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Fuelwood Scarcity, Energy Substitution and Rural Livelihoods in Namibia

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Abstract

In Namibia, as in many parts of Africa, households are highly dependent on fast-degrading forest resources for their livelihoods, including energy needs. Using data originally collected for Namibia's forest resource accounts and insights from a non-separable household model, this paper empirically estimates household fuelwood demand. In particular, the factors underlying the substitution between fuelwood collected from open access forest resources, cow dung and fuelwood purchased from the market are analysed. Heckman two-step estimates show that households respond to forest scarcity, as measured by the opportunity costs of collecting fuelwood, by increasing labour input to collection more than by reducing energy consumption. There is limited evidence for substitution from fuelwood to other energy sources, particularly with the declining availability of forest stocks. All of the estimated elasticities are low confirming observations made elsewhere, particularly in South Asia. Policy interventions including energy efficiency measures and tree planting schemes are considered in the Namibian context.

Keywords: Africa, forests, fuelwood, scarcity, energy, substitution, livelihoods

JEL codes: Q23, Q41, Q42

1. Introduction

According to FAOStat data (2007), more than half of global wood production is classified as non-industrial roundwood, mostly used as fuelwood for energy production. Wood and charcoal are the dominant sources of energy for over two billion people, mainly rural households in developing countries, for use in cooking and heating. Fuelwood collection in rural areas can potentially contribute to deforestation and forest degradation, although the extent to which this occurs depends on the source of supply and demand, the nature of fuelwood and charcoal markets and household behaviour (Arnold et al., 2003).

There is a two-way relationship between fuelwood collection and forest degradation, in which fuelwood demand can cause degradation to the extent that collection exceeds sustainable yield (Heltberg et al., 2000). Degradation, on the other hand, can lead to a situation of fuelwood scarcity. Dependence on forests for energy implies that scarcity can impact on household welfare. Fuelwood, while 'free' financially, incurs opportunity costs in the form of collection labour time (Amacher et al., 1993a; Heltberg et al., 2000). Higher opportunity costs may constrain resource degradation and induce substitution to alternatives and improved energy efficiency.

At the household level, substitution from fuelwood to alternative sources of energy such as crop residues or animal dung, in addition to more widespread use of improved end-use technologies, e.g. stoves, can reduce pressure on forests (Amacher et al., 1999; Heltberg et al., 2000). But crop residues and dung are also important farm inputs in many poor households in Asia and Africa. Using these for fuel instead of manure can impact on soil fertility.

Empirical evidence about the consumption and production of fuelwood in rural households has shown that fuelwood consumption tends to be own-price inelastic (see Cooke et al., 2008). Thus, while its consumption declines with increases in its price (market or shadow), household expenditures increase, often in the form of increased labour allocated to collection (Kumar and Hotchkiss, 1988; Cooke, 1998a, 1998b). Additional to walking longer distances to collect fuelwood, households faced with scarcity may also reduce their consumption of energy, or use lower quality fuelwood (Brouwer et al., 1997). With higher incomes households may switch to marketed energy sources such as kerosene or coal, although perhaps only under conditions of severe scarcity (Hyde and Köhlin, 2000; Le Chen at al., 2006).

In 2004, data on household forest use were collected by Namibia's Ministry of Environment and Tourism (MET), in collaboration with the Institute for Environment and Development (IIED).[1] The study's objective was to develop the physical and economic forest resource accounts for Namibia (see Barnes et al., 2005; Nhuleipo et al., 2005). Physical resource scarcity, i.e. the stock and density of forest resources, was addressed by the former, while the latter measured the economic value of direct forest uses including non-marketed goods such as fuelwood and poles (for buildings) as well as non-timber forest products (NTFP).[2] The raw data also permit the estimation of economic scarcity at the household level.

The factors underlying rural households' responses to economic scarcity in Namibia are the focus of this paper. At the household level, scarcity is dependent on a wide range of factors including physical scarcity, household endowments and institutions for natural resource management (Heltberg et al., 2000). In addition to fuelwood producer-consumers, the household sample also contains a number of non-collecting fuelwood buyers. This implies that the shadow price of fuelwood is higher than the market buying price. For producer-consumers, the shadow price is higher than the selling price. Wide price bands for factors of production and produced goods reveal market failures (Sadoulet and de Janvry, 1995). Missing local markets for fuelwood in the study area suggest the use of a non-separable or non-recursive household model, where all production, consumption and labour time decisions are decided simultaneously (Hyde and Köhlin, 2000).

Guided by the model, we empirically estimate the household demand for fuelwood and the factors underlying the substitution between fuelwood, cattle dung and fuelwood bought from the market. Specifically, the elasticities of demand for fuelwood with respect to energy alternatives are derived in order to investigate household responses to increasing fuelwood scarcity. We find that with higher collection times, Namibian households increase their labour allocation to fuelwood collection more than by reducing energy consumption. There is only limited evidence for substitution among alternative energy sources such as dung, particularly where there is a high ratio of population to available forest stock. In line with previous studies, fuelwood demand among rural households in Namibia is inelastic.

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1 www.met.gov.na/, www.iied.org/.

2 See Hyde and Amacher (1996) for a review of forest values in environmental accounts.

The paper joins a relatively small, empirical literature on this topic, one that is dominated by South Asian cases.[3] Similar to much of Africa, Namibia remains mired in poverty, with up to 90 percent of the rapidly growing population dependent on fuelwood and other biomass for their energy needs, harvested from increasingly degraded forest stocks (FAO 1997, 2007). In the remainder of the paper, section 2 presents the background to the study area and data collection, along with some results of the resource accounts developed by the IIED-MET collaboration. A conceptual model for the supply and demand of fuel is outlined in section 3. In section 4, the method of empirical application is described, with the results discussed in section 5. Conclusions and policy implications are presented in section 6.

2. Background

2.1 Background to Namibia's forests and study area

Situated on the south-west coast of Africa, Namibia's 7.7 million hectares of forests, nine percent of the country's land area, are mainly contained in woodlands and savannas (shrublands). These increase in density from the extremely sparse, arid desert environment in the south towards the semi-arid north-east. Between 1990 and 2005, Namibia's forest area declined by 1.1 percent (United Nations, 2007). In common with much of Africa,[4] the country contains relatively little 'forest' in the conventional sense. Forest resources are defined in this paper as all woody plants that occur in the woodlands and savannas.

Per capita GDP of N$ 46,000 (US$ 7,400)[5] masks acute income inequality and widespread poverty. An estimated 90 percent of the population lives on less than US$ 2 per day, with dependence on natural resources for livelihoods. Fuelwood is typically gathered in land that the government classifies as 'public forest'. Namibia's forest resources are, in effect, *de facto* open access. Relatively little was known about forest utilization rates and the direct use values derived by local people, particularly those that are unmarketed or traded in the informal sector. Namibia's MET in collaboration with the IIED designed a survey to assess forest resource utilisation for rural livelihoods, forest cover and both the regional and national economies, through the development of asset and flow accounts (see Barnes et al., 2005).

[3] For a recent review of empirical studies, see Cooke et al. (2008).
[4] Up to 60 percent of African fuelwood supply originates from non-forest areas such as agricultural land (see FAO, 2000).
[5] 2006 figure (www.cia.gov). Exchange rate used is US$ 1.00: N$ 6.30.

The survey focuses on the semi-arid woodlands in the north-central regions (NCR). While only comprising four percent of Namibia's land area, it is densely populated, supporting up to half of the country's population of around two million people. Low value rainfed crop production and livestock grazing along with forest resource use dominate the local, infrastructure-poor economy. Forest cover has also been found to decline in recent decades in the NCR, especially in the densely-settled central area of the region (see Erkkilä, 1996).

2.2 Surveys and data collection

The datasets were established in 2004. Household and focus group surveys were conducted to obtain data on the use of forest resources (specifically fuelwood, poles and NTFPs) among rural residents. The household questionnaire was aimed at obtaining quantitative information on volumes of forest products harvested, consumed and sold, along with prices and harvesting costs.[6]

A stratified sample of 182 households from 19 villages in the Ohangwena, Omusati, Oshana and Oshikoto sub-regions of NCR was selected. It was designed to cover residents in all of the biomes[7] present in the sub-regions. Household sampling within biomes was randomized on the basis of forest dependence for livelihoods (see MacGregor et al., 2007). A comparison with NCR Census data from 2001 showed that household characteristics are, in general, representative of the entire population of the NCR. Furthermore, the NCR shares a number of characteristics (climate, flora and fauna, etc.) with other regions in northern Namibia. Thus, findings in this paper have policy implications beyond the NCR.

2.3 Descriptive statistics & Namibian resource accounts

Rural life in the NCR is largely based on subsistence, with 83 percent of respondents classifying themselves either as subsistence farmers or unemployed. Only three percent of the sample claim formal employment. Compared to the national average,

[6] Following two pilot surveys, six trained enumerators were deployed. Household heads were interviewed for one hour. A complementary sample of 25 forest product traders in the NCR was interviewed for information on volumes, prices and costs for forest products. Qualitative information was also gathered from local forestry experts, regional councillors and regional development planners.

[7] The political regions are not differentiated according to ecology or biome, although the latter is more informative with respect to the availability of forest resources. The predominant biomes are western Kalahari, mopane shrubland, cuvelai drainage, Kalahari mosaic and mopane woodland. The physical data were collected according to political region alone, which sometimes incorporates estimates across different biomes.

average incomes are low at around N$ 2,000. Income derives mostly from paid employment, local informal economic activity and pensions, with indications of a substantial informal economy in the NCR. Access to a car is limited to less than 10 per cent of households, distributed evenly among political and ecological regions. At an average of 7.5 people across the sample, household sizes are large.

The NCR account for 10 percent of Namibia's forest area, 29 percent of forest biomass and 27 percent of physically suitable yield for fuelwood and poles (Nhuleipo et al., 2005). The NCR accounts for an estimated half of all Namibia's fuelwood utilization and two-thirds of poles. Excluding the use of forests for grazing, Namibia's standing forests had a total asset value of almost N$ 600 million in 2004, with fuelwood alone accounting for over half of this estimate (Barnes et al., 2005). Poles and fuelwood in the NCR have an estimated value of almost N$ 200 million, around a third of the value for the whole country (see table 1). By contrast, Namibia's official forest sector contributed N$ 430 million to GDP in 2004, or 1.1 percent of the total.

TABLE 1 HERE

There is a high, local dependence on forest resources for cooking, heating and building materials. On average, a household uses almost 12,000 kg of wood for energy and shelter annually, split between fuelwood and poles. The average per capita consumption of fuelwood is 913 kg, ranging from 144 kg in Oshana to 1,202kg in Ohangwena. With annual harvests in fuelwood and poles exceeding the physically suitable annual yield, there appears to an over-harvesting of forest resources in Oshana. The other sub-regions are characterized by relative forest resource abundance rather than scarcity with current rates of use below sustainable yields.

Limited local markets exist for fuelwood and for other forest products, as is typical for rural subsistence households (Hyde and Köhlin, 2000). There are 30 fuelwood-purchasing households, comprising 16 percent of the sample. Of these, 24 buyers collect fuelwood as well. Fuelwood is typically bought from traders at open markets in the local town or by the side of the road. For the sample as a whole, fuelwood purchases account for nine percent of total annual consumption, and 39 percent of annual consumption for the buying sub-sample. Only three households in the sample sell fuelwood, one of which also buys fuelwood. Thus buyers easily outnumber sellers in the Namibian household sample.[8] Over half of the sample is unaware of official restrictions on the use of forest resources.

In addition to fuelwood and poles, the main forest resources used by households are NTFPs.[9] Over 80 per cent of sampled households received some income from forest product and livestock sales. Forest resources are also used for grazing and shelter of livestock. There are substantial tracts of open-access grazing land throughout the NCR, and ownership of livestock (cattle, goats, donkeys) is widespread. No respondents buy fodder for their livestock.

3. Household model

The model captures a rural household in a developing country context engaged in agricultural production, off-farm work and energy collection. The rural household in Namibia is located in an environment characterised by a number of market failures for some of its inputs, e.g. to agricultural production, and products. A market may fail for a particular household when it faces wide price margins between the low price at which it could sell a commodity or factor and the high price at which it could buy that product or factor (Sadoulet and de Janvry, 1995).[10] Faced with such a margin, the household may choose self-sufficiency in the good or factor if its shadow price falls inside the margin. Given the relatively small numbers of buyers and (in particular) sellers, the Namibian dataset provides limited evidence for a fuelwood price band: the average sales price is N$ 0.33 per kg, while the average buying price is N$ 0.41.[11]

As most rural domestic fuels are not traded but produced and consumed by the household itself, the model used is a non-separable (or non-recursive) household model[12]. When markets fail, there are direct interrelations between production and consumption decisions. In the context of energy collection, this implies that household resource allocation (including energy supply, energy demand, farm and

[8] By contrast, similarly poor households in other countries often become fuelwood sellers to generate income (Hyde and Köhlin, 2000). Poorer households were not under-sampled in Namibia. While a relative lack of selling households could indicate that they were stocking up for the future, excessive stockpiling by households was not observed in the field.
[9] These include plant products for craft production (carving, basket-making); plant products for food, medicine and cosmetics; and, grass for thatching.
[10] The size of the price band may rise due to one or a combination of transactions costs, shallow local markets, price risks and risk aversion (Sadoulet and de Janvry, 1995).
[11] To place these figures in perspective, if households were to purchase all their fuelwood from the market, an average fuelwood consumption of 5,572 kg per year (from table 2) would imply annual expenditure of over N$2,200, easily in excess of average annual incomes.
[12] The full version of the household model was originally developed by Barnum and Squire (1979), and further elaborated in Singh et al. (1986).

off-farm labour supply) is decided simultaneously. This also means that each household determines energy production and consumption by maximising its utility subject to a shadow price of energy which is unobserved and unknown except to the household itself. Such a model was originally developed by Amacher et al. (1999) and Heltberg et al. (2000), focusing on the substitution of forest and non-forest fuels in Nepal and India, respectively. These studies found that households respond to forest scarcity and increased fuelwood collection time by substituting from private sources for fuelwood. Regarding the effect of scarcity on time allocation, Kumar and Hotchkiss (1988) found that Nepalese women increase their time spent on fuelwood collection when wood becomes scarce. Cooke (1998a, 1998b) showed that scarcity, again in Nepal, motivates increased collection time but unlike Kumar and Hotchkiss found no significant effect on labour in agriculture. Fisher et al. (2005) supports some of Cooke's findings using data collected in Malawi.

Closely following Heltberg et al. (2000), the model focuses on the choice of energy sources for heating, e.g. of homes, water, etc., and cooking, among fuelwood gathered from the forest, producing energy using cow dung and fuelwood purchases. The hypothesis to be tested is that fuelwood, dung and marketed energy sources are substitutes in domestic energy consumption. First, the household maximises utility defined as:

$$\underset{c_{FW}, c_M, q_{FW}, q_{AG}, q_D, l_{FW}, l_{AG}, l_{OFF}}{Max U} = U(c_E, c_M, c_L; z^{HC}) \tag{1}$$

where c_E denotes consumption of household goods and services such as cooked food and heating that require energy inputs; c_M are other consumption goods and services; and c_L is leisure for all working household members. No distinction is made between time allocation for male and female household members due to a lack of data[13]. z^{HC} is a vector of household characteristics relating to consumption such as wealth and household size.

In the Namibian context household goods and services, including cooking and heating, are mainly produced with energy inputs from fuelwood and dung:

$$c_E = \Gamma(c_{FW}, c_D) \tag{2}$$

[13] Earlier studies, e.g. Williams (1983), have shown that fuelwood collection in Africa is dominated by women and children, while more recent ones have found that both men and women collect, see for example, Mekonnen (1998).

Consumption of fuelwood collected from *de facto* open access forest areas[14], as undertaken by 86 percent of sampled households, is denoted c_{FW}. Consumption of dung, by 13 percent of sampled households, is denoted c_D. No stove technology or similar is used by any of the sampled households.

As described in the previous section, limited local markets exist for fuelwood. There are 30 households, comprising 16 percent of the sample that bought fuelwood during the study period. Only three households in the sample sold fuelwood. The net marketed quantity of fuelwood is thus $q_{FW} - c_{FW}$, where q_{FW} denotes household fuelwood production. If no firewood is bought or sold by the household, this quantity is equal to zero, i.e. supply is equal to consumption of fuelwood. To simplify the model and the empirical analysis in the following section, we focus on fuelwood buyers and non-buyers, hence excluding sellers. The net, non-negative amount of fuelwood used in the household can be written as:

$$c_{FW} - q_{FW} \geq 0 \qquad (3)$$

Fuelwood production is assumed to be a concave function of household labour time spent collecting fuelwood, l_{FW}, and household fixed factors of production (e.g. harvesting equipment such as hand-held parangs), a_{FW}:

$$q_{FW} = g_{FW}(l_{FW}, a_{FW}; z^V) \qquad (4)$$

where z^V is a vector of exogenous characteristics describing forest stock and access conditions. These include population density, management institutions and distance from the household to the forest.

Households produce agricultural goods using the following production function:

$$q_{AG} = g_{AG}(l_{AG}, d_{AG}; z^K) \qquad (5)$$

where l_{AG} is household farm labour, d_{AG} denotes the use of animal dung as an agricultural input, and z^K is a vector of household agricultural endowments such as land and livestock. Labour was not hired in by any of the sampled households. As in Heltberg et al. (2000), the total amount of dung used as an agricultural input is modelled as a fixed proportion of agricultural output αq_{AG}. To capture the trade-off in using dung as a farm input or as a source of energy, dung energy supply is given as the residual of farm biomass not used as inputs:

[14] Namibian households do not tend to have private forest resources that other households cannot access.

$$q_D = \alpha q_{AG} - d_{AG} \tag{6}$$

where q_D denotes the amount of dung collected by the household from cattle left to graze in fields and forest. Dung is not traded, i.e. consumption of dung equals production, $q_D = c_D$. The household budget constraint is given by the income from agricultural production, off-farm employment, and other sources such as savings:

$$p_{AG} q_{AG} + w l_{OFF} + e = p_M c_M + p_{FW}(c_{FW} - q_{FW}) \tag{7}$$

where p_{FW}, p_{AG} and p_M refer to the exogenous, market prices of fuelwood, agricultural goods, and other goods, respectively; w is the exogenous wage rate; l_{OFF} is household labour time in off-farm work; and e is other household income.

Households have a labour endowment, T, which is allocated over fuelwood collection, on- and off-farm employment. Thus, total household leisure, c_L, is given as:

$$c_L = T - l_{AG} - l_{OFF} - l_{FW}. \tag{8}$$

Additional to (3), the following non-negative constraints apply to the model:

$$\begin{aligned} &q_i \geq 0; c_j \geq 0; l_K \geq 0 \\ &i = FW, AG, D; \\ &j = L, FW, D, M, E; \\ &k = FW, AG, OFF \end{aligned} \tag{9}$$

By inserting (2) to (8) into (1), the Lagrangian for an internal solution to the problem can be formulated:

$$\begin{aligned} \ell = {} & U\left[c_M, \Gamma(c_{FW}, q_D), T - l_{AG} - l_{OFF} - l_{FW}; z^c\right] - \\ & \lambda\left[p_M c_M + p_{FW}(c_{FW} - q_{FW}) - p_{AG} q_{AG} - w l_{OFF} - e\right] - \\ & \eta\left[q_{AG} - g_{AG}\left(l_{AG}, \alpha q_{AG} - q_D; z^K\right)\right] - \\ & \psi\left[q_{FW} - g_{FW}\left(l_{FW}, a_{FW}; z^V\right)\right] - \mu\left[q_{FW} - c_{FW}\right] \end{aligned} \tag{10}$$

The first-order conditions for this problem are:

$$\frac{\partial \ell}{\partial c_{FW}} = \frac{\partial U}{\partial \Gamma}\frac{\partial \Gamma}{\partial c_{FW}} - \lambda p_{FW} - \mu = 0$$

$$\frac{\partial \ell}{\partial c_M} = \frac{\partial U}{\partial c_M} - \lambda p_M = 0$$

$$\frac{\partial \ell}{\partial q_{FW}} = \lambda p_{FW} - \psi + \mu = 0$$

$$\frac{\partial \ell}{\partial q_{AG}} = \lambda p_{AG} + \eta\left[\alpha \frac{\partial g_{AG}}{\partial d_{AG}} - 1\right] = 0$$

$$\frac{\partial \ell}{\partial q_D} = \frac{\partial U}{\partial \Gamma}\frac{\partial \Gamma}{\partial q_D} - \eta \frac{\partial g_{AG}}{\partial d_{AG}} = 0$$

$$\frac{\partial \ell}{\partial l_{FW}} = \psi \frac{\partial g_{FW}}{\partial l_{FW}} - \frac{\partial U}{\partial c_L} = 0$$

$$\frac{\partial \ell}{\partial l_{AG}} = \eta \frac{\partial g_{AG}}{\partial l_{AG}} - \frac{\partial U}{\partial c_L} = 0$$

$$\frac{\partial \ell}{\partial l_{OFF}} = \lambda w - \frac{\partial U}{\partial c_L} = 0$$

$\mu > 0$, if $c_{FW} - q_{FW} > 0$; $\mu(c_{FW} - q_{FW}) = 0$ otherwise, where $q_{FW} = c_{FW}$ (11)

The conditions in (11) can be rearranged to give:

$$\frac{\partial U}{\partial c_L} = \eta \frac{\partial g_{AG}}{\partial l_{AG}} = \psi \frac{\partial g_{FW}}{\partial l_{FW}} = \lambda w \quad (12)$$

Equation (12) shows how the household allocates its time among leisure, fuelwood collection and agricultural activities. More precisely, households collect fuelwood until the marginal utility of leisure, i.e. the opportunity cost of household labour, is equal the marginal product of household labour in agriculture, which in turn is equal to the marginal product of household labour in fuelwood collection. It is also equal to the off-farm labour wage.

While only limited fuelwood markets exist, it can be seen from the first and third conditions in (11) that the marginal utility of fuelwood consumption for all households is equal to the shadow cost of collecting it, ψ. For the vast majority of sampled households, the reservation price of fuelwood is lower than the market buying price and higher than its market selling price implying that they prefer to consume whatever they collect, i.e. are self-sufficient[15]. For buyers, the reservation price exceeds the market buying price, N$ 0.41 per kg, at the upper-end of the price band. Thus, the market price determines fuelwood production and consumption levels for fuelwood buyers.

Dung is used for energy production and as an input to agriculture. From the fifth condition in (11), dung is used as a source of energy until the marginal utility of energy is equal to the marginal product of dung as an agricultural input. Thus, dung use is determined by the opportunity cost of dung as an input to agriculture.

[15] For the two sellers of fuelwood in the sample, the market selling price can be said to exceed their reservation price for fuelwood.

In summary, the model shows that fuelwood collection is determined by the households' opportunity costs of time, which are mainly determined by agricultural activities. Dung use is determined by the opportunity costs of using dung as an input to agriculture. The opportunity costs of household time are driven by the wage. An increase in the wage draws labour away from agriculture, and also from fuelwood collection[16].

4. Empirical application

To test for the determinants of energy sources among rural households in Namibia, the model presented in section 3 is applied empirically to the dataset described in section 2. However, missing markets for fuelwood and labour across the sample and the non-separable property of the model imply that household fuelwood demand and supply decisions have to be considered together. From the first order conditions in (10), four reduced-form equations are derived, showing amount of fuelwood collected, amount of time spent collecting, amount of dung produced, and amount of fuelwood consumed (including amounts purchased) as functions of all the exogenous variables:[17]

$$\left.\begin{matrix} q_{FW} \\ l_{FW} \\ q_D \\ c_{FW} \end{matrix}\right\} = f(p_{FW}, p_{AG}, p_M, w, z^H, z^V, z^C, T) \qquad (13)$$

These equations are used to investigate fuelwood collection, scarcity and energy substitution behaviour in Namibian households. In particular, to examine the trade-offs between: household fuelwood collection and purchases; fuelwood collection and dung consumption; and labour input to fuelwood collection and off-farm labour.

The household sample consists of 30 buyers, two sellers, one buyer and seller and 149 households that neither bought nor sold fuelwood. The presence of four sub-groups complicates the empirical analysis, although the very small sizes of the seller and buyer/seller sub-samples precludes these from further meaningful consideration.

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[16] Where there may be direct links between fuelwood collection and deforestation, an increase off-farm wages may reduce pressures on forests. See Kaimowitz and Angelsen (1998) for a review of the evidence for such an effect.

[17] An inability to separate consumption and production decisions in the household means that there are no restrictions on functional form and parameters, at least when considering the reduced form in (13). Consequently, price, wage, income and resource variables must all remain as explanatory variables in all equations (Amacher et al., 1996).

Divided between buyers and non-buyers, the sample is reduced to 179 households. As noted in the previous section, fuelwood market prices are only relevant for the former while the latter are influenced by unobservable shadow prices. Thus, the variable for market prices is incidentally truncated (Greene, 1993). These different price regimes cannot be accommodated by dividing the sample in two and conducting separate Ordinary Least Squares (OLS) regression analyses. Since households are distributed non-randomly, this would lead to inconsistent parameter estimates and selectivity bias. The method used to address this problem and estimate the parameters of the model is Heckman's (1976, 1979) two-step estimator, in which a prediction from the first model is used as a covariate in a second model[18]. The binary indicator variable is whether or not households buy fuelwood.

The independent variables used for estimation are listed and summarised in table 2, along with their mean values. Given the original focus of the fieldwork on constructing forest resource accounts, these data are limited in their application to this analysis, e.g. there is no variable that can usefully proxy for household labour endowment, *T*.

TABLE 2 HERE

Cow dung is not traded and hence, its price is not included among the independent variables. Since dung is used an energy input, its relative scarcity is assessed through head of cattle owned. This is expected to have a positive impact on dung consumption because households with larger herds have easy access to dung for burning. Cattle owned also proxies for household capital, z^K, since these tend to be the household's most valuable form of capital.[19] Moreover, households with more animals tend to have other forms of capital, which were not captured in the survey. For a given labour input, greater capital may have a positive impact on agricultural production and household incomes. In turn, this may induce a greater consumption of leisure in addition to goods and services requiring energy inputs. The expected effect on

[18] See also Murphy and Topel (1985). As recommended by Puhani (2000), exploratory work is undertaken to reduce collinearity problems among the independent variables in order justify the use of Heckman's two-step estimator.
[19] A separate variable for total numbers of livestock owned is not possible due to collinearity with head of cattle. Since cattle are more valuable compared to other livestock, these alone act as a reasonable proxy for household capital in our sample.

fuelwood consumption is positive while those for fuelwood collection and labour input to fuelwood collection are unclear.

Regarding other household characteristics, z^{HC}, household size is expected to influence fuelwood collection positively, both because of increased energy demand (e.g. for cooking) and because of increased labour supply. The expected impact of household size on dung consumption is unclear because more household labour means increased demand for energy, but also greater scope for substituting fuelwood, which is relatively labour intensive, for dung. There are data on exogenous market incomes for almost all households. Wealthier households may collect less of their own fuelwood and rely more on market purchases with an indeterminate overall effect on fuelwood consumption.

For the non-buying sub-sample, market prices of fuelwood, p_{FW}, were not surveyed. Household responses to fuelwood scarcity can be assessed through the impact of non-price variables on fuel consumption. Collection time (per kg of fuelwood collected) captures the time cost or shadow price of gathering fuelwood. Potential endogeneity was tested by regressing collection time on the other independent variables selected in this section. This model was found to be a poor fit ($R^2 < 0.20$) thus allowing for the use of collection time as an independent variable. Increasing prices are expected to have a negative impact on fuelwood collection. Household fuelwood expenditures, in the form of labour allocated to collection, are also expected to rise.

Regarding the buying sub-sample, the market price is either smaller than or equal to the shadow price.[20] Rising shadow prices may be expected to increase fuelwood purchases, although a decline in collection means that the overall effect on consumption is unclear. Given missing markets, fuelwood prices are unlikely to be completely exogenous. There is wide variation in market prices (N$ 0.05 to 0.83 per kg). To test for the level of endogeneity and hence, their suitability for inclusion among the regressors, fuelwood prices are regressed on the other independent variables. The model was found to be a good fit ($R^2 > 0.80$) thus confirming a high level of endogeneity. Instead of using market prices, collection time per kg of

[20] Note that fuelwood buyers typically travel to local markets, on foot or via public or private transport. It is this cost plus the actual market price that would need to be at or below the shadow price of own fuelwood collection for fuelwood purchases to be attractive to households.

fuelwood is also used to proxy for fuelwood market price for buyers, i.e. we assume that market price equal the shadow price for a household.

Cross-price elasticities of demand for fuelwood and dung are used to assess the extent to which households substitute among energy sources. Substitution between dung and fuelwood can be evaluated through the impact of collection time on dung consumption and through the effect cattle herd size has on dung collection. Increasing prices are expected to have a positive impact on use of dung. However, a number of household dung collectors neither collect nor buy fuelwood. Other households only buy but do not collect fuelwood. Missing price observations for these 28 non-fuelwood collecting households are proxied by upper-bound collection time data collected for other households sampled in their villages and respective ecological regions.[21] In light of potential biases in the regression results, a sensitivity analysis is undertaken in the next section using the lower-bound collection time estimates.

Data for agricultural output prices, p_{AG}, and those for other goods, p_M, were not collected. However, fieldwork observations confirm the assumption that these vary relatively little across the households in the samples. Also, data for off-farm wage rates, w, are unavailable. Instead, a continuous variable measuring the number of years the household head had spent in education is included to account for unobserved labour market opportunities. Greater labour market opportunities is expected to effect less input to fuelwood collection, less fuelwood and dung collection and more fuelwood purchases. Another proxy for labour market opportunities is age of household head; a relatively young household head may have the skills, strength and ambition to realise an off-farm labour opportunity compared to an older one. However, age is collinear with a number of other variables including size of household and income thus excluding it from the model.

Collected fuelwood can have high opportunity costs, which varies according to the density, distance and accessibility of forest resources (z^V). Forest stock availability is measured as population per cubic metre of forest biomass in each political region. These stocks are assumed to be contained within public forests. With higher population relative to available forest, it is expected that more households will substitute fuelwood for dung. Access to forest for fuelwood could be given by distance from the household, although collinearity with collection time excludes it

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[21] Some villages straddle more than a single ecological region.

from the analysis. Improved access to forest resources or to the market could be measured through access to motorised transport, although the data are limited to private ownership and no information is available on access to public forms of transport. Awareness of state restrictions on harvesting open access forest resources is included as a dummy variable. Increased awareness is expected to lead to less fuelwood collection, more dung use and more fuelwood purchases.

5. Empirical results and discussion

All four regressions are estimated using the Heckman two-step estimator in which a predictor from the first, probit model is used as a covariate in a second, linear regression model. In the probit model, variable values are only recognised when the household is identified as a fuelwood buyer. In the second stage, the predictors are regressed on buyer-dependent variable values. Despite its consistency, the relative inefficiency of the Heckman estimator suggests using the maximum likelihood estimate (MLE) of the same model (see Puhani, 2000).

The second stage MLE results from the selection model regressions of fuelwood collection, fuelwood consumption, labour allocation to collection, and dung consumption are presented in table 3. Due to the presence of heteroscedasticity in the income variable, a third-degree polynomial in household income variable is included in all four regression equations. Despite generally conforming to prior expectations, the results show quite a poor model fit with only up to about a third of variation in outcomes explained by the independent variables. This exposes the limitations of variables derived solely from the resource accounts dataset. For example, data were not collected on local-level resource management, market access and household landholdings. Nevertheless, with collinearity problems minimised, the MLE gives interesting results that are robust to minor changes in specification.

TABLE 3 HERE

The prediction success rate is high at 84 percent for the selection (probit) equation in all four regressions, i.e. in predicting whether a household is a buyer or not. Although the probit results are not shown in table 3, fuelwood collection time is weakly significant (at the 0.10 level) in predicting whether or not a household is a buyer in the fuelwood consumption equation. Thus, the higher the price, the more likely fuelwood is purchased from the market. Collection time has a stronger effect (0.05 level) on whether or not a household is a fuelwood buyer in the dung collection equation. Relatively insignificant effects are recorded for collection time in the other two equations. Size of current household has a consistent and significant effect (0.05 level) on the choice of a household to buy fuelwood or not in all four selection equations. Thus, the bigger the household, the more likely a household will purchase at least some fuelwood from the market. By contrast, the other variables have consistent albeit considerably weaker impacts in the selection equations.

As shown in table 3, fuelwood collection time has a negative effect on the amount of fuelwood collected and a positive effect on labour input to fuelwood collection. Both effects are significant at the 0.01 level. As forest resources become increasingly scarce, households react by reducing the amount collected. A one percent increase in time to collect one kg of fuelwood results in a 0.2 percent decline in the amount of fuelwood collected, thus revealing price inelasticity. This estimate is within the range observed by Amacher et al. (1993a) and Heltberg et al. (2000).[22] Mekonnen (1999), using demand shadow price rather than collection time, obtained a less inelastic result in the more arid uplands of Ethiopia. A one percent increase in collection time also leads to 0.4 percent increase in labour input to fuelwood collection, a result that is consistent with those found, for example, by Kumar and Hotchkiss (1988), and Cooke (1998a; 1998b). Thus, households respond to forest scarcity, as measured by collection time, by increasing labour input to collection and hence, household expenditures, more than by reducing energy consumption.

With respect to dung consumption, the effect of collection time is positive but insignificant. This suggests that households do not respond to scarcity by switching directly from fuelwood to dung collection, instead preferring to allocate more labour time to fuelwood collection as indicated above. These results are consistent with those obtained by Kumar and Hotchkiss (1988), Amacher et al. (1993a), and Heltberg et al. (2000). Our elasticity estimate, 0.11, is similar to that of Heltberg et al. (2000), a result they also found to be insignificant.[23] From table 3, the effect of collection time on overall fuelwood consumption is also negative albeit insignificant, which seems to

[22] Our results are also consistent with other Asian estimates, e.g. Lind-Rahr (2003) and Pattanayak et al. (2004).

[23] Note that this result is for the consumption of all private fuels (crop residues, dung, etc.), and not just for dung alone.

imply that households are also not responding to scarcity by buying more fuelwood from the market.

Cattle ownership is found to significantly increase dung collection (0.01 level). As expected, owning cows leads to the increased availability of dung both for energy and as an agricultural input. Evidence for dung being used as an energy source can be seen with the negative and weakly significant impact (0.10 level) of cattle ownership on fuelwood collection. One additional cow is estimated to increase the amount of dung consumed by approximately 29 kg and to reduce the amount of fuelwood collected by 39 kg. This result seems to imply that dung is used to some extent as an energy substitute for fuelwood instead of as an input to agriculture. Data on agricultural inputs would be required to substantiate this, however. Cattle ownership has a positive albeit insignificant impact on labour input to fuelwood collection. Households with larger herds may spend more time in grazing areas, which may double-up as time for collecting fuelwood as well. Cattle ownership appears to be a better proxy of dung price than of household capital with a different sign of effect on fuelwood consumption than expected, although this is an insignificant result.

Forest stock, measured as the ratio of population to available forest biomass, is found to have a positive and significant effect on dung collection, while having a negative and significant effect on labour input to fuelwood collection (both at the 0.01 level). In other words, the greater (smaller) the number of people relative to available biomass, the more (less) dung that is collected and the smaller (greater) the labour input to fuelwood collection. Thus, a one percent increase in forest stock leads to a 0.89 percent increase in dung collected (equal to 80 kg) and a 0.25 percent decline in labour input to fuelwood collection (equal to 42 kg). These estimates, while having similar signs, are inelastic compared to those observed in Heltberg et al. (2000). Moreover, Mekonnen (1999) finds that Ethiopian households do not use less dung when forest biomass is more available due to complementarity between dung and fuelwood for cooking particular local dishes. Despite showing the anticipated signs, the effects of forest stock on fuelwood collection and consumption are not significant. By contrast, Heltberg et al. (2000) found forest stock to have a significant effect on fuelwood collection.

Taken together, these results only provide limited evidence for substitution between dung and fuelwood. As fuelwood becomes scarcer, poor rural households usually have relatively few alternatives available to them (Cooke et al., 2008).

Rearing cattle may require substantial investment, suitable grazing areas as well as specialised knowledge. For poor households residing in densely populated areas with relatively little pastoral knowledge and where scarcity has only recently become a problem, substituting between fuelwood and dung may not be a feasible option. Households in areas such as Oshana, where a pastoralist culture is long established and where forest resources have long been scarce, increasing dung collection would be a rational response to scarcity. Note, however, that cattle grazing also lead to the degradation of forest resources and hence, forest scarcity, which in turn may affect the household response to scarcity.

Size of current household has a positive and significant impact both on fuelwood collection and consumption (both at the 0.05 level). A weaker though still positive effect is observed for dung collection (0.10 level). These results show that larger households have higher energy demands. Household size has a positive though insignificant effect on labour input to fuelwood collection, in contrast to Heltberg et al. (2000) who found a significant result.

The other independent variables listed in table 3 have weaker effects on the dependent variables compared to the ones discussed up to now. In particular, household incomes and years of education (a proxy for off-farm labour opportunities) appear to have little impact on household behaviour. The directions of effect are as anticipated for dung collection and labour input to fuelwood collection. Small positive income effects on both fuelwood production and consumption indicate normal goods (Cooke et al., 2008). Mekonnen (1999) found a similar, smaller albeit significant result in Ethiopia. Our finding confirms the observation that the effect of income on forest product consumption is generally small with households only switching from fuelwood collection to commercial fuels in the event of severe scarcity (see Hyde and Köhlin, 2000). In three out of four sub-regions sampled, it is clear from the physical scarcity data presented in section 2 that this point is yet to be reached.

In section 4, missing price observations for the 28 non-fuelwood collecting households in the sample were approximated to upper-bound collection time data collected for other households residing in the same villages and ecological regions. A sensitivity analysis is undertaken to test the upper-bound assumption. Data for the lower-bound estimates are entered into the four regression equations. The results show that the independent variables remained consistent in their effects on the dependent variables. One exception is a weakening of the effect of collection time on fuelwood collection. This is perhaps to be expected given that use of lower-bound price estimates decreases the measure of fuelwood scarcity.

It should be noted, however, that there are wide disparities between the upper- and lower-price bounds even among households in the same village. Forest resources in these villages (to be found mainly in the Oshana sub-region) tend to be particularly scarce, compared to the sample as a whole. Many households rely on dung for their energy needs. The justification for using the upper rather than lower estimates is that the lower ones are almost all derived from households that have access to a private vehicle and can travel long distances to find and gather fuelwood. As a result, collection times for these households per kg of fuelwood collected are among the lowest in the entire sample and hence, are not representative of vast majority of households that do not have access to a private vehicle. It is for this reason that the fuelwood prices for non-collecting households have been approximated to the upper bound estimates.

6. Conclusions and policy implications

This paper estimated a household model for domestic energy supply and demand using primary data originally collected in the NCR of Namibia for the development of its forest resource accounts. As described in section 2, the population of the NCR relies on forests for its energy needs and shelter as well as providing shelter and grazing for livestock. Since fuelwood demand is unlikely to decline in Africa soon (FAO, 2007), fuelwood scarcity is likely to become more severe. Given the importance of forest resources for rural livelihoods and rapidly rising populations, the findings for northern Namibia are also relevant for people residing on communal lands throughout southern Africa.

Despite the limitations of the survey data, the results of the empirical analysis presented in section 5 broadly support the theoretical predictions made in section 3. In line with previous studies, including those undertaken in South Asia, many of the key estimated elasticities are low. As fuelwood is a basic necessity, perhaps only the poorest households should be expected to be particularly responsive to fuelwood scarcity (Hyde and Köhlin, 2000). We find that Namibian households respond to scarcity by increasing labour input to collection more than by reducing energy consumption or by substituting between fuels. This response to scarcity is underlined by the relative abundance of forest resources in three out of four sub-regions, as revealed by the physical resource accounts.

There is limited evidence for substitution between fuelwood and dung. However, the inelasticity of fuelwood demand suggests that there are few genuinely close substitutes available. Marketed fuelwood, while relatively cheap, still carries a price higher than the shadow price of collection for most households. Using cattle dung as an energy source instead of fuelwood only appears to be a serious option where cattle herding is already a way of life, which can be passed on from generation to generation, and where fuelwood scarcity is already a long-established problem. Adoption of cattle herding by households on a wider scale is likely to be very difficult given costs and a lack of grazing lands in densely populated areas.

The inelasticity of fuelwood demand therefore suggests limited scope for demand-side policy interventions (Cooke et al., 2008). Our results imply that increasing fuelwood scarcity in the NCR, associated with higher collection time, is unlikely to reduce rates of deforestation or forest degradation. With severe scarcity, households may start planting trees themselves (see for example, Amacher et al., 1993b; 2004). This would require investment (in resources and time) along with foresight on scarcity levels to realise the benefits of home-produced fuelwood. The poorest households would almost certainly require outside assistance. Open access conditions and weak communal property rights may, however, ensure the failure of tree planting schemes on a scale to match the typical household demand for fuelwood.

Any interventions that seek to increase forest stock, such as through plantation development may have little or no impact unless the underlying causes of forest degradation are addressed. Strengthening property rights would help in mitigating the worst effects of open access. Property rights reforms could be implemented in tandem with, for example, the adoption of the community-based natural resource management (CBNRM) programmes. These have already been implemented elsewhere in Namibia and have been shown to be effective under certain conditions. Community-driven schemes could, however, increase scarcity for the poorest, i.e. the landless, if they not actively involved in communal schemes (see Agarwal, 2001).

Other policy interventions that could be considered for the NCR include the introduction of improved biomass stoves (see, for example, Amacher et al., 1993a), or the promotion of ‘modern’ energy use such as electricity (Edmonds, 2002). But the evidence on these interventions suggests that there is much variation in their effectiveness, which implies that they would need to be carefully targeted. Policy in the NCR could thus focus on combining targeted 'technological fixes' such as improved stoves along with community-based tree planting schemes. Long-term funding for the latter could potentially come from participation in carbon sequestration programmes, for example, under the Kyoto Protocol's Clean Development Mechanism (CDM). Such schemes attempt to combine carbon benefits along with direct benefits for local people as demonstrated in other countries in southern Africa such as Tanzania (see Jindal et al., 2006).

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Table 1: Measures of physical and economic scarcity in the NCR, 2004

Factor		Political sub-region				NCR total (t) / average (a)
		Oshikoto	Ohangwena	Oshana	Omusati	
Forest biomass[1]	Total (‘000 m^3)	44,237	21,388	781	8,538	74.95[t]
	Density (m^3/ha)	11.44	20.00	0.90	3.22	13.36[a]
	Per capita (m^3)	1,557	595	26	224	567[a]
Physically suitable annual yield[2]	Fuelwood (‘000 m^3/yr)	2,389	1,540	35	384	4,348
	Poles (‘000 m^3/yr)	398	257	6	64	725[t]
Annual harvest	Fuelwood (‘000 m^3/yr)	114	171	92	175	552[t]
	Poles (‘000 m^3/yr)	74	59	46	77	256[t]
Economic value	Fuelwood total (‘000 N$)	37,207	55,518	29,840	56,900	179,465[t]
	Fuelwood per capita (N$)	231	244	184	249	230[a]
	Poles total (‘000 N$)	5,105	4,068	3,171	5,333	17,677[t]
	Poles per capita (N$)	32	18	20	23	23[a]

Source: Barnes et al. (2005), Nhuleipo et al. (2005), MacGregor et al. (2007)
Note: 1. Total standing stock of forest resources; 2. From standing biomass – not necessarily economically exploitable.

Table 2: Independent and dependent variables

Variable	Definition	Mean values
	Endogenous (dependent) variables	
Amount of fuelwood collected	Total collection time for fuelwood in hours per year	5071
Amount of Fuelwood consumed	Fuelwood consumed by the household in one year in kg	5572
Labour input to fuelwood collection	Total household hours in a year spent collecting fuelwood	195
Amount of dung consumed	Dung consumed by the household in one year in kg	901
	Exogenous (independent) variables	
Forest stock	Availability of forest biomass; population per cubic metre of forest biomass in each political region	0.036
Cattle	Number of cows owned by the household	9.43
Income	Exogenous household income in N$ per household	1877
Cutting regulation	Awareness of state restrictions on harvesting of public forest resources, where 1 codes for awareness	-
Household size	Number of people living in the immediate household	7.61
Education	Number of years household head in state education system	6.34
Collection time of firewood	Collection time in hours per kg of firewood collected	0.07

Source: Ministry of Environment and Tourism (MET), Namibia.

Table 3: Maximum Likelihood Estimates of the two-step selection model

Variable	Amount of fuelwood collected			Amount of fuelwood consumed			Amount of dung consumed			Labour input to fuelwood collection		
Constant		5347 (991)***			4872 (1238)***			-806 (955)			175 (81.6)**	
Forest stock	-	-11524 (9561)	-0.08	-	-15402 (13351)	-0.10	+	22165 (4358)***	0.89	-	-1328 (407)***	-0.25
Cattle	+/-	-41 (25.0)*	-0.08	+	-41.1 (40.5)	-0.07	+	30.6 (10.4)***	0.32	+/-	0.77 (1.19)	0.04
Income	-	0.20 (0.64)	0.07	+/-	0.44 (0.86)	0.15	-	-0.73 (0.67)	-1.52	-	-0.034 (0.046)	-0.32
$(\text{Income})^2$		-0.00047 (0.00019)			-0.00084 (0.00023)			0.00015 (0.00018)			0.00010 (0.00011)	
$(\text{Income})^3$		0.20D-08 (0.12D-07)			0.47D-08 (0.14D-07)			-0.77D-08 (0.10D-07)			0.60D-09 (0.63D-09)	
Cutting regulation	-	-179 (623)		+/-	-335 (868)		+	-387 (776)		-	-1.91 (45.4)	
Household size	+	134 (58.0)**	0.20	+	181 (72.6)**	0.25	+/-	86.9 (49.3)*	0.73	+	3.56 (5.28)	0.14
Education	-	91.5 (90.8)	0.11	+	113 (114)	0.13	-	80.7 (88.7)	0.57	-	-5.09 (6.32)	-0.17
Collection time per kg fuelwood collected	-	-14477 (4577)***	-0.20	+/-	-9272 (7379)	-0.12	+	1400 (5126)	0.11	+	1093 (177)***	0.40
Sample size (degrees of freedom)		179 (168)			179 (168)			179 (168)			179 (168)	
R^2		0.27			0.24			0.29			0.18	

Source: Ministry of Environment and Tourism (MET), Namibia.

Note: For each regression equation, the first column gives the expected sign, the second gives the coefficient and standard error and the third gives the elasticity (evaluated at the mean). *significant at the 0.10 level; **significant at the 0.05 level; ***significant at the 0.01 level.