwood. From our sample, 46% of the households in our sample collect their fuelwood from the forest reserves. The forest reserves consist of natural woodlands dominated mainly by *Brachystergia*, *Julbernadia* and *Isoberlinia* species (Ngulube, 1999). Although fuelwood collection in the forest reserves is restricted by law (except under co-management arrangements), surrounding communities illegally gain access to these reserves to derive their livelihoods in the forms of fuelwood, non-timber forest products (NTFP), timber, and poles. Earlier studies have shown that the share of forest income to total household income can reach as much as a quarter of their total earnings especially where the reserves are located close to major trading centres (Jumbe and Angelsen, 2007). In fact, there is evidence of intensive forest harvesting from indigenous forests including forest reserves in the Southern Region of Malawi for charcoal production to supply urban markets, some of which is sold along the roadsides.

Customary forests are the second most important source of fuelwood accessible by rural households. In 2007, 54.6% of rural households collected their fuelwood from customary land for free (NSO, 2007), contributing 35% of the total fuelwood consumption. The results of a NSSO study in India in 1993–94 also showed that on average about 55% of household needs for firewood are collected free, most of which can be assumed to come from common pool resources (Arnold et al., 2000). Customary forests consist of natural (tropical)

* Corresponding author. Centre for Agricultural Research and Development, Bunda College of Agriculture, P.O. Box 219, Lilongwe, Malawi. Tel.: +265 1 277433; fax: +265 1 277286.
E-mail addresses: charlesjumbe@yahoo.com (C.B.L. Jumbe), arild.angelsen@umb.no (A. Angelsen).

[1] In this paper, customary forests refer to all forest resources mainly natural woodlands on customary land which is held in trust by traditional chiefs who determine how it should be used.

0140-9883/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.eneco.2010.12.011

woodlands dominated by *Uapaca*, *Parinari*, *Julbernadia* and *Brachystergia* species. Customary forests are on land that is controlled by local chiefs. Most of these forests are degraded due to uncontrolled fires and overexploitation by the local people except where Village Natural Resource Management Committees (VNRC) that were established to manage and regulate access to these forest areas.

Plantation forests are the third most important source of energy supplying nearly 20% of the fuelwood in our sample. These consist of exotic tree species, most of which were established by the government in the mid 1970s with support from the donor community and the private sector. The government established 0.5 million ha of softwood plantation (mainly *Pinus patula*) across the country for pulp, paper and timber, and hardwood species (*Eucalyptus* species) for fuelwood and poles. Within plantation forests, own woodlots/woodlands and trees outside forests contribute 4.1% of the total fuelwood supply. Of the total area under plantation forests (111,000 ha), only 0.8% is owned by the private sector mainly for processing of tea and tobacco.

2. Fuelwood problems in Malawi

Malawi was once heavily forested with 59% of the total land area of 9.4 million ha covered by forests in the 1960s. Recent estimates indicate that the country lost a significant share of its remaining forest cover from 45% of the land area in 1972 to 25.3% in 1990 (Satellitbild, 1993), and an extra 25% (669,000 ha) by 2008 as cultivated land expanded by 27% (MARGE, 2009). The estate-oriented agriculture propagated in the 1970s caused massive conversion of forests into estates and forest degradation due to increased demand for fuelwood for the processing of tobacco especially flue-cured tobacco (Jumbe, 2005). According to the Food and Agriculture Organization (FAO), the total forest area is currently estimated at 3.2 million ha, the majority of which (60%) comprises naturally regenerated forests, while primary and planted forests account for 29% and 11% of the total forest area, respectively (FAO, 2010).

Although Malawi is relatively endowed with vast forest resources, they are not evenly distributed across the country with 43.7% of the country's forests in the Northern Region with only 13% of the country's population of 13 million people (NSO, 2008) compared to 26.3% in the Central Region with 42% of the population, or 30% in the Southern Region where 45% of the population resides (Zulu, 2010). The relative abundance and scarcity of wood in different regions (i.e. supply and demand imbalance) partly explain the recent shift in energy use pattern from fuelwood mostly from using firewood to charcoal and electricity within the energy mix. For example, in 2008, urban households consumed 19,076 TJ of energy of which charcoal accounted for 33% of total consumption, up from 24% in 1994, while firewood's share has gone down from 66% to 56% over the same period. According to Arnold et al. (2006), charcoal is regarded as the "transition" fuel to which fuelwood users are most likely to switch in urban areas. The contribution of electricity has doubled nationally, from 4% to 8% since 1994 and urban electricity consumption increased from 6% to 20% over the same period (MARGE, 2009).

The scarcity of fuelwood increases the burden of fuelwood collection as people have to walk long distances to fetch fuelwood. According to Arnold et al. (2006), responses to fuelwood shortage are largely determined by the household's capacity to access resources such as labor, land, and money besides as access to and the availability of substitute fuels. In extreme cases, households resort to cooking with inferior fuels such as crop residues out of desperation. Recent estimates indicate that crop residues contribute 6.6% of the total biomass energy consumption (MARGE, 2009). Increased use of crop residues exposes households especially women to air pollution which can have a negative impact on their health.[2] Zhang et al. (1999) estimated that burning crop residues for one hour produces carbon monoxide (CO) concentration of 241 parts per million (ppm), which exceeds the exposure limit of 30 ppm according to the WHO Air Quality Guidelines (WHO, 1999). It is estimated that worldwide more than 2.5 million people mostly women and children die every year from breathing noxious fumes from inferior energy forms.

Apart from health hazard of using crop residues, their removal from gardens exposes the soil to erosion and deprives livestock of fodder. It also reduces agricultural productivity, since most farmers who cannot afford chemical fertilizers use crop residues as compost manure to replenish soil nutrients (Leach and Gowen, 1987; IEA, 2002; Heltberg, 2005). However, the trade-off between these uses is dependent on alternatives being available. If wood is scarce, then most of the residues will be used for cooking and heating (MARGE, 2009). In tobacco growing areas of Malawi, tobacco stems are popularly used for cooking, which can have even more devastating health impacts especially on infants who are carried on their mothers' backs when the mothers are cooking and tending fires. Tobacco smoke contains more than 4000 compounds including 40 human carcinogens and toxic agents (Jantunen et al., 1997).

Another problem is that the bulk of the forest resources (2.3 million ha) are protected areas such as forest reserves, national parks, catchment areas and wildlife reserves (FAO, 2010). For many years, local people surrounding forest reserves were not allowed to collect fuelwood or any other forest and non-forest products from these reserves. As one way of reducing pressure on customary forests, in 1996 the Malawi government with financial support from the World Bank and the British Government launched the forest co-management (FCM) program in Chimaliro and Liwonde forest reserves located in the Central/Northern and Southern Regions of Malawi, respectively. The aim of the project was to enhance rural livelihood by allowing program participants to collect fuelwood and other forest products in exchange for undertaking silvicultural management practices such as boundary marking, firebreak maintenance, pruning, early burning and patrolling to monitor unauthorized forest extraction (Kayambazinthu and Lockie, 2002). Under the project, 210 ha and 1172 ha out of 160,000 ha and 274,000 ha of Chimaliro and Liwonde forest reserves respectively were demarcated for joint management between the government and surrounding communities.

This paper uses original survey data from the two locations to examine factors that influence household choice of fuelwood collection source. While cross-sectional micro data do not capture the true fuel dynamics, they do help us to analyze the relationship between energy choices and their determinants (Rao and Reddy, 2007). Today, micro-level studies are being collected in developing countries undertaken every year. While data collected for such studies include detailed information on fuelwood use, few studies have undertaken a similarly detailed quantitative analysis of household fuelwood choice decisions.

3. Theoretical model and empirical strategy

The theoretical framework for analyzing household's decisions on the choice of fuelwood source can be cast in a random utility model (e.g., McFadden, 1973, 1974; Train, 1998; Ben-Akiva et al., 1993). Formally, consider a household i from a sample of N households who has to choose a fuelwood collection source from a feasible set defined by $j = 1,2,3$ alternative collection sources, namely, forest reserves (1), customary forests (2), and plantation forests (3). We assume that each household attaches a utility value U_{ij} to each source depending on personal perception of source-specific attributes η_{ij}, participation status in the FCM program I_i, and household-specific factors h_i. If η_{ij}, I_i and h_i include all the relevant factors, utility derived by an individual who chooses a fuelwood collection source j can be written as:

$$U_{ij} = U\left(\eta_{ij}, I_i; h_i\right) \quad \forall j = 1, 2, 3. \tag{1}$$

[2] For a survey of health implications of indoor pollution, see Schirnding et al. (2002) and Bruce et al. (2002).

In this model, a household chooses the fuelwood collection source that maximizes utility. Let D_{ij} denotes a discrete choice variable taking the value of 1 if a household collects its fuelwood exclusively from a collection source j and zero (0) otherwise. For exposition, a utility maximizing household will choose the first alternative (forest reserve) only if the following inequality holds:

$$D_{i1} = 1 \text{ if } U_{i1} > U_{ij}, j = 2,3 \\ D_{i1} = 0 \text{ otherwise} \tag{2a}$$

and the corresponding probability that a household i collects its fuelwood from the forest reserves can be expressed as:

$$P_{i1} = Pr(U_{i1} > U_{i2} \text{ and } U_{i1} > U_{i3}). \tag{2b}$$

Although the utility a household derives from choosing a particular collection source is not observable, some of the characteristics of the household and attributes of the collection sources are observable. The utility that a household obtains from alternative j can be represented as:

$$U_{ij} = V_{ij} + \varepsilon_{ij} \quad \forall j = 1,2,3 \tag{3}$$

where $V_{ij} = \delta_j X_{ij}$ is the representative utility, X_{ij} is a vector of observed variables relating to the alternatives and the individuals, ε_{ij} captures other unobserved factors that affect utility, and δ_j is a vector of unknown parameters. The probability of choosing the first alternative is:

$$P_{i1} = \Pr(\varepsilon_{i2}-\varepsilon_{i1}<V_{i1}-V_{i2} \text{ and } \varepsilon_{i3}-\varepsilon_{i1}<V_{i1}-V_{i3}) \\ = \Pr\left(\varepsilon^*_{i,21}<V^*_{i,12} \text{ and } \varepsilon^*_{i,31}<V^*_{i,13}\right) \tag{4}$$

where P_{i1} is the probability of fuelwood collection from the forest reserve,

$$V^*_{i,12} = V_{i1}-V_{i2}, \quad V^*_{i,13} = V_{i1}-V_{i3}, \quad \varepsilon^*_{i,21} = \varepsilon_{i2}-\varepsilon_{i1} \text{ and } \varepsilon^*_{i,31} = \varepsilon_{i3}-\varepsilon_{i1}.$$

We assume that ε_{ij} has the density function $f(\varepsilon_i)$ where $f(\varepsilon_i) = f(\varepsilon_{i1}, \varepsilon_{i2}, \varepsilon_{i3})$ and has the mean vector equal to zero (0) with the following corresponding variance–covariance matrix:

$$\Omega = \begin{pmatrix} \sigma^2_{i,1} & \sigma_{i,12} & \sigma_{i,13} \\ \sigma_{i,12} & \sigma^2_{i,2} & \sigma_{i,23} \\ \sigma_{i,13} & \sigma_{i,12} & \sigma^2_{i,3} \end{pmatrix}. \tag{5}$$

Eq. (4) suggests that the *choice probability* is a cumulative distribution, which is the probability that the difference in the random component of the utility from two alternatives is below the difference in their deterministic components (Train, 2003). From Eq. (4), the corresponding cumulative probability of fuelwood collection from the first alternative (forest reserve) is:

$$P_{i1} = \int_{-\infty}^{V^*_{i,12}} \int_{-\infty}^{V^*_{i,13}} f_1\left(\varepsilon^*_{i,21}, \varepsilon^*_{i,31}\right) d\varepsilon^*_{i,21} d\varepsilon^*_{i,31}. \tag{6}$$

Similar expressions can be derived from the probabilities of collecting fuelwood from customary and plantation forests. The model is estimated by Monte-Carlo simulations of the choice probabilities and substituting these simulated probabilities into the following log likelihood function:

$$lnL(\psi^*) = \sum_{i=1}^{N} \sum_{j=1}^{J} D_{ij} \, ln\left(P_{ij} | \psi^*, V^*_{i,kj}\right) \quad \forall j, \; j \neq k \tag{7}$$

where $\left(P_{ij} | \psi^*, V^*_{i,kj}\right) = \Pr\left(\varepsilon^*_{ij} < \varepsilon^*_{ik} \forall k | \psi^*, V_{ik} - V_{ij}\right)$, ψ^* is a vector of parameters and k represents the chosen alternative. The error terms $\varepsilon^*_{i,21}$ and $\varepsilon^*_{i,31}$ are assumed to have a density function $f_1(\varepsilon^*_{i,21}, \varepsilon^*_{i,31})$ derived from the density function $f(\varepsilon_i)$, and are bivariate normal with mean vectors zero (0).

The multinomial logit (MNL) models have been commonly applied to analyze discrete choice data such as the choice of vote-choice of a particular voter in a multiparty election (e.g., Michael and Nagler, 1998); transportation planning (e.g., McFadden, 1973). For example, Rao and Reddy (2007) used the MNL models to assess the variations in energy use among Indian households taking advantage of its flexibility in all logits are estimated simultaneously that enforces logical relationship among the parameters. One of the criticisms of the multinomial logit models is the strong assumption of independence of irrelevant alternatives (IIA). This assumes that an individual's choice of an alternative relative to another would not change even if a third viable alternative is added or dropped. In practice, an individual can switch between or among alternatives based on the idiosyncratic assessment of the utilities derived from each alternative. As such, when IIA is violated, MNL is an incorrectly specified model, and the estimated coefficients are biased and inconsistent.

To avoid making the independence of irrelevant alternatives, Linde-Rahr (2003) applied an extension of multinomial logit model, the Random Parameter Logic model to explore the substitution patterns among fuelwood collection sites and market alternatives in Vietnam. In this study, we apply the MNP model following Hausman and Wise (1978) to analyze fuelwood choice decisions which allows for the error correlations along with the estimated coefficients. According to Alvarez and Nagler (1998), MNP model and the estimates are more accurate than MNL as it does not assume IIA.

In estimating the MNP model, not all J sets of regression parameters and elements of the variance–covariance matrix are identifiable (Train, 2003). Since our interest is to compare utilities across fuelwood sources, the variance of forest reserve is normalized to one (1) as the base alternative. For identification, we also normalize the variance of customary forests to one (1) as the scale alternative; hence, we have the following variance–covariate matrix:

$$\Omega_1 = \begin{pmatrix} 1 & \sigma_{12} \\ \sigma_{12} & \sigma_{22} \end{pmatrix}. \tag{8}$$

One aspect investigated in this paper is the impact of participation in forest co-management program on household choice of fuelwood source. Since participation in FCM program is potentially endogenous, we first estimate the following probit model of participation:

$$I_i = W_i \varsigma + u_i \tag{9}$$

where I_i is a binary variable taking the value 1 if the household participates in forest co-management program or 0 otherwise. W_i is a vector of other variables that affect participation (e.g., age, sex, and past group experience), ς is a vector of unknown parameters and u_i is a vector of error terms. From Eq. (9), we obtain the predicted values of the probability of participation. These are included as one of the exogenous variables in the following multinomial probit model of household's choice of fuelwood source:

$$P_{ij} = \alpha + \delta_{1j} w_j + \delta_{2j} x_i + \gamma \hat{I}_i + \varepsilon_{ij} \tag{10}$$

where w_{ij} is a vector of alternative-specific variables (i.e., areas of fuelwood sources (ha), forest collection restrictions, and number of fuelwood species),[3] x_i is a vector of household-specific characteristics (e.g., age, education, gender, family size and sex ratio) and $\hat{I}_i$ is the

[3] The information on the alternative-specific attributes (sizes of fuelwood source, list of preferred species and existence of fuelwood collection restrictions) was solicited through the rapid rural appraisals conducted in each of the sampled village involving traditional leaders and villagers comprising both program participants and non-participants.

Table 1
Summary statistics.

	Forest reserve (46%)		Customary forest (35%)		Plantation forest (19%)	
	Mean	SD	Mean	SD	Mean	SD
Age (years)	43.63	14.95	43.99	14.61	42.86	15.46
Gender (female = 1)	0.912	0.416	0.901	0.454	0.818	0.388
Education (primary education = 1)	0.795	0.405	0.845	0.363	0.818	0.389
Family size	5.281	2.199	5.310	2.267	5.506	2.337
Sex ratio (female to male)	1.172	0.935	1.185	0.774	1.120	0.886
Average no. of preferred species	5.720	1.481	2.514	0.878	2.089	0.858
Distance to collection source (km)	1.314	1.318	0.667	0.975	0.582	0.390
Amount collected per trip (kg)	30.21	6.94	30.98	6.53	30.00	6.74
Income poor (earn below US$1.00 = 1)	0.751	0.433	0.725	0.448	0.403	0.494
Livestock ownership (own = 1)	0.357	0.480	0.366	0.483	0.351	0.480
Per capita land size (ha/household)	0.776	0.768	0.895	0.857	0.893	1.011
Availability of access rules	1.000	0.000	0.349	0.477	0.961	0.489
Program participants (N = 182)	0.451	0.298	0.368	0.301	0.181	0.108
Size of fuelwood source (ha/person)[a]	13.338	13.772	0.056	0.040	0.064	0.067
Annual fuelwood consumption (ton)	4.631	1.801	4.599	1.649	4.406	1.538
Weekly fuelwood collection (trips)	3.200	1.031	2.972	0.882	3.234	1.012

predicted participation from Eq. (9). α, δ_{1j}, δ_{2j} and γ are the parameters while ε_{ij} is the error term.

For empirical application, we use pooled data from the household survey conducted in villages surrounding Chimaliro and Liwonde forest reserves in 2002. The survey covered 404 randomly selected households from 31 villages: 205 households were sampled from 20 villages in Chimaliro and 199 households from 11 villages in Liwonde. Summary statistics of all variables used in the analysis are presented in Table 1.

4. Results and discussion

4.1. Descriptive statistics

Before discussing the empirical results, we briefly discuss features that characterize our data. Table 1 reveals a number of interesting issues. Firstly, despite that area under forest reserve per household is larger compared to the other two fuelwood sources, the annual fuelwood consumption is almost the same across sources (approximately 4.5 tons/year/household). This indicates that much of the pressure is put on customary and plantation forests since fuelwood collection from the forest reserves follows strict guidelines in terms of frequency of collection, type and quantity of fuelwood collected and that households are only allowed to collect fallen and/or dead wood.

Secondly, one would expect program participants to rely on forest reserves for their fuelwood. However, we note that only 45% of those who participate in the FCM program collect their fuelwood from the forest reserves. This indicates a weak correlation between participation and fuelwood source.

Lastly, the table shows that 75% and 72% of households who collect their fuelwood from forest reserves (N = 185) and customary forests (N = 142) respectively are poor households (i.e., households who earn less than US$1.00 a day). In contrast, only 40% of those who collect from plantation forests (N = 77) are poor households. This

Table 2
Marginal effects at means from alternative-specific multinomial probit estimates.

	Pr(choice = FR) = 0.4704		Pr(choice = CF) = 0.3531		Pr(choice = PF) = 0.1765	
	dP/dx	S.E.	dP/dx	S.E.	dP/dx	S.E.
A. Household-specific variables						
Age	0.0050	0.0841	0.0197	0.0820	−0.0248	0.0642
Gender	0.0220	0.0620	−0.0546	0.0620	0.0326	0.0477
Sex ratio (female to male)	0.0281	0.0308	−0.0291	0.0302	0.0010	0.0241
Education (primary = 1)+	−0.0272	0.0717	0.0214	0.0696	0.0059	0.0562
Family size	−0.0194*	0.0104	0.0026	0.0129	0.0168*	0.0099
Income poverty(below US$1.00 = 1)	0.0770	0.0625	0.0629	0.0610	−0.1399**	0.0560
Assets						
Land holding (ha/person)	−0.0961	0.0935	0.0379	0.0877	0.0582	0.0631
Livestock (own = 1)	0.0238	0.0578	0.0078	0.0567	−0.0316	0.0434
Distance to fuelwood source(km)	−0.0374**	0.0184	0.0715***	0.0184	−0.0341**	0.0147
Predicted participation	−0.0362	0.0249	0.0519**	0.0247	−0.0157	0.0199
B. Alternative-specific factors						
Access fuelwood collection restrictions+						
Forest reserve	0.0852	0.0539	−0.0653	0.0399	−0.0199	0.0241
Customary forest	−0.0663	0.0411	0.0931*	0.0496	−0.0268	0.0170
Plantation forests	−0.0203	0.0237	−0.0262*	0.0157	0.0465	0.0293
Area of fuelwood source (ha)						
Forest reserve	0.0790*	0.0442	−0.0600**	0.0297	−0.0190	0.0217
Customary forest	−0.0600*	0.0297	0.0843**	0.0393	−0.0243**	0.0133
Plantation forests	−0.0190	0.0217	−0.0243*	0.0183	0.0434**	0.0213
Availability of preferred species						
Forest reserve	0.1214***	0.0433	−0.0922**	0.0419	−0.0292	0.0236
Customary forest	−0.0922**	0.0419	0.1296**	0.0542	−0.0374*	0.0208
Plantation forests	−0.0292	0.0236	−0.0374*	0.0168	0.0666***	0.0251
Location dummy (Chimaliro = 1)+	0.3596***	0.1294	−0.2967**	0.1371	−0.0628	0.0811

*Significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

seems to suggest that dependence on forest reserves and customary forest is positively correlated with poverty.

4.2. Empirical results

We present the marginal effects from the multinomial probit model of the determinants of household choice of fuelwood source in Table 2. The estimated probabilities of household fuelwood collection from forest reserves, customary and plantation forests are 47%, 35% and 18%, respectively.

Household characteristics such as age, gender and sex ratio do not have a significant influence on the choice of fuelwood source. Family size is, however, significant indicating that an increase in the family size by one unit reduces the probability of fuelwood collection from the forest reserves by 1.9 percentage points, and correspondingly increases the probability of fuelwood collection from plantation forests and customary forests by 1.6 percentage points and 0.3 percentage points, although the latter is not statistically significant. Thus, larger households prefer plantation forests, which is the most convenient source of fuelwood. Since land and labor are required for establishing woodlots, these results confirm that availability of labor (large households) is important.

Distance to the forest reserves is another important determinant of households' fuelwood choice. An extra kilometer from the forest reserve reduces the propensity of fuelwood collection from both forest reserves by 3.7 percentage points, while exerting pressure on community forests by increasing the probability of fuelwood collection from this source by 7.2 percentage points. This demonstrates the importance of closeness to the fuelwood source. Thus, the value attached to the time spent on fuelwood collection is an important factor in the household choice of fuelwood source.

4.2.1. How does poverty affect household choice of fuelwood source?

In general, income poverty increases the propensity of fuelwood collection from the forest reserves and customary forests although the effects are not significant. Results indicate that poverty reduces the propensity of fuelwood collection from plantation forests by 14 percentage points. These results are consistent with descriptive data in Table 1. Most income-poor households cannot afford fuelwood from plantation forests and are too land-poor to invest in tree planting. Their average land size is only 0.42 ha/person compared to 1.2 ha/person among income-rich households. As a result, only 23% of the income-poor households have private woodlots compared to 70% of the income-rich households. Another poverty indicator used in the analysis is the lack of household assets (i.e. land and livestock ownership). Using these indicators, however, we find that household asset-poverty does not influence household's choice of fuelwood source.

4.2.2. What impact does participation in the FCM program have on household choice of fuelwood source?

Our results show that participation in forest co-management program has a small negative but statistically insignificant influence on household's propensity of fuelwood collection from forest reserves and plantation forests. Participation in the program significantly increases the propensity of fuelwood collection from customary forests by 5.2 percentage points. These results are surprising, as we expected that program participation would increase the likelihood of collection from forest reserves, one of the intentions of the program. This is nevertheless an indicator that the program does not work in line with the intentions of providing benefits from the forest reserve exclusively to the participants. This suggests that households are motivated to participate in forest co-management program by other factors rather than the need to gain access to the forest reserves for fuelwood (Jumbe and Angelsen, 2007).

To assess the impact of forest regulations on household's choice of fuelwood source, villagers were asked during the participatory rural appraisals whether there were restrictions on the types or species, frequency or amount of fuelwood collected from different sources. Our data show that forest reserves and almost all plantation forests have restrictions compared to only 34% of the customary forests that have restrictions. Our econometric results indicate that fuelwood collection restrictions on both *forest reserves* and *plantation forests* do not have any significant impact on household fuelwood collection decisions. These findings highlight that restrictions do not deter households from collecting fuelwood from either plantation forests or forest reserves, possibly due to limited fuelwood collection options. Alternatively, these results may reflect weak enforcement of forest regulations, especially on forest reserves under the FCM program and the inability of forest co-management structures to exclude non-participants since these co-management structures do not have the legal authority to prosecute violators (Kayambazinthu, 2000).

We note that fuelwood collection restrictions on *customary forests* significantly increase the propensity of fuelwood collection from customary forests by 9.3 percentage points. While this result may appear contradictory, one explanation may be that restrictions on customary forests help to restore degraded forests and enhance their productivity, thereby making them to be more attractive. This suggests that instituting regulations on customary forests can generate long-term benefits to the rural communities. The difference between the three types of forest is noteworthy: only for customary forest do restrictions seem to have an impact on fuelwood collection.

4.2.3. Would expanding area under co-management reduce pressure on customary forests?

We address this question by examining the impact of: (a) expanding the area under the FCM program and (b) the number of fuelwood species that can be legally collected from the forest reserves. In Malawi, certain fuelwood species are regarded as endangered species and are prohibited from collection. These include *Terminalia sericea*, *Adina microcephala*, *Cordyla africana* and *Khaya anthotheca*.

From the results, we see that increasing the area under the FCM program by 1.0 ha/household increases the propensity of fuelwood collection from the forest reserves by 7.9 percentage points, but reduces pressure on customary forests by 6 percentage points, and with no statistically significant effect on plantation forests. Thus, one might argue that expansion of area under forest co-management is a possible route to reduce the degradation of community forests. However, results also indicate that location of forest reserves also matters greatly. As such, any policy to expand area under forest co-management program may have little effect on reducing pressure in customary forests as households prefer to collect fuelwood from nearby sources.

Another possible policy measure for addressing fuelwood shortage in rural areas is to promote establishment of plantation forests. Interestingly, expanding the area of plantation forests by 1.0 ha/household does not significantly affect fuelwood collection from forest reserves, while it significantly reduces pressure on customary forests (2 percentage points), and increases the propensity for fuelwood collection from plantation forests by 4.3 percentage points.

A similar pattern is observed for the impact of fuelwood species on household choice of fuelwood source. Our results indicate that relaxing the restriction on the fuelwood species would lead to a 12 percentage points increase in the propensity of fuelwood collection from forest reserves, and significantly reduces pressure on both customary and plantation forests by 9.2 percentage points and 2.9 percentage points, respectively (although the latter is not statistically significant). Similarly, more fuelwood species on customary forests increases propensity of fuelwood collection from customary forests by 13 percentage points, and significantly reduces pressure on both forest reserves and plantation forests by 9.2 percentage points and 3.7 percentage points, respectively. Increasing the number of fuelwood species on plantation forests (e.g., by planting different species) significantly reduces the propensity of fuelwood collection from customary forests by 3.7 percentage points and leads to a 6.7 percentage points increase in the propensity of fuelwood collection from plantation forests, with no significant effect on forest reserves.

Taken together, the above results indicate that strong substitution opportunities exist between customary forests and forest reserves, and between customary forests and plantation forests, but limited substitution between plantation forests and the forest reserves. From a conservation perspective, efforts to reduce pressure on forest reserves may be addressed by strengthening community-based institutions for managing local forest resources, while encouraging individuals, households and communities to establish woodlots can be an effective measure to reduce pressure on customary forests. Our findings may also indicate the fuelwood collection transition from forest reserves (most intact forests) to customary forests and plantation forests, where one step is taken at the time.

We include a location dummy variable to capture differences in fuelwood collection choices among households from the two locations. The coefficient for the location dummy is positive and significant under forest reserves, while it is negative and significant under customary forests. The coefficient is negative but not significant under plantation forests. The results imply that households in Chimaliro depend relatively more on forest reserves, while households in Liwonde depend relatively more on customary or plantation forests for domestic fuelwood consumption. Liwonde is located along the busy main road connecting two large cities of Blantyre and Lilongwe, and most households are involved in the selling of fuelwood and other forest-based products by the roadside to the traveling public. These findings suggest that fuelwood collected from customary forests is mainly for domestic use while that collected from the forest reserves is for sustaining their businesses. In contrast, Chimaliro is located in a remote area where markets for forest products are underdeveloped such that fuelwood that is collected from the forest reserves is predominantly for domestic use.

5. Conclusions

This paper has analyzed household's choice of fuelwood source and its environmental consequences. We applied a multinomial probit model on data from 404 households in 31 villages surrounding two forest reserves in Malawi. The analysis yielded several important insights. Firstly, we find a strong correlation between specific attributes of fuelwood collection sources and household's choice of collection source. Specifically, we find that area of the fuelwood source (ha), fuelwood species and distance to the fuelwood source are important determinants of household choice of fuelwood collection source. Further, we find that customary forests and forest reserves are substitutes, as is customary forests and plantation forests, while substitution is more limited between plantation forests and forest reserves.

Secondly, although fuelwood collection from the forest reserves under the FCM program is subjected to regulations and restrictions, we find no significant evidence to suggest that these restrictions deter households from collecting fuelwood from the forest reserves. This highlights weak enforcement of rules since co-management structures do not have the legal mandate to prosecute violators (Kayambazinthu, 2000). Thirdly, empirical results indicate that increasing area under the FCM program can help to reduce pressure on customary forests. However, we contend that this policy will be limited by the importance given to proximity of the fuelwood source in household's choice, and the fact that most households are located away from the forest reserves.

Considering the importance of fuelwood in the rural livelihood system, the finding that customary forests generate environmental benefits supports the need to expand and strengthen community-based institutions to manage local forest resources and design complementary interventions to encourage individuals, households and communities to establish their own woodlots or forest plantations to reduce pressure on customary forests.

Acknowledgements

This paper benefited from comments and constructive suggestions from Frode Alfnes, Baikuntha Aryal, Olvar Bergland, Dadi Kristofersson and Ragnar Øygard (UMB), Bruce Campbell (CIFOR), Christopher Baum, Richard Gates (StataCorp LP) and Marc Gurgand.

References

Arnold, J.E.M., Kohlin, G., Persson, R., 2006. Woodfuels, livelihoods, and policy interventions: changing perspectives. World Development 34 (3), 596–611.

Ben-Akiva, M., Bulduc, D., Bradley, M., 1993. Estimation of travel model choice models with randomly distributed values of time. Transportation Research Record 1413, 88–97.

Bruce, N., Perez-Padilla, R., Albalak, R., 2002. The health effects of indoor air pollution exposure in developing countries. WHO/SDE/OEH/02.05.

Food and Agriculture Organization (FAO), 2010. Global Forest Resources Assessment 2010: main report. FAO Forestry Paper 163. Rome.

Hausman, J.A., Wise, D.A., 1978. A conditional probit model for qualitative choice: discrete decisions recognizing interdependence and heterogeneous preferences. Econometrica 46 (2), 403–426.

Heltberg, R., 2005. Factors determining household fuel choice in Guatemala. Environment and Development Economics 10, 337–361.

Jantunen, M., Jaakkola, J.J.K., Krzyzanowski, M., 1997. Assessment of exposure to indoor pollutants. European Series No. 78. WHO Regional Publications.

Jumbe C.B.L., 2005. Community Forest Management, Poverty and Energy Use in Malawi. PhD Thesis. Norwegian University of Life Sciences, Norway.

Jumbe, C.B.L., Angelsen, A., 2007. Forest dependence and participation in CPR management: empirical evidence from forest co-management in Malawi. Ecological Economics 62, 661–672.

Kambewa, P., Mataya, B., Sichinga, W.K., Johnson, T., 2007. Charcoal—the reality: charcoal consumption, trade and production in Malawi. Technical Report to the Forest Governance Learning Group. Malawi COMPASSII, Blantyre, Malawi.

Kayambazinthu D., 2000. Empowering Communities to Manage Natural Resources: Where Does Power Lie? The Case of Malawi. In: S.E., Shackleton, and B. Campbell (Eds.), Empowering Communities to Manage Natural Resources: Case Studies from Southern Africa. SADC Wildlife Sector Natural Resources Management Program, Lilongwe, Malawi, CSIR, Pretoria and WWF, Southern Africa, pp. 37–58.

Kayambazinthu, D., Locke, C., 2002. Forest management and diverse livelihoods in Malawi. Ladder Working Paper II4. University of East Anglia.

Leach, G., Gowen, M., 1987. Household energy handbook: an interim guide and reference manual. World Bank Technical Paper No. 67. Washington D.C.

Malawi Government, 2006a. Malawi Growth and Development Strategy (MGDS): from Poverty to Prosperity 2006–2011.

Malawi Government, 2006b. Malawi's National Adaptation Programmes of Action (NAPA). Environmental Affairs Department, Lilongwe.

MARGE, 2009. Malawi Biomass Energy Strategy. Consultancy study for Government of Malawi and European Union Partnership Dialogue Facility. Marche'age et Gestion de l'Environnement (MARGE), Lilongwe.

McFadden, D., 1973. Conditional logit analysis of qualitative choice behavior. In: Zarembka, P. (Ed.), Frontiers in Econometrics. Academic Press, New York.

McFadden, D., 1974. The measurement of urban travel demand. Journal of Public Economics 3, 303–328.

Michael, A.R., Nagler, J., 1998. When politics and models collide: estimating models of multiparty elections. American Journal of Political Science 42, 55–96.

National Statistical Office (NSO), 2008. 2008 Population and Housing Census. Zomba.

Ngulube, M.R., 1999. The utilization of non-timber forest products from the Miombo woodlands in Malawi: a case study. In: Ngulube, M.R., Mwabumba, L., Chirwa, P. (Eds.), Community-based Management of Miombo Woodlands: Proceedings of a National Workshop, 27–29 September, 1999. Forestry Research Institute of Malawi, pp. 44–69.

NSO, 2007. Monitoring the situation of children and women. Malawi Multiple Indicator Cluster Survey 2007. Preliminary Report. National Statistical Office, Zomba, Malawi.

Rao, M.N., Reddy, B.S., 2007. Variation in energy use by Indian household: an analysis of micro-level data. Energy 32, 143–153.

Satellitbild, 1993. Forest Resources Mapping and Biomass Assessment for Malawi. Sattelitbild/Department of Forestry, Lilongwe, Malawi.

Schirnding, Y.V., Bruce, N., Smith, K., Ballard-Tremeer, G., Ezzati, M., Lvovsky, K., 2002. Addressing the impact of household energy and indoor air pollution on the health of the poor: implications for policy action and intervention measures. WHO/HDE/HID/02.9. World Health Organization.

Train, K., 1998. Recreation demand models with taste variation. Land Economics 74, 230–239.

Train, K.E., 2003. Discrete Choice Methods with Simulation. Cambridge University Press. 342 pp.

World Health Organization (WHO), 1999. Monitoring Ambient Air Quality for Health Impact Assessment. European Series No. 85. WHO Regional Publications.

Zhang, J., Smith, K.R., Uma, R., Ma, Y., Kishore, V.V.N., Lata, K., Khalil, M.A.K., Rasmussen, R.A., Thorneloe, S.T., 1999. Carbon monoxide from cook stoves in developing countries: 2. exposure potentials. Chemosphere-Global Change Science 367–375.

Zulu, L.C., 2009. The forbidden fuel: charcoal, urban woodfuel demand and supply dynamics, community forest management and woodfuel policy in Malawi. Energy Policy 38, 3717–3730.