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Seeing the forest for the fuel

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ABSTRACT. We demonstrate a new approach to understanding the role of fuelwood in the rural household economy by applying insights from travel cost modeling to author-compiled household survey data and meso-scale environmental statistics from Ruteng Park in Flores, Indonesia. We characterize Manggarai farming households' fuelwood collection trips as inputs into household production of the utility yielding service of cooking and heating. The number of trips taken by households depends on the shadow price of fuelwood collection or the travel cost, which is endogenous. Econometric analyses using truncated negative binomial regression models and correcting for endogeneity show that the Manggarai are 'economically rational' about fuelwood collection and access to the forests for fuelwood makes substantial contributions to household welfare. Increasing cost of forest access, wealth, use of alternative fuels, ownership of kerosene stoves, trees on farm, park staff activity, primary schools and roads, and overall development could all reduce dependence on collecting fuelwood from forests.

1. Introduction

Forests play a profound role in rural livelihoods in the developing world. This has important implications for conservation policies because protected areas can impose significant human costs by excluding people (Shyamsundar and Kramer, 1996) or generate important local benefits by preserving access to the resource through cooperative management (Pattanayak and Sills, 2001). This reflects the broader debate about poverty and the environment, with some arguing that there is a vicious cycle of poverty and environmental degradation, while others suggesting that the poor's dependence on the natural environment leads them to protect it

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(Duraiappah, 1998; Wunder, 2001). Fuelwood is a key issue in the debate both because it is the primary energy source for more than 2 billion poor people and because it is considered an important factor in forest degradation (Trossero, 2002). One key to this debate and to developing an appropriate policy response lies in understanding patterns of household dependence on the forest for fuelwood. In this paper, we investigate how forests contribute to household welfare, and how that contribution varies across households along the socio-economic spectrum.

There is a small but growing empirical literature on fuelwood, most set in the household production framework (Hyde and Köhlin, 2000; Sills *et al.*, 2003). Broader application has been constrained by insufficient ecological and economic data at the household level and failure to take advantage of the available data by applying appropriate micro-econometric tools. We demonstrate a new approach to the topic by applying insights from travel cost modeling in combination with household production theory to author-compiled household survey data and meso-scale environmental statistics from Ruteng Park in Flores, Indonesia. By focusing on a weak complement to forest fuelwood – labor – our analysis provides microeconomic evidence on (a) the contribution of fuelwood to the household economy and (b) the factors influencing household dependence on the forest, including household wealth and indicators of park management. In doing so, we begin to evaluate the relationship between poverty and forest use.

The following common aspects of fuelwood use in developing countries are taken from a comprehensive overview of fuelwood issues by Mercer and Soussan (1992). (1) Fuelwood is the primary energy source for rural households and is used mainly for cooking. (2) Although fuelwood collection from small woodlands in predominantly agricultural landscapes can result in substantial land degradation, typically fuelwood collection is not a major factor in tropical deforestation. Trees are usually pruned, rather than felled, for fuelwood. (3) Household labor is the chief input for fuelwood collection. The amount of time required depends on the quality of the terrain and the forests. (4) Policy makers need better information on collection, use, and stocks of fuelwood. (5) Barring these few generalizations, the fuelwood problem and its solution are location specific. This general characterization of the fuelwood issue accurately describes our case study of fuelwood collection from the forests surrounding villages in the buffer zone of Ruteng Park in Flores, Indonesia.

Microeconomic studies of fuelwood typically include econometric estimation of supply and demand of fuelwood quantity and collection time (Amacher *et al.*, 1993, 1996, 1999; Bardhan *et al.*, 2001; Cooke, 1998a; Heltberg *et al.*, 2000; Joshee *et al.*, 2000; Kanel *et al.*, 2000; Köhlin and Parks, 2001; Mekonen, 1999). These functions are derived within the household production framework using a static household utility maximizing model.[2] Although no general rule exists for income elasticity of fuelwood consumption, it has tended to be small and negative or insignificant (Hyde *et al.*, 2000). Fuelwood collection has been found to

[2] A dynamic simulation, based on a household production structure, is described in Bluffstone (1995).

depend on a range of economic factors and resource conditions (Sills *et al.*, 2003). In particular, Hyde and Köhlin (2000: 294) find broad support for 'the contention that the collection of fuelwood and other forest products declines with decreases in the available forest stock and with decreases in the accessibility of the remaining stock'. Resource scarcity or difficult access encourage household use of woodlots (Köhlin and Parks, 2001), tree planting (Patel *et al.*, 1995), and substitution of other fuels for wood (Mekonen, 1999; Hyde and Köhlin, 2000). These studies also collectively show that fuelwood collection, and alternative behaviors, are highly sensitive to wage, or more generally cost of collection, but that the elasticity varies across regions. Thus, Hyde and Köhlin (2000: 294) 'recommend closer attention to wages and collection time than to prices as evidence of the sort of increasing scarcity that will induce substitution and deter deforestation'.

The recreation demand literature of environmental economics provides an analytical model in which wages and travel time – a parallel to collection time – play a central role. To the authors' knowledge, with the exception of a recent paper by MacDonald *et al.* (2001), environmental economics models and methods have not been adapted to analyze the microeconomics of fuelwood. This gap is surprising because the travel cost (or recreation demand) model offers obvious transferable insights (Mercer, 1991). Similar to recreation trips, fuelwood collection trips can be modeled as functions of travel costs (shadow prices) and resource quality (forest condition). Travel cost models can also be derived within the household production framework (Smith, 1991). Following this literature, we analyze household use and valuation of forests (a non-market good) by modeling household allocation of the complementary input labor, which is traded in markets at given wage rates.

Irrespective of whether we approach modeling via the development or environmental economics literature, household production theory allows us to conceptualize the economic role of non-market environmental goods such as fuelwood and therefore the factors that motivate households to collect fuelwood. It also allows us to derive testable hypotheses about fuelwood collection activities. We contend that economic factors such as the opportunity cost of collection, availability of fuel alternatives, and wealth are the primary determinants of collection, and therefore of economic welfare from fuelwood collection (see Bardhan *et al.*, 2001 for a similar contention). While environmental, demographic, and policy factors introduce considerable heterogeneity, they do so by moderating these economic influences. Thus, we speculate that policy levers that directly and indirectly affect economic variables, for example by raising cost of collection or providing credible alternatives, will be important. To test this, we use a model of household labor, taking advantage of the complementary relationship between the forest and labor as inputs to fuelwood collection.

We apply this model to Manggarai households living in the buffer zone of Ruteng Park in Flores, Indonesia, presenting a brief description of the study area and data set in section 3. Our empirical strategy is to identify patterns of correlation among fuelwood collection, travel costs, and fuel alternatives, as moderated by household and community characteristics reflecting economic development. After exploring households choices about fuel sources, we focus on the approximately two-thirds of households who collect fuelwood from forests. Our estimated model of their labor demand accounts for the positive integer nature of the dependent variable by using a truncated count distribution.

2. Household production model of fuelwood collection

In the travel cost methodology, recreation trips are considered inputs into household production of utility-yielding recreation services, and the derived demand for recreation trips is a function of travel costs (Smith, 1991). Adapting this logic, fuelwood collection trips can be described as inputs into household production of utility-yielding fuel services (Z), i.e. primarily cooking (Mercer, 1991). Households produce this 'Z service' by using their own labor in the collection of fuel from forests (L_f) or alternatives (L_a, e.g. agricultural residues). Labor input into forest collection can be described as the product of fuelwood collection trips to the forests (T_f) and the time per collection trip (l_f). The time per trip is influenced by the quality and composition of the forests (Q). The household production framework is appropriate for describing this situation because (a) although we do not observe the final output, we know that it contributes to utility, and (b) the household's own labor is a primary input in the production process.

Our focus on forest collection trips has at least four advantages (see Pattanayak and Sills, 2001 for similar reasoning). First, labor is more easily observed than the quantity or value of fuelwood collected in a year. This approach parallels recreation demand modeling in which the empirical focus is on visits to a recreation site as an essential input to the production of unobservable 'recreation goods and services' (Smith, 1991). Likewise, we focus on the demand for a private, observable input: labor time in the forest. Second, from a data collection perspective, survey respondents found it easier to decompose 'labor time in forest' into the product of 'total trips' and 'time per trip'. That is, it was easier for survey respondents to recollect and report discrete events such as trips as compared with the continuous variable of collection time. Third, labor markets are often relatively complete in developing countries, giving us an exogenous, observable measure of the opportunity cost of household time. Pitt and Rosenzweig (1986), Benjamin (1992), and Pattanayak and Kramer (2001) describe econometric evidence of complete labor markets in Indonesia. Cooke (1998a) and Bardhan *et al.* (2001) make similar assumptions of complete labor markets even where fuelwood markets are incomplete in South Asia. Fourth, the labor input is a weak complement to the forest (as a source of fuelwood), and thus the value of changes in forest access or quality could potentially be estimated from the resulting shifts in the labor input demand (Pattanayak and Butry, 2003).

Households also have alternative technologies for producing Z, including purchase of fuelwood, and collection or purchase of other fuels. As discussed below, fuelwood markets are very thin in Ruteng, and we therefore rule out fuelwood purchase to keep our conceptual and empirical models simple.[3] Some households have stoves – indicating that they use kerosene, and these are important fixed assets affecting fuelwood collection. Households also collect fuel from alternate sources, such as agricultural fields and fallows. This fuel may include wood from trees outside of forests, agricultural residues, and other non-wood fuel sources such as a wild reed known locally as *sensus*. Thus, attributes of farm fields, and particularly the number of planted trees, are important determinants of household choices. Collectively, these alternatives may lead to two-part decision-making (Zorn, 1998): the household decides first whether to collect any fuelwood from forests and second how much of this 'forest fuelwood' to collect. Characteristics of the farm, the households, and the community may play different roles in the two stages. While we consider this distinction empirically, we combine the two in our stylized conceptual model presented next.

Our model of households describes utility (U) as a function of Z (fuel services), agricultural commodity consumption (X_c), and leisure (L_h). Preferences are influenced by household characteristics (H), including wealth. Households maximize utility subject to four constraints. First, there is the household production technology for Z, which depends on forest fuelwood (F_f) and alternative fuels (F_a), and is conditioned by H, including ownership of stoves. Both forest fuelwood and alternative fuels require labor inputs. We write forest fuelwood as a function of fuelwood collection trips (T_f). Note that T_f is equivalent to total time allocated to fuelwood collection (L_f) divided by the time per collection trip (l_f). Second, households use an agricultural production technology in which farm labor (L_x) is the primary input to the production of farm products that may be sold or consumed at home. Third, households face a time constraint such that time allocated to leisure, farm labor, forest fuelwood collection ($T_f\ l_f$), alternative fuels (L_a), and any off-farm wage labor must equal the household endowment of labor, L. Time per collection trip (l_f) is a function of both household and environmental (Q) characteristics, as described below. Fourth, households face a cash income constraint such that expenditures on consumption commodities and any hired labor are less than or equal to the sum of wage income and agricultural revenues net of any non-labor inputs. This constrained optimization problem for the households is described by equation (1), with the labor constraint embedded in the budget constraint (expressed in terms of a full income) and binding

[3] If markets for fuelwood were complete, the price of fuelwood would become another parameter in the decision to collect fuelwood from forests. In a nutshell, households would collect as long as the opportunity cost of collection was lower than the market price (See Amacher *et al.*, 1999 and Hyde and Köhlin 2000 for additional details.) Only 24 out of 494 households in our sample reported purchasing fuelwood. We include a dummy variable of whether a household purchases fuelwood in our descriptive model of who collects fuelwood from forests, but do not include this variable in any of our structural models because of endogeneity concerns.

technology constraints for agricultural production (X) and fuel services (Z)

$$\text{Maximize } \ell_{X_c,L_h,L_x,L_a,T_f} = U[Z, X_c, L_h; H] + \gamma\{Z[F_f(T_f), F_a(L_a); H]\} \quad (1)$$
$$+ \lambda(wL + P_X X(L_x; H)) - P_X X_c - w(L_h + L_x + T_f l_f(Q, H) + L_a)$$

As summarized in equation (2), the first-order conditions for the choice variables (X_c, L_h, L_x, L_a, T_f) result in familiar marginal conditions for optimal allocations that balance or equate marginal benefits and marginal costs

$$\frac{\partial \ell}{\partial X_c} = \frac{\partial U}{\partial X_c} - \lambda P_X = 0 \quad (2a)$$

$$\frac{\partial \ell}{\partial L_h} = \frac{\partial U}{\partial L_h} - \lambda w = 0 \quad (2b)$$

$$\frac{\partial \ell}{\partial L_x} = P_X \frac{\partial X}{\partial L_x} - w = 0 \quad (2c)$$

$$\frac{\partial \ell}{\partial L_a} = \gamma \frac{\partial Z}{\partial F_a} \cdot \frac{\partial F_a}{\partial L_a} - \lambda w = 0 \quad (2d)$$

$$\frac{\partial \ell}{\partial T_f} = \gamma \frac{\partial Z}{\partial F_f} \cdot \frac{\partial F_f}{\partial T_f} - \lambda w\, l_f(Q, H) = 0 \quad (2e)$$

The first order condition with respect to fuelwood collection trips (2e) can be re-arranged (3a) to show that the rational household balances the per trip travel cost (3b) against the monetary equivalent of the utility gained from a trip to collect fuelwood from forests. This gives the implicit result in (3c) that the demand for collection trips depends on the travel cost (P_T) and all exogenous parameters in the model, as reflected in the marginal utility of fuel (γ) and the marginal utility of income (λ)

$$\frac{\gamma}{\lambda} \frac{\partial Z}{\partial F_f} \cdot \frac{\partial F_f}{\partial T_f} = w l_f(Q, H) \quad (3a)$$

$$\text{where } w l_f(Q, H) \equiv P_T \quad (3b)$$

$$\therefore T_f^* = T(P_T; P_X, L, H) \quad (3c)$$

$$\Rightarrow T_f^* = T(P_T, F_a; H) \quad (3d)$$

Empirically, the travel cost will be a function of wage rates and environmental characteristics, and – as discussed below – will be partly a household choice. Thus, travel costs are endogenous and must be predicted using exogenous household, environmental, and market characteristics. An implicit function similar to (3c) could be defined for fuel alternatives. Because these alternatives are often a key policy interest, we incorporate them in the final model of fuelwood collection trips as a second endogenous variable. Due to multi-collinearity introduced through prediction of these endogenous variables, the empirical model is simplified to (3d), our reduced form, derived demand for fuelwood collection trips as a function of travel costs. Note that the dependent variable is the number of trips (T_f), and the travel cost is the wage (opportunity cost of time) for household members who collect, multiplied by the time per trip ($P_T = wl_f$). Below we describe each of the factors expected to influence the collection of fuelwood from forests, addressing the potential simultaneity or endogeneity of those factors.

We start with the central variable of interest – the travel cost or the 'shadow price' of a collection trip. In much of the literature on fuelwood, the authors contend that either the labor or the product market is complete, allowing estimation of shadow wages or shadow prices for the other incomplete market. When the labor market is complete but the product market is incomplete (as in our case), the shadow price of fuelwood can be estimated as the value of the time required to collect a unit of fuelwood.[4] For example, Cooke (1998a) and Bardhan *et al.* (2001) use time to collect a kilogram of fuelwood multiplied by the household wage (imputed, in Cooke, 1998a case). In an approach similar to ours, MacDonald *et al.* (2001) calculate the cost of a collection trip (wage multiplied by trip time) to estimate a discrete choice travel cost model of fuelwood collection.

The travel cost as constructed here is a marginal cost of production that does not include the marginal user cost (scarcity rent) associated with depletion of the local resource base for fuelwood. For publicly provided private goods, the private marginal user cost is zero. Moreover, this is a reasonable assumption for an area that is suffering from neither acute widespread fuelwood shortages nor extensive deforestation. To obtain a per unit cost of fuelwood (as in Cooke, 1998a and Bardhan *et al.*, 2001), we could divide P_T by the quantity of fuelwood collected per trip. Unfortunately, it is notoriously difficult to precisely measure quantities of fuelwood. This is not a substantial constraint if the variation in fuelwood collected per trip is either not significant (which is what our data suggest) or not significant compared with other sources of variability, such as variable heat content (quality) of different fuel species (cf. MacDonald *et al.*, 2001). Given problems with measuring fuelwood consumption, we follow Pattanayak and Sills (2001) and focus on the labor input into fuelwood collection.

Randall (1994), Fix *et al.* (2000), and Larson and Shaikh (2001) have argued that recreation demand modelers must account for the potential endogeneity of travel costs. In the case of fuelwood collection, this is particularly important, because households can choose from many possible

4 If labor markets are incomplete, the estimation follows a two-stage strategy similar to the one we propose to address endogeneity of travel costs. In the first stage, econometric instruments are used to predict household shadow wages, and this predicted shadow wage is used to explain labor allocation in the second stage. This is similar in spirit to our two-stage approach, in that we predict the shadow price using household characteristics and environmental factors. The key difference is that we argue that the entire travel cost (not the labor wage *per se*) is endogenous because households can choose from many possible collection sites in the forest and also who (which household members) will collect. Thus, the household partly determines both the time spent and the opportunity cost of that time. In practice, both approaches end up predicting the opportunity cost of fuelwood collection.

collection sites in the forest. Further, households choose who (which household members) will collect. Thus, the household partly determines both the time spent and the opportunity cost of that time, clearly making travel cost an endogenous variable. We argue that household travel costs depend on market factors that shape household activities such as wages, policy levers such as provision of roads and schools or enforcement activities regarding park boundaries, household endowments such as family size, and environmental factors such as extent and quality of forests.

Returning to our earlier statement that labor input into forest fuelwood collection is a weak complement to the forest, we argue that this complementarity is through the impact on travel costs. Pattanayak and Butry (2003) present a formal summary of weak complementarity between environmental resources (e.g. forests) and economic goods (e.g. labor) through 'economic' prices (e.g. shadow prices). The claim that environmental or resource quality improvements lower the effective costs of related economic activities dates back to Willig's (1978) idea of 'cross-product repackaging'. Previous fuelwood studies implicitly made this claim by including some proxy measure of the forest stock or distance to forest. By including forest quality variables as instruments for the 'endogenous' travel costs, we estimate a more structural link.[5]

Our conceptual model describes the role of fuel alternatives in the production of utility-yielding fuel services such as cooking and heating. If markets for fuel were complete, the price of fuel would explain the number of the trips to collect fuelwood from forests. In the absence of such markets, some measure of fuel alternatives – be it quantity of alternatives, or labor input to collection of alternatives – can be an important influence. Previous literature has often included ownership of an alternative fuel technology, such as a kerosense stove, and found this dummy variable to have the expected negative effect on collection and consumption. Because upfront costs of kerosene stoves are substantial, stove ownership is usually treated as a fixed household characteristic. In contrast, fuel alternatives such as agricultural residues are clearly endogenous to models of forest fuelwood collection. That is, households will simultaneously choose to collect fuel from forests and from agricultural fields. Households are unlikely to make single-purpose trips to collect fuel from agricultural fields, however, making the decision of whether or not to collect any fuel from fields easier to measure than the level of collection (i.e., number of trips).[6] The conceptual model (equations (1)–(2)) suggests that demand-side factors such as wealth

[5] Pattanayak (forthcoming) presents a related example in which household collection costs for water from streams depend on objective indices of watershed protection and in-stream water availability. Thus, environmental improvements lower household costs in that study.

[6] There may also be joint production activities with fuelwood collection from the forest. We do not have reliable data on joint activities but suspect that they would be less of an issue with trips to the forest than with trips to fields, which are almost certainly combined with the primary household activity of farming.

and economic prosperity, as well as supply-side factors such as number of trees in fields, can serve as instruments for the household decision whether to obtain fuel from sources other than the forest.[7]

Household assets may also affect both production capabilities and preferences, and studies of fuelwood and other forest products often include some measure of household wealth, usually as an exogenous proxy for permanent income. For example, wealth has been represented by landholdings (Edmunds, 2002) and livestock ownership (Gunatilike, 1998; Amacher *et al.*, 1993). Others have used expenditures and/or 'exogenous income' from non-forest sources. To the extent that labor is often the main resource of smallholders, household size is also an important household asset, whether defined as number of people, number of adults, or number of adult equivalents in the household (Brouwer *et al.*, 1997). Household size has been found positively and significantly related to collection time, gross income from fuelwood, and production and consumption of fuelwood. In general, the effect of household assets and wealth vary across studies, even for the same region (compare Amacher *et al.*, 1999 and Edmunds, 2002). Given this range of influences, we include measures of household wealth among the determinants of travel costs, fuel substitutes, and forest fuelwood collection.

Finally, we consider a set of 'policy' or 'management' variables that could potentially influence fuel choices (Bluffstone, 1998). These could directly impact choices or more subtly by changing the environmental and economic circumstances over a longer time frame. Previous studies have included a range of variables to capture these policy factors, some of which are included in our case study and described in the next section. Despite the commonalities across models described in the previous paragraphs, the specific combination of variables, and specific measurement of these variables, vary substantially across studies. Hyde and Köhlin (2000) provide an excellent summary of specification and estimation results from the microeconomic fuelwood literature.

To sum, the travel cost method provides an empirical model with testable assumptions to describe the fuelwood collection activities of farming households. The core of this model is that the derived demand for fuelwood collection trips is a function of travel costs, substitutes, and socio-economic status (e.g. wealth). We turn next to the specification of our empirical model using data from a household survey in buffer zone villages around Ruteng Park in Flores, Indonesia with meso-level environmental statistics for the region.

[7] As Heltberg *et al.* (2000: 223) note, 'the number of trees on the farm is treated as exogenous because it enters the decision-making process in a much longer time horizon than the fuel substitution decisions considered here.' Based on personal observations, trees on farms in Ruteng are most likely to be scattered in fields or along fence rows and not in woodlots that compete for agricultural land. Thus, we treat the number of trees planted on the farm as an exogenous quasi-fixed input, not affected by current year labor allocations.

3. Data: buffer zone of Ruteng Park in Flores, Indonesia

The empirical analysis presented in this paper is a component of a study addressing the economics of biodiversity conservation in Siberut and Ruteng national parks in Indonesia (Kramer *et al.*, 1997). The data used were drawn from a survey of 494 households in 47 *desas* (village clusters) in the buffer zone of Ruteng Park in February, 1996. Households were chosen from a sampling frame of about 13,500 households in the buffer zone on the basis of stratified random sampling in which the weights reflected the population densities of the desas. The survey was administered by 16 Indonesian undergraduate agronomy students who spoke the local Manggarai dialect. The interviewers received three days of training and were monitored during the data collection. The survey was comprised of five sections: demographic characteristics, environmental profile of farm land, farm and home production budget, labor and financial allocations, and contingent valuation. It was designed using focus groups, pretests, and expert opinions (Kramer *et al.*, 1997).

Survey results show that the average Manggarai household has little education and wealth. They exhibit a heavy reliance on agriculture, primarily growing coffee, rice, and cassava, and raising chickens and pigs. About 90 per cent of the local population is engaged in agriculture. Labor and fertilizers are the key agricultural inputs.[8] Manggarai households do have some off-farm employment opportunities, including positions with the local government, non-governmental organizations, kiosks, and logging crews. There is substantial participation in labor markets, with 58 per cent of all households working off-farm and 31 per cent hiring labor to work on their farms. In all desas sampled at least one household was hiring out labor, and in 87 per cent of the desas at least one household was hiring in labor. These statistics, the fact that a large proportion of households report input and output prices, and the proximity of roads and other market infrastructure (e.g. stores and credit facilities) provide evidence that markets are complete for agricultural products and labor. We use households' reported wages.[9] We do not use income measures in our empirical models because of potential endogeneity problems. Instead, we consider three measures of wealth or assets – the market value of all animals, farm size, and a wealth index.[10] Our wealth index is a simple count of household possessions: radio, television, electricity, wall clock, wrist watches, kerosene

[8] While agricultural fields in this region were originally carved out of forests, households are no longer expanding their agricultural lands by clearing forest, probably in large part due to the park. Only 36 of the households interviewed (or 7 per cent) said that they planned to expand their fields in the coming year, through purchase or other means.

[9] Because our survey covered a year, we do not have information on seasonal variation in wages. We acknowledge that this may be an important factor in fuelwood collection decisions, as demonstrated by Cooke (1998b).

[10] Income is traditionally included in fuelwood studies as a determinant of collection, with little or no acknowledgement of its potential endogeneity. Asset holdings, which take time to accumulate, are potential instruments for income. We thank one of the reviewers for convincing us to investigate this issue more closely.

stove, and motorcycle. The average count is about 1. As discussed above, family size could also be considered as a household asset or as the available labor force. All four of these measures are statistically correlated with the sum of wage income and the cash value of crop production.

We also consider a set of variables that are amenable to 'policy' or 'management' changes, several of which are reported in government statistical reports (Badan Pusat Statistik, 1995) and management plans (Indonesian Ministry of Forestry, 1995). Clearly, the extent and quality of forest cover is a potential policy lever, and we present details on this measure. About 2 per cent of our sample of households live in 'enclaves' or in holdings within the park. About 7 per cent live in 'less-developed' desas targeted by a federal poverty reduction program, called *Inpres Desa Tertinggal* (IDT, presidential instruction program for less-developed villages), which makes them eligible for block grants. The dummy variable representing whether a household is in an IDT desa is best viewed an indicator of overall development, rather than a specific forest policy lever.

To represent forest policy and park management, we construct two indices at the desa level. First, we calculate the percentage of households in a desa who are aware of the park boundary and activities (based on their response to survey questions), as an index of the extent of monitoring and communication by the park. The average across desas is 33 per cent. Second, we calculate the percentage of households in a desa who have been visited by park staff (again, based on their response to survey questions) as an index of extension and assistance. The average across desas is 15 per cent. Public infrastructure, such as primary schools, also varies across desas. The average number of primary schools per desa is 2.7, ranging from a minimum of 1 to a maximum of 5. Finally, we construct several location variables, such as distance to paved roads and towns, in order to capture the effects of market access and urbanization. These are described next, along with other variables constructed with the help of geographic information system (GIS) tools.

Given that we implement our empirical model by combining socio-economic survey data with forest ecological data, we draw attention to the precision of our ecological data. Priyanto (1996) provides estimates of secondary (or regenerating) and primary (undisturbed) forest cover by micro-watershed. The core forests of Ruteng Park have enjoyed some form of official protection for about 80 years (Indonesian Ministry of Forestry, 1995). Secondary forests are largely the result of logging by family or commercial firms from outside our study area (Blomkvist, 1995). In the long run, intensive fuelwood collection could also lead to degradation of forest, which might then be categorized as secondary (Moeliono, 1995). We find that population density is inversely correlated with primary forest cover.[11]

[11] While this may suggest that population density impacts primary forests, it is also likely that forests were protected and designated as park areas in regions with lower population density. Given the problems with establishing causality in general and collinearity of the two variables, we only include forest variables in our regression models, but we mention the potential population impacts in our discussions of the effects of primary forests. Moreover, the population impact is

For our household model, however, we treat quality of forest available to households as exogenous to their current year decisions about collection, because that quality is generated by longer-term activities in the entire desa and not by an individual household's decisions in a given year. By overlaying environmental (e.g., watershed boundaries) and administrative (e.g., desa boundaries) data in a GIS, we obtain estimates of forest cover by desa. For example, if two watersheds overlap with a particular desa, we use GIS to first calculate the fraction of the watersheds that lie in the desa, and then use this fraction multiplied by the total primary forest cover in a watershed to estimate a proportion of primary forest cover available to the desa. Proportions are similarly computed for each overlapping watershed and summed to generate an aggregate measure of primary forest cover available to desa households. On average, a typical desa has 25 hectares of primary forests and 97 hectares of secondary forests. These area estimates serve as an index of forest access and quality. GIS was also used to compute distances to nearest paved road, the capital city of the district – Ruteng – and to two towns – Iteng and Mborong. On average, desas are 6.8 kilometers from paved roads, 15.4 kilometers from Ruteng, 21.4 kilometers from Mborong, and 24.6 kilometers from Iteng.

Of the 494 households interviewed, 305 report collecting fuelwood from forests, and 310 report collecting alternative biomass fuels from agricultural fields and fallows (crop residues, coffee shrubs, and trees maintained for fuelwood) or *sensus*, a pioneering reedy species growing in patches on cleared land close to agricultural fields, which serves as a fuel supplement when dry. Note that 134 households collect both fuel alternatives and fuelwood from forests. Survey respondents were asked about the typical trip to collect fuelwood from forests, including who participates, the time required, and the number of trips. Seventy per cent of the households reported that adult males are the primary collectors, whereas children are the collectors for 23 per cent of the households. On average, households make 218 fuelwood collection trips per year. They spend an average of 2 hours per trip, which reflects a range from as little as 0.5 hours to as much as 5 hours per trip. The travel cost for a forest fuelwood collection trip is calculated as the product of the number of hours per trip and the average hourly wage rate for the household members who collect. The average cost for a typical fuelwood collection trip is \$0.19, using the exchange rate of rupiah 2,200 per dollar that was prevalent at the time of the survey.

4. Estimating models of forest fuelwood collection

To implement the travel cost method, we estimate a model of the number of fuelwood collection trips (T_f) to forests. The key explanatory variable is the travel cost (P_T). The collection of fuel alternatives, wealth, and policy variables are other potential determinants. The model specification is intentionally parsimonious, because as explained in the previous two sections, several environmental, household, market, and policy variables influence the forest fuel collection decision indirectly through the fuel

partly captured in our empirical models by our stratified sampling strategy, which includes proportionately more households from desas with higher populations.

substitute and travel cost variables. Because the number of trips is always a positive integer, we use a count data model truncated at one (Hellerstein and Mendelsohn, 1993). Assuming a negative binomial distribution, for the discrete random variable T_f, with observed frequencies $t_{fi}, i = 1, \ldots, N$ ($t_{fi} > 0$), regressors P_T, alternatives (F_a), wealth (I), and policy variables (M), the truncated probability distribution is described by equation (4)

$$\Pr(T_{Fi} = t_{fi}) = \frac{\left[\frac{\Gamma(t_{fi} + \theta)}{\Gamma(\theta)\Gamma(t_{fi} + 1)}\right]\left[\frac{\omega_i}{\theta + \omega_i}\right]^{t_{fi}}}{\left[\frac{\theta}{\theta + \omega_i}\right]^{-\theta} - 1} \tag{4}$$

Where $\ln(\omega_i) = \beta_p \cdot P_{Ti} + \beta_f \cdot F_{ai} + \beta_i \cdot I_i + \beta_m \cdot M_i + \varepsilon$ and θ defines the overdispersion parameter, $\alpha = 1/\theta$.

The expected value of the distribution, or predicted number of trips, and the variance are given in Cameron and Trivedi (1998: 119). The significance of the coefficient on the overdispersion parameter is a test for this model vs. the truncated Poisson.

Truncated models can be criticized for ignoring choices at the extensive margin, i.e. the decision whether or not to collect any fuelwood from the forest. We have both a conceptual and a practical reason for using a truncated model. Conceptually, we are interested specifically in the behavior of the fuelwood collectors as a group, separate from the issue of who does and does not collect. The practical reason is that we do not observe travel costs for non-collectors. We choose not to impute travel costs, because we consider them an endogenous variable, determined by the household jointly with the number of trips. Therefore we use the truncated model to explore the behavior and benefits of forest access to fuelwood collectors.

To explore the extensive margin of choice, we estimate a two-part or hurdle model that first describes which households collect (Mullahy, 1986; Zorn, 1998) as a function of a wide range of variables, including some that are most likely endogenous. The first part is simply a probit model of the decision to collect fuelwood from forests as a function of household characteristics (e.g., ownership of stoves, availability of trees on farms, purchase and sale of fuelwood, park monitoring and extension indices), and several determinants of travel costs (e.g., forest quality, road distance, and location within park enclaves). The second part is the collection trip model described above.

Another complicating econometric issue is the endogeneity of fuel alternatives and travel costs. To correct for endogeneity, we use the two-stage technique of first estimating the probability of collecting alternatives and the travel cost and then using the predicted values in the regression on trips.[12] As discussed earlier, we focus on the decision whether or not to collect any fuel alternatives, estimating a probit model of this probability.

[12] Using predicted values in the second-stage count model will introduce sampling variation (Mullahy, 1997). Therefore, bootstrapping techniques could be used to check if the statistical significance of the pre-estimated variables is sensitive to the pre-estimation process. For example, in a 50 iteration bootstrap of the models

We increase the efficiency of estimation by recognizing that the error is likely to be correlated with the error in the model of whether or not to collect fuelwood from the forest. Thus, we estimate a bivariate probit model (equation (5))

$$\Pr(F_f = 1, F_a = 1) = \Phi(\gamma_f' X_f, \gamma_a' X_a, \rho) \quad (5)$$

where γ_f is a vector of coefficients to be estimated for forest fuelwood collection; X_f is a vector of household, management, and travel cost variables described in the previous paragraph; γ_a is a vector of coefficients to be estimated for the fuel alternatives model; X_a is a vector of wealth, economic prosperity, availability of trees, and park management variables explaining collection of fuel alternatives; and ρ is the correlation of errors across the two models. Thus, the descriptive model of forest fuelwood collection when jointly estimated with the predictive model of fuel alternative collection can potentially improve our prediction of the probability of collecting fuel alternatives, which we carry forward to the final model of fuelwood collection trips.

We use several instruments to account for the endogeneity of travel costs, estimating a least squares regression model

$$P_t = \kappa_m X_m + \kappa_o X_o + \kappa_h X_h + \varepsilon$$

where κs are the coefficients to be estimated; X_m is a vector of management and policy variables including extent of primary and secondary forests, index of park monitoring and extension, number of primary schools, and location in an 'enclave within park'; X_o is a vector of opportunities such as hourly wage rate and distance to paved road; and X_h is a vector of household characteristics such as family size and average family illness count. Further discussion of these variables is presented below along with the model results.

Descriptive statistics for the variables used in all three models – alternative fuels and forest fuelwood, travel cost, and forest fuelwood collection trips – are presented in table 1. Before turning to results for these three models, consider an important limitation of cross-sectional data sets for estimating household production models. In the household production framework, many choices are linked, if not simultaneous, making it somewhat difficult to econometrically identify the system of equations and, therefore, to definitively establish causality. We use two strategies to address this challenge. First, we focus only on key endogenous variables – travel costs and fuel alternatives – directly relevant to the forest fuelwood collection problem. Second, we use exogenous variables selectively, ensuring both that we have 'good' instruments for the endogenous variables and that these instruments do not induce too much multi-collinearity in our trip model. The results show that our strategy is largely successful.

presented in tables 3 and 4, we find that the coefficient on travel cost is always negative.

Table 1. *Descriptive statistics for fuelwood collection variables (all three models)*

Variable	*Unit*	*Mean*	*St. Dev*	*Model*
Fuelwood collection trips per year*	count	218.23	138.48	tr
Travel cost of forest fuel collection*	$	0.19	0.14	tr, tc
Price of labor	rupiahs/hour	248.45	46.82	tc
Primary forest accessible to desa households	hectares	23.73	25.50	tc
Secondary forests accessible to desa households	hectares	108.27	100.19	tc, bpf
Distance to nearest paved road	kilometers	6.84	7.16	tc, bpf
Distance to Ruteng, capital of Manggarai district	kilometers	15.44	10.00	tr
Average illness events in household	count	1.08	0.53	tc
Family size	count	4.28	1.51	tc, bpa
Log (market value of farm animals)	$	3.86	4.18	bpa
Wealth index (count of radio, tv, electricity, stove, clocks, motorcycle)	count	1.33	1.07	tc
Percent of village visited by park staff	%	0.16	0.18	bpa, bpf
Percent of village aware of park boundaries and activities	%	0.35	0.24	tc, bpf
Number of primary schools in desa	count	2.71	1.04	tc
	Coding	*% Households*		*Model*
Collect fuelwood from forests?	1= yes; 0 = no	61.5		bpf
Collect alternative fuels?	1= yes; 0 = no	61.7		bpa
Own kerosene stoves?	1= yes; 0 = no	5.3		bpf
Purchased fuelwood?	1= yes; 0 = no	4.9		bpf
Sold fuelwood?	1= yes; 0 = no	3.2		bpf
Have trees on farm?	1= yes; 0 = no	62.3		bpa, bpf, tc
Live in 'enclave within park'?	1= yes; 0 = no	2.4		bpf
Live in 'IDT desas'?	1= yes; 0 = no	6.7		bpa, bpf

Notes: Models code: tr = truncated negative binomial trip, tc = OLS travel cost, bpa = bivariate probit alternative fuel, bpf = bivariate probit forest fuel. Sample sizes for the * variables are 305 and 290 respectively. For remaining variables, the sample size is 494.

Table 2. *Bivariate probit model of collection of alternative fuel and forest fuel*

Variable	*Coeff* (γ)	*P-value*
Alternative fuel		
Regression constant	−0.57	0.001
Market value of farm animals	0.05	0.000
Family size	0.07	0.030
Percent of village visited by park staff	0.61	0.109
Have trees on farm?	0.45	0.000
Live in 'IDT desas'?	0.67	0.011
Live in 'enclave within park'?	−0.23	0.574
Forest fuel		
Regression constant	0.40	0.004
Percent of village visited by park staff	−0.79	0.086
Have trees on farm?	−0.18	0.166
Live in 'IDT desas'?	0.43	0.201
Live in 'enclave within park'?	0.51	0.196
Own kerosene stoves?	−0.75	0.000
Secondary forests accessible to villagers	0.00	0.057
Distance to nearest paved road	0.02	0.010
Percent of village aware of park boundaries and activities	0.33	0.270
Purchased fuelwood?	−0.85	0.002
Sold fuelwood?	1.21	0.001
Error correlation parameter (ρ)	−0.86	0.000
Log-likelihood	−540	
Sample size	494	

Bivariate probit models of fuel choice

The results of a bivariate probit model to instrument the probability of collecting alternative fuel and to describe the patterns of which households collect fuelwood from the forest are presented in table 2. The estimated coefficients (γs) and associated probability values are reported in columns 2 and 3. The correlation coefficient ρ is statistically significant, suggesting gains from estimating the two decisions together. Starting with the alternative fuel model, we find five variables are positively correlated with collection of alternatives. Wealthier households, as proxied by the market value of livestock, are more likely to collect alternatives. This might also suggest that there is joint production of livestock and fuel alternatives. Households with larger families are more likely to collect alternatives, because they have a greater demand and/or more people who can collect fuel. Households who have trees on their farms are more likely to collect fuel alternatives, presumably from their fields. We see that households in desas with more visits by park staff (a greater percentage have met the staff) are more likely to collect alternatives. This could be because the park staff provide technical assistance and education about the use of alternatives, persuade households of the merits of protecting forests, and/or warn households that they may be penalized for collecting fuelwood from the park (leading to general fear of collecting from the forest). Households living in 'enclaves' within the park are no more likely to collect fuel alternatives than households living in the buffer zone. However, households living in the poorer 'IDT desas' are more likely to collect fuel alternatives. Based on the estimated coefficients from this model, we predict a household-specific probability of collecting fuel alternatives and use it in the model of trips to collect fuelwood from the forest.

Turning to the model of which households collect forest fuelwood, we see that households who own stoves (which are positively correlated with other measures of wealth) are less likely to collect forest fuelwood. Households with access to more secondary forests are less likely to collect forest fuelwood. In comparison to primary forests, regenerating 'secondary' forests are often denser (harder to penetrate) and lacking in dry fuelwood. Distance to paved roads, which proxies access to labor markets and remoteness, is positively correlated with collection. That is, households who have lower opportunity cost of time or face less competition from other people are more likely to collect the fuelwood from forests.

Looking at some of the policy variables, the estimation results suggest that households in poorer 'IDT desas' and in 'enclaves' within the park are more likely to collect forest fuelwood. The coefficients on these two variables are significant at the 20 per cent level, which is at least suggestive of correlation in a sample of less than 500 observations. Consistent with the logic presented for the alternative fuel model above, we see that households in desas that have more visits by park staff and that have trees on their farms are less likely to collect forest fuelwood. Finally, we see that households that sell fuelwood are more likely to collect, whereas households that buy fuelwood are less likely to collect fuel from forests. Recall that we have estimated this model for descriptive, not predictive purposes, and therefore include these endogenous variables to better understand the extensive margin of forest fuel collection. The buying and selling households (only 4 per cent and 3 per cent of households who report fuelwood collection trips) are dropped from the sample for the remainder of the analysis.

Least squares model of travel cost

The results of a least square model to instrument travel costs are reported in table 3. The estimated coefficients (κs) and associated probability values are reported in columns 2 and 3. An R^2 statistic of 0.27 and a F-statistic [9,280] of 11.5 with a p-value of 0.000 suggest good overall fit for this small cross-sectional sample. Several variables have intuitively appealing and policy-relevant coefficients. As suggested in section 2, area of primary forest cover is negatively correlated with travel cost. *Ceteris paribus*, more primary forests imply households will have to expend less effort in collecting forest fuelwood. This could also suggest the impacts of lower competition among people because there are fewer people in areas with greater primary forests. As a corollary to this result, we find that area of secondary forest cover (or recent regeneration) is positively correlated with travel costs. It may be more difficult to collect from secondary forests, or the presence of secondary forest in a desa (often around home sites) may mean that household members have to walk further to the primary forests. We find that households living further

Table 3. *Least squares model of travel costs*

Variable	*Coeff* (κ)	*P-value*
Regression constant	−0.005	0.924
Primary forest accessible to desa households	−0.001	0.020
Secondary forests accessible to desa households	0.0003	0.008
Distance to nearest paved road	−0.003	0.003
Price of labor	0.001	0.000
Per cent of village aware of park boundaries and activities	0.166	0.000
Live in 'enclave within park'?	−0.037	0.415
Number of primary schools in desa	0.018	0.019
Family size	−0.011	0.023
Average illness	−0.022	0.128
R^2	0.27	
F [9, 280] statistic	11.48	0.000
Sample size	290	

from paved roads face lower costs, presumably because of greater fuelwood availability and lower competition among households at sites further from roads and populations. This could also reflect lower opportunity costs for household members. A more direct measure of opportunity costs is the average hourly agriculture wage rate (price of labor), which we find to be positively correlated with costs as expected.

Considering other policy variables, we see that households in villages with greater awareness of park boundaries and activities of park staff have higher costs. Households in these villages may be expending greater effort in collecting from forests that are distant from the park and/or minimizing the likelihood of being caught by park staff. The dummy for 'enclave within park' is not significant. Households in desas with a greater number of primary schools have higher costs, suggesting that schools draw children out of collection, thus raising costs to households by shifting the burden of collecting to adults with higher opportunity costs of labor. Alternatively, schools could be considered to raise the households' opportunity cost of time, by raising expected future earnings. The trade-off between education and fuelwood collection is often remarked upon, but usually in the sense of children leaving school in order to collect fuelwood. Here, we consider the impact of educational opportunities on fuelwood collection.

Turning to household characteristics, we find that households with larger families have lower costs. As suggested by the literature, labor shortage is one of the primary constraints on fuelwood collection. The coefficient on the health index (average number of illnesses per household member) is negative, suggesting that ill health leaves people with fewer market options and a lower opportunity cost of time. As in the alternative fuel model, we use the estimated coefficients reported in Table 3 to predict a travel cost for every household and use this predicted value in the fuelwood collection trips model below.

Table 4. *Truncated negative binomial model of fuelwood collection trips to forests*

Variable	*Exogenous model* Coeff (β)	*Exogenous model* P-value	*Endogenous model* Coeff (β)	*Endogenous model* P-value
Regression constant	6.060	0.000	6.098	0.000
Travel cost	−1.179	0.003	−1.811	0.040
Wealth index	−0.158	0.000	−0.169	0.002
Collect alternative fuel	−0.512	0.000	−0.058	0.654
Distance to Ruteng	−0.005	0.340	−0.008	0.209
Over-dispersion parameter (α)	0.520	0.000	0.574	0.000
Notes: Log-likelihood	−1681		−1696	
$\chi^2(4)$ statistic	46	0.000	16	0.002
Sample size	274		274	

Truncated negative binomial model of fuelwood collection trips

Results of the negative binomial model of the number of collection trips to the forests are reported in table 4. Overall model statistics represented by log-likelihood, χ^2, and probability values (less than 0.00) suggest reasonable fit for parsimonious models using small samples. The four variables are jointly statistically significant. Estimated coefficients in columns 2 and 3 refer to the models (a) without instruments, labeled 'exogenous model', and (b) with instrumented alternative fuel and travel cost, labeled 'endogenous model'. In both cases, the over-dispersion parameters are significant, suggesting that the negative binomial model is preferable to the Poisson model for these data.

Our key finding is the negative and significant coefficient on travel cost; that is, travel cost has the expected downward-sloping demand relationship with collection trips in both the endogenous and exogenous models. This indicates that farm households around Ruteng Park are economically rational in choosing the number of fuelwood collection trips ('to some this is a truism, to others it is a conclusion', Binkley, 1981). The collection of fuel alternatives is negatively correlated with forest collection trips, although it is statistically significant only in the exogenous model. This loss in statistical significance could be because our instruments either are not 'good enough' predictors or are not 'different enough' from the instruments for travel cost. The negative coefficient on the wealth index indicates that fuelwood is an inferior good, at least in the long term as households build wealth. Finally, we find some evidence that households living further from Ruteng, the capital of the district, take fewer trips to collect forest fuelwood. Given that the travel cost variable already accounts for supply-side factors related to distance from urban centers, this suggests two potential demand side effects.[13] First, many households living in and around Ruteng are

[13] A third possibility is the existence of fuelwood markets closer to urban centers. It is possible that households under-reported the actual sale of fuelwood, whereas their trip behavior reveals their true needs – that is, to collect fuelwood for sale.

non-Manggarai migrants to the region. Thus, this result could be capturing some cultural differences between non-Manggarai immigrants and the local Manggarai. Second, the desas close to Ruteng are at higher altitudes, experiencing a colder and wetter climate. Thus, distance to Ruteng could also proxy for lower demand due to warmer and drier surroundings.

The corrections for endogeneity of fuel alternatives and travel cost by using predicted values have the expected statistical effects. Overall, the model that accounts for endogeneity has slightly lower explanatory power (log-likehood of −1696 versus −1681 for exogenous model). The travel cost and fuel alternatives are 'less significant', most clearly for the latter. The coefficient on the alternative fuel variable, though no longer significant, is approximately one-tenth of the coefficient in the exogenous model. This suggests that there may be less substitution between these two fuel sources, once we control for the fact that collection of fuel substitutes is jointly or simultaneously determined with the collection of forest fuelwood. The travel cost parameter, which is key to the model described and implemented in this paper, is significant in both specifications. The most economically significant difference between the models is the size of the travel cost coefficient, which is almost one and a half times larger in the endogenous model. Given that economic welfare measures are inversely related to this parameter, our results suggest that models that do not account for endogeneity of travel cost could substantially over-estimate the welfare significance of fuelwood collection. In other words, the endogenous model shows that the elasticity of demand with respect to the travel cost is almost 1.5 times as large as estimated from the exogenous model, presumably because households can adjust their behaviors, and therefore their costs and their reliance on fuelwood from the forests.

5. Discussion

Using a household production framework, we characterize Manggarai farming households' fuelwood collection trips as inputs into household production of utility-yielding fuel services (cooking and heating). Our methodological contribution is adaptation of the travel cost model from environmental economics to analyze the primary energy source and a potential cause of forest degradation in developing countries: fuelwood collection. Rather than measure and model fuelwood quantity collected, we follow Pattanayak and Sills (2001) and Pattanayak and Butry (2003) in focusing on the weak complement – labor input into forest fuelwood collection. The basic proposition is that fuelwood collection trips are a function of travel cost, which is the shadow price of the time required to collect fuelwood. We implement our travel cost model of fuelwood collection by estimating the derived demand for collection trips to the forest, with a truncated negative binomial model. We find econometric instruments to address endogeneity of the travel cost and fuel alternatives variables. We use GIS to match household survey data to meso-scale environmental data on forest quality and distances to roads and thus identify some of the environmental determinants of travel costs.

The coefficients on travel cost suggest that the Manggarai are 'economically rational' about fuelwood collection from the forests. Demand theory evidently holds for use of energy from a protected forest in this agrarian developing country setting. As a reviewer pointed out, our findings contribute to a growing body of evidence that poor households behave rationally from a private perspective in their choices regarding forest uses. The elasticity of 0.35 (endogenous model) shows that the demand for fuelwood collection trips is inelastic with respect to the shadow price of fuelwood (the travel cost), indicating that fuelwood is essential for these households. Accounting for endogeneity results in higher elasticity (and lower consumer surplus), suggesting that it is critical to consider households' ability to adapt in fuelwood collection studies. Collection of fuel alternatives is negatively related to the number of trips; while tempered by econometric uncertainty, this may indicate a potential avenue for discouraging fuelwood collection from the forests. Wealth is also negatively related to the number of collection trips to forests, supporting the conventional wisdom that fuelwood is an inferior good (Mercer and Soussan, 1992; Hyde and Köhlin, 2000).

Our estimation results can further inform policy on three fronts. First, the travel cost results allow us to assess the benefits to the Manggarai people of continued access to Ruteng Park for fuelwood collection and provide a partial measure of forest dependence. The model of collection trips reveals that the Manggarai have a credible demand for these forests as an important source of fuelwood, their primary energy source. The per trip consumer surplus of $0.55, calculated as the inverse of the coefficient on the travel cost variable, provides a measure of the Manggarai people's welfare gain from access to forests for fuelwood. The average annual consumer surplus is $122 per household.[14] To put this in context, consider that the average household in this region earns just $780 per year in net cash returns from agricultural production plus any wage income. While this earnings figure, as a measure of producer value added to household labor (cf. Yang and An, 2002 for a similar measure of farm household value added), is not directly comparable to the estimated consumer surplus, it does indicate that $122 is substantial for households in this poor region. Restricting access to the forest would impose significant costs on the Manggarai.

Second, the models show us how these fuelwood benefits – or forest dependence – vary across households. Households with higher shadow prices (travel cost), greater wealth, and perhaps with alternative biomass fuels (from agricultural fields and *sensus* patches) are less dependent on the forests for fuelwood. The supporting models show how travel cost and alternative fuel collection vary across our sample. Households that are wealthier and have more trees on their farms, and that live in desas with more schools and closer to paved roads, are more likely to collect alternative fuels and/or have higher travel costs. The descriptive model of fuelwood collection also suggests that households who have trees on their farms, own kerosene stoves, and purchase fuelwood, are less likely to collect forest fuelwood. Across the models, we find that schools, roads,

[14] This is calculated as the product of per trip consumer surplus and the predicted number of trips. The predicted trips in a truncated negative binomial model equals $\hat{\omega}/(1 - [\alpha/(\alpha + \hat{\omega})]^{\alpha})$, where α and ω are defined in equation (4).

and wage opportunities are likely to lower dependence on forest fuelwood, presumably by encouraging collection of alternative fuels and/or raising the shadow price of collection from forests.

Third, the previous two points assume that current use rates are biologically sustainable and economically optimal. It is beyond the scope and the data of this paper to evaluate sustainability in aggregate. We can, however, address a narrower set of issues related to park managers' interest in discouraging fuelwood collection from the forests (Blomkvist, 1995; Indonesian Ministry of Forestry, 1995; Moeliono, 1995). The previous paragraph suggests the kinds of policy handles available for influencing the Manggarai's choice amongst fuel sources and intensity of fuelwood collection. Park managers should recognize that collection of alternative fuels, higher shadow prices, and greater wealth will reduce the intensity of fuelwood collection from forests. As suggested by Wells (2003), park management activities that seek to directly reduce fuelwood collection, such as regular visits, communication with communities, and maintenance and education about park boundaries, are important complements to policies that tackle the problem indirectly by lowering the cost of fuel alternatives and raising the effective price of fuelwood collection from the forest. At the extensive margin of choice, park managers can reduce collection of fuelwood from forests and promote collection of alternative fuels by assisting households to plant trees on farms and acquire kerosene stoves. Finally, to some extent, broader development tools such as primary schools, paved roads, higher wages and overall development complement the above approaches.

Overall we find strong evidence that market factors can raise the opportunity cost of time and therefore lower fuelwood collection from forests. We note that our results reflect household decisions given the current market structure, that is, without an active market for fuelwood. As pointed out by reviewers, substantially increasing market opportunities could lead to the development of a fuelwood market and displacement of fuelwood pressure to other forests.[15] Thus, increasing market opportunities should be part of a policy package that also supports alternatives such as stoves and planted trees; park staff activity such as enforcement of park boundaries; and development infrastructure such as roads and schools.

Our study shows that access to forests for fuelwood is substantively important to local people. Consistent with the sustainable development paradigm in which ecological protection occurs in tandem with economic growth, we also find that improved economic conditions that increase household wealth and raise opportunity costs could reduce household dependence on fuelwood from forests and, thereby, potentially reduce forest degradation. This conclusion is supported by the coefficients on wealth variables in all three models (alternative and forest fuels, travel cost, forest collection trips). Household attributes, forest quality, park management, and development infrastructure and opportunities all have discernible

[15] Questions of this nature are better addressed through general equilibrium models that investigate changes in several markets, and/or panel data sets that consider the dynamics of behaviors and policy impacts.

influences through the shadow price of and alternatives to fuelwood collection from forests. By encouraging credible alternatives, enhancing returns to labor, and improving public infrastructure, policy makers could use the demonstrated economic rationality of farming households to reduce fuelwood collection and encourage households to see the forests for more than just the fuel.

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