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Policy Options

Reducing degradation of forests in poor countries when permanent solutions elude us: what instruments do we really have?

RANDALL A. BLUFFSTONE
Harvard Institute for International Development, 14 Story Street, Massachusetts 02138, United States, E-Mail: rbluffst@hiid.harvard.edu

ABSTRACT. This paper evaluates policies for addressing forest degradation in developing country hill areas, where agriculture is the major activity and villagers depend on forests for important economic inputs. Population growth, poverty, and open access probably explain most 'overuse' in such areas, but these are very difficult, long-term problems. The paper argues that under such conditions interim demand-side policies should be seriously considered, but the case is also made that the set of feasible instruments is quite small. Focusing on the case of Nepal, two instruments for reducing fuelwood demand – promotion of more efficient, wood-burning cookstoves and policies that reduce the prices of alternative fuels (e.g., through subsidies) – are evaluated. Using a simple analytical model and results from two household surveys conducted in Nepal, it is concluded that promoting improved stoves is a much more efficient and equitable instrument than, for example, subsidizing the major alternative fuel, which is kerosene. The cost of fuelwood saved using improved stoves is predicted to be a very low $2.77 per metric ton.

1. Introduction

Various authors have explored reasons for forest degradation and deforestation in developing countries, including chaotic political environments (Deacon, 1995), government policies that explicitly encourage land expansion (Mahar, 1989; Repetto and Gillis, 1988), open access (Ostrom, 1990, 1995), poorly functioning labor markets (Bluffstone, 1995) and poverty that, combined with ambiguities in property rights, causes people to heavily discount the future (Dasgupta, 1996; Dasgupta and Maler, 1993;

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Larson and Bromley, 1990; Perrings, 1989). This paper focuses on identifying and evaluating policies for addressing the forest degradation that often occurs in developing country hill areas, where agriculture is the major activity. In such areas, farmers depend on forests for nutrient transfers to agriculture because of low soil productivities, as well as for other economic inputs, such as fuelwood, wood construction materials, fodder and animal bedding. Fuelwood is often a particularly important demand on forests. About three billion people worldwide cook with fuelwood (Kammen, 1995) and one source estimated that 80 per cent of all wood felled in developing countries is used for fuel (Xinhua News Agency, 1986). Often fuelwood is available to villagers through open access regimes, and the problem of access is surely a factor leading to reduced forest quantity and quality.

The regions of interest in this paper are ones where intensive agriculture is practiced and deforestation is therefore primarily not a question of land expansion – the extensive margin is more-or-less exhausted – but of day-to-day demands by households for key complements with *existing* agricultural land and for inputs needed to process agricultural production. This type of deforestation/degradation is quite common in poor areas of South and East Asia, as well as East Africa and Central America. While not explaining large worldwide forest losses – land expansion for agriculture and grazing is almost certainly more important – these losses arguably affect the largest number of people.

Of course, reliance on the natural environment is not itself the problem. Policy issues arise when harvests exceed the growth of forests on public lands and there is no efficiency-based reason why that should occur. Three interrelated factors, population growth, poverty (exacerbated by poorly functioning labor markets) and open access to forests probably explain the majority of any ‘overuse’ I am concerned with in this paper.[1] Poverty and runaway population growth are perhaps two of the most fundamental and difficult policy problems that exist, but even addressing the much more restricted issue of substituting common or private property for open access is not so easy.[2] As noted by Dasgupta (1996), privatization of key resources like forests is typically not seriously considered, and indeed technological indivisibilities may preclude their privatization. Examples of such indivisibilities include cases where forests are primarily degraded by grazing animals that require easements to reach distant grazing areas, and when smaller plots would result in more intensive grazing. Private property may in any case not improve resource management, because tradability of property rights can increase uncertainty, reduce interdependence, and shorten time horizons (Runge, 1981; Seabright, 1993). Greater dependence on open access resources by poor people in South Asia may also impose

[1] For discussions of these complex issues see, for example, Ostrom (1990), Dasgupta and Maler (1993), Dasgupta (1992), Dasgupta (1996), Hanna *et al.* (1995), Bluffstone (1995).

[2] Ostrom (1995) provides an excellent conceptual discussion of the complexities of constructing communal management and the context-specific nature of such systems.

major political barriers to changing access regimes. In the Indian states of Gujarat, Maharashtra, and Rajasthan, for example, no less than 66 per cent of all fuel requirements of the rural poor came from open access forests, compared with a maximum of 23 per cent among the non-poor. Income derived from such resources was approximately 20 per cent for poor households versus 1–3 per cent for others (Jodha, 1990).

It is also likely that without progress on the other two issues that the creation of common property will be particularly difficult. As Hanna *et al.* (1995) note: 'Property rights have failed in the past and are continuing to fail when overwhelmed with ... population growth and increased per capita demand for resources.' In Nepal, which is the focus of this paper, recent experience with re-establishing local common property management after the nationalization of forests in 1957 has indeed been decidedly mixed. The predominance of women and children as gatherers of forest products – and the virtual absence of these groups from decision making – also probably interferes with the development of common property, except in areas of acute scarcity, where it is reportedly of more interest. Pradhan and Parks (1995), quoting Gilmour (1988), for example, note that 'as long as ample forest resources are available, there is practically no interest in protecting or managing forests'. Swallow and Bromley (1995) suggest that such issues are not peculiar to Nepal, and they point to several cases where grazing associations in Africa were unsuccessful or difficult to establish.

This paper examines some of the short- and medium-term policy alternatives that are available while more fundamental issues are being addressed. The next section highlights some of the specifics of the Nepal case and discusses the efficacy of various policy instruments for addressing the problem of forest degradation. It is argued that within such a context, subsidy policies are really the only feasible options. Using a simple behavioral model, section 3 focuses on two demand-side policy regimes, policies that reduce the prices of non-wood fuels,[3] and promotion of more efficient wood burning cookstoves.

Section 4 simulates this model and it is found that while both policies are likely to reduce losses of forest biomass – and indeed the magnitudes to be expected from these tools are roughly similar – important differences in economic efficiency and distributional impacts are predicted. Indeed, the non-wood fuel subsidies will mainly benefit higher-income groups and, though not analyzed in detail, the economic distortions from those subsidies are expected to be quite large. For these reasons, technology policies are preferred as long as improved stoves save wood as expected, are acceptable to villagers, and subsidy costs are reasonable. Section 5 there-

[3] For simplicity, and because it reflects the reality of the Nepali situation, this policy will be called a subsidy. It should be recognized, however, that what is important is the price decline. In contexts where energy is highly taxed, a reduction in taxes would have the same behavioral effect, though the social costs would be lower than with a subsidy policy. Subsidies, of course, create deadweight losses, while energy tax reductions may have net social benefits. This is particularly likely if energy taxes are relatively high-cost revenue policies.

fore examines these questions using household survey data. Based on these results it is concluded that not only are technology policies preferred, but they probably also give extremely good value for the money.

2. Some specifics of the Nepal case

Nepal certainly fits the profile of an agro-forestry dependent, poor, high population growth country. In 1994, 87 per cent of the population lived in rural areas and most were subsistence farmers. Average annual population growth during 1990–94 was estimated at 2.5 per cent and in 1994 per capita income was $200. With a population twice that of the Czech Republic, Nepal's national income was one-sixteenth as large (World Bank, 1996). The approximately 21 million Nepalese live in a country that is roughly the size of the US state of Tennessee, on a landscape that is approximately three-quarters mountainous. It is this mountainous portion of the country that is the focus of this paper.

In terms of forest resources, while a substantial portion of the flat, southern *Terai* belt has been cleared for agriculture, most of the middle hills (altitudes of 2,000–10,000 feet above sea level), where about 55 per cent of the population lives, remains forested. Though in the 1970s and early 1980s many worried about the complete deforestation of the hills of Nepal, in reality forest area has probably changed relatively little during the past 15 to 20 years (Virgo and Subba, 1994; Wallace, 1987). Between 1983 and 1993 it is estimated, for example, that the total area of forest and woodland in Nepal increased by 4.4 per cent (World Resources Institute, 1996). This is not to imply that forests are terribly lush. Forests are typically very thin, and if areas have been stable or increasing over time the proportion of pine trees has also expanded at the expense of deciduous species, reducing the capability of forests to provide fodder and high-quality fuelwood to villagers (Schreier *et al.*, 1994).

As is true throughout South Asia, forest resources are closely linked with food production and preparation, because villagers rely on cattle and buffalo for traction and dung fertilizer, and they cook with fuelwood. In the middle hills it is indeed unlikely that hill agriculture would be possible on a long-term basis without the manure generated by large ruminants (Schreier *et al.*, 1994; Simmons, 1989). Households living in the hills are therefore understandably reluctant to use manure, and to a somewhat lesser extent crop residues, for fuel. Large animals are also important because households sell a variety of animal products. Over 90 per cent of households cook with wood and a similar percentage of fuelwood is used for household cooking (Shrestha, 1986; Amacher, Hyde, and Joshee, 1991).

In the early 1980s it was believed that loss of forest cover in the hills had substantial downstream effects, even affecting river levels in Bangladesh. More recently, however, these notions have been called into question (e.g., Metz, 1991). The effect of forest degradation on households is not, to my knowledge, in dispute. Depending on the season, households might devote up to five hours per day to fuelwood gathering and another ten hours per day to fodder collection and grazing. Certainly since the 1960s these time costs have expanded substantially, diverting more of household members' energies into these activities. These increased burdens have also fallen disproportionately on women and children who are more involved with natural resource-based activities than men (Acharya and Bennett, 1983; Bluffstone, 1993; Hotchkiss and Kumar, 1988). It is these effects of forest degradation on households – primarily working through labor supply decisions – that are of principal interest in this paper.

In previous work the demand for fodder and grazing in hill areas was at least partially analyzed. The main result was that availability of off-farm income is crucial for creating incentives to reduce herd sizes, and policies that improve the performance of rural labor markets are therefore likely to be particularly important (Bluffstone, 1995). This paper therefore focuses exclusively on the demand for fuelwood in the middle hills.

From the perspective of individual Nepali villagers, access to fuelwood (and also fodder and grazing area) is normally open. This does not imply that villagers can take all the forest products they want, but it does mean that for normal household uses controls are generally few. Though forest management has almost certainly improved during the past decade, with more management of forests being delegated to local areas (e.g., see Fox, 1993),[4] supervision of forests is still relatively weak. I am not, however, aware of any comprehensive evaluation of the scope and effects of changes in management, and therefore it is likely that the actual effects to date of these promising institutional changes are at least uncertain.

3. What interim instruments do we have?

What are some policy instruments to complement long-term efforts to reduce population growth, poverty, and open access in Nepal? Optimal user fees might seem attractive, but they are likely to be infeasible because enforcement costs are so high. For example, imagine the costs of collecting an optimal cattle tax to discourage large animal overstocking in Nepal. Even stumpage fees are likely to be very difficult to collect in low-income countries because of monitoring difficulties (Soussan, Mercer, and O'Keefe, 1992).

I would argue that while the fundamental, intertwined problems of poverty, rapid population growth, and open access are being addressed over time, we are in a world in which the best instruments available are ones that improve the use of natural resources while simultaneously distorting markets or requiring the use of public funds. Often such instruments are termed 'second best'. Within the realm of second-best *demand-side* policies, which are the focus of this paper, economic instruments are most attractive, because they allow agents flexibility to adjust to policy incentives (Hahn and Stavins, 1992). For example, rationing access to forests in Nepal would probably be less efficient than a reasonable system of economic incentives for the same reasons performance standards are less efficient than charges and tradable permits for controlling pollution. While it is recognized that supply policies like developing fuelwood markets and promoting private and public plantations are

[4] At *http://www.info.usaid.gov/countries/np/success/success3.htm* there is a description of USAID's efforts and successes with community forestry in the Rapti Zone in western Nepal.

potentially important in the poor country contexts of interest here, analyzing these instruments is left to others and for future work.

As Deacon (1992) pointed out, there are three major classes of economic instruments that might be considered second-best interventions. First, excise tax and subsidy policies can be used to alter the consumption of goods that use natural resources as inputs. For example, when kilns in Nepal are fired by wood, a brick manufacturing tax might be used to reduce over-harvesting of fuelwood. Such a tax, of course, carries with it the usual disadvantage that the demand for all other inputs to produce bricks will be distorted. Also, when wood is used as an input into a non-marketed good (e.g., home-cooked food), this type of tax is not an option. As was already discussed, in Nepal most wood is cut for fuelwood and most of this wood is used by the collectors for household cooking.

Alternatively, tax differentiation may be used to alter the equilibrium quantity of substitutes for forest products. For example, in Nepal fuelwood use may be reduced by decreasing taxes or increasing subsidies for producers or consumers of the major alternative fuel, which is kerosene.[5]

Yet another potential second-best intervention is to tax or subsidize the purchase of complements in the consumption of fuelwood. Because incomes are so low and demand for fuelwood is so tied to food consumption, taxing, for example, inefficient cooking stoves is really not a viable option. Instead of taxing inefficiency, since the 1970s the emphasis has been on supporting the adoption of improved wood burning cookstoves for household use. Many of the early programs (early to mid-1980s) failed, but recent efforts have been more successful as the importance of catering to user preferences has been recognized.

The last two policies are perhaps the only real possibilities, and both are subsidies. Both these instruments have been used internationally, and both have at best mixed reputations. Energy subsidies, for example, even if they are for environmental purposes, can generate distortions in the overall structure of energy demand. Important factors in evaluating such policies therefore include the subsidy level to achieve ecological objectives, the degree of substitutability of alternative fuels with fuelwood, whether there are many uses for the alternative fuel, the ability of the government to target the assistance, and the level of transactions costs. As Pitt (1985) pointed out with regard to the Indonesian case, the use of kerosene subsidies also generates distributional problems, because they typically go to higher-income households.

There is also extensive experience with the promotion of improved stoves, not only in Nepal, but throughout the developing world. These programs earned somewhat of a bad reputation during the 1970s and 1980s, but this has changed as designs have improved and large successes have occurred in China, where over 65 per cent of rural households regularly use approximately 130 million improved stoves (Smith *et al.*, 1993; Chege, 1993). Over 500,000 stoves are also in use in Kenya.

[5] It is generally agreed that in Nepal kerosene would be the likely alternative to fuelwood (Field, 1993; Fox, 1993; Gregersen *et al.*, 1989). This is also true in other countries, such as Haiti (Hosier and Bernstein, 1992).

The reasons that many stove programs failed have also been analyzed, and it is now recognized that it is not improved stoves *per se* that are inappropriate, but poorly engineered, poorly promoted, and poorly serviced stoves (Kammen, 1995). It has also been recognized that urban areas where households buy fuelwood are an easier sell than rural households where wood is collected (Bluffstone, 1989; Chege, 1993).

In Nepal, the most extensively promoted cookstove is the *New Magan Chulo*, which was originally developed by UNICEF and introduced in Nepal in 1981. Other designs also exist, but they are broadly similar (Sulpya, 1989; Catterson and Bhattarai, 1988). Improved cookstoves promoted in Nepal are estimated to be 35 per cent more efficient than traditional stoves (Bluffstone, 1989; Sulpya, 1989). Similar percentages were saved by improved charcoal stoves (so-called *jikos*) in Kenya (Kammen, 1995; Chege, 1993).

The *New Magan Chulo* is a ceramic insert stove that is manufactured by skilled potters, who also install the stoves. It has typically been promoted with a chimney that offers improved indoor air quality compared with traditional stoves that vent smoke inside homes. During installation, the *New Magan Chulo* is surrounded by clay and rocks to give the appearance of the standard *chulo*.

The next two sections examine the workings of these two subsidy instruments within the context of a simple household model.

4. Model of a representative household agro-forestry system

A representative household in the model is a small user of open access forests, a price-taker in all markets, and engages in productive activities using only one variable input, homogeneous household labor. This endowment is optimally allocated between four activities: cutting fodder and grazing cattle in forests, non-stochastic agricultural production, fuelwood collection, and non-deforesting off-farm work. Though not incorporating all categories of work, depending on gender and ethnic group, these activities represent 63–99 per cent of Nepali villagers' working time (Acharya and Bennett, 1983).

Villagers obtain fuel from two sources, purchasing kerosene and collecting fuelwood; private woodlot production is assumed to be suboptimal. Households can work a continuous number of off-farm hours at an exogenously determined wage rate and can earn cash from the sale of animal products. Likely opportunities for work include cottage industry, local wage labor, and seasonal migration, primarily to India. Seasonal migration is particularly important in the hills of Nepal. Villagers spend incomes on a non-wood fuel and grains to be cooked at home.

A representative household is assumed to maximize the present discounted value of utility, which is a function of the consumption of cooked food.[6] Households view the dynamics of the time price of forest products

[6] Other goods are not included, because purchases of non-food products are minimal in the hills of Nepal and incomes are quite low (Nepal Bank Limited, 1985). Leisure is not included, because work days are on average 9–12 hours per day (Acharya and Bennett, 1983).

as being unaffected by their choice variables, because they are small and collect within open access systems. They therefore take time paths as *given* and solve essentially static optimization problems. Maximizing the present discounted value of utility in (1) therefore simply implies the maximization of $U(F_t)$ for each period t

$$U = U(F_t) \tag{1}$$

This maximization takes place subject to four constraints that hold for all time periods

$$F_t = F(E(T_t^E, S_t) + e_t, g_t + G_t) \tag{2}$$

In (2) cooked food (F_t) is an increasing function of fuelwood collected (E) and kerosene purchased (e), both denominated in energy units, and the sum of purchased (g) and home-produced (G) grains.[7] Purchased and home-produced grains are perfect substitutes as are the two fuels. The amount of fuelwood collected depends only on labor supply (T_t^E) and the state of forests (S_t), which is defined as the time required to gather one kilogram of fuelwood. This deforestation measure also captures the cost of fodder, because fodder and fuelwood extractions are interdependent. For example, branches that are used for fuelwood are cut at the same time fodder is harvested

$$wT_t^L + P^m m(M(f(T_t^A, S_t))) = P^e e_t + P^g g_t \tag{3}$$

In the budget constraint (3) cash incomes are earned from off-farm labor (T_t^L) at a rate w, and cattle raising, which produces 'milk' (m) sold at price P^m. Milk production is a function only of the number of cows raised (M), which depends on fodder production (f); f is then assumed to be a function of time allocated to animal raising (T_t^A) and the state of forests. In this model cattle do not fulfill a savings or insurance function. $E(.)$, $M(.)$, $m(.)$ and $f(.)$ are increasing in labor supplied (T_t^i) and decreasing in the level of deforestation (S_t). The inverse functions of M and f are assumed to exist.

In (4) grain production (G) is a strictly increasing, concave function of labor (T_t^G) and the number of cattle equivalents (M) held for fertilizer and milk production.

$$G_t = G(T_t^G, M(f(T_t^A, S_t))) \tag{4}$$

The time constraint (5) is defined as a fixed endowment (T hours) available to households. As was already mentioned, there is no leisure in the model because work days are generally quite long; the labor–leisure tradeoff is therefore not particularly interesting

$$T = T_t^G + T_t^E + T_t^L + T_t^A \tag{5}$$

Substituting (2) and (4) into (1), we formulate the Lagrangian (6) maximized by the representative household for each time period t. Households optimize over their uses of labor and consumption of purchasables, yielding six first-order conditions.

[7] Grain consumption occurs at all meals and provides a reasonable index of total food intake.

$$L = U(F_t(E(T_t^E,S_t) + e_t,g_t + G(T_t^G,M(f(T_t^A,S_t)))))$$
$$+ \lambda_{1,t}(T_t^L - \frac{P^e e_t + P^g g_t - P^m m(M(f(T_t^A,S_t)))}{w}) + \lambda_{2,t}(T - T_t^G - T_t^E - T_t^L - T_t^A) \quad (6)$$

Four manipulations of the first-order conditions are of particular interest

$$\lambda_{1,t} = \lambda_{2,t} \quad (7)$$

$$\frac{\frac{\partial F}{\partial G}\frac{\partial G}{\partial T^G}}{\frac{\partial F}{\partial E}} = \frac{w}{P^e} \quad (8)$$

$$\frac{\frac{\partial F}{\partial E}\frac{\partial E}{\partial T^E}}{\frac{\partial F}{\partial F}} = \frac{w}{P^g} \quad (9)$$

$$\frac{\partial M}{\partial f}\frac{\partial f}{\partial T^f}(\frac{\partial G}{\partial M}P^g + P^m) = \frac{\partial G}{\partial T^G}P^g = \frac{\partial E}{\partial T^E}P^e = w \quad (10)$$

Equation 7 indicates that in this model the shadow price of money is equivalent to the shadow value of time. In (8) and (9) we see that households allocate incomes and time to the point where the ratios of the marginal products equal the relevant price ratios. In each case the price of time is the wage rate. In (10) the household hires itself for the three on-farm activities and this is done with respect to the wage rate, as would occur if the household was hiring-in labor. This result suggests that labor market performance is a key determinant of on-farm labor supply, and implies that it is unnecessary to explicitly include a labor market.[8]

From the last equality in (10) we know that households gather fuelwood until the optimal hiring condition is fulfilled. We can therefore define wage levels for all prices of alternative fuels and fuelwood collection technologies ($w^* = P^e - \partial E/\partial T^E$) such that households purchase kerosene. Because households are price takers, w and P^e are exogenous. If we also assume users are small and collect under open access, $\partial E/\partial T^E$ is also a constant, which generates two distinct fuel regimes in which households either collect fuelwood or purchase kerosene depending on the condition given in (11). Households will not use both fuels simultaneously

$$\begin{matrix} E > 0 \\ e \end{matrix} = 0 \text{ iff } P^e\frac{\partial E}{\partial T^E} > w$$
$$\begin{matrix} E = 0 \\ e \end{matrix} > 0 \text{ iff } P^e\frac{\partial E}{\partial T^E} < w \quad (11)$$

A representative village is now defined as being made up of several households differentiated by the wage rate available to them. The distri-

[8] More details on this point are available in Bluffstone (1995).

bution of income is important, because from (11) we know that wage levels determine whether households gather fuelwood or buy kerosene. For simplicity, a bi-modal distribution is assumed, with two-thirds of the households in a low-wage labor market (the 'poor') and one-third having wages that are 10 per cent higher (the 'rich'). The magnitude of the wage differential does not affect the substance of the results, but varying the distribution will affect the magnitude of the conclusions drawn in the following section.

The distribution assumed is derived from a nationwide survey of incomes sponsored by the Central Bank of Nepal during the period 1983–1985. Using the data from several villages in one hill district (Salyan) located in Rapti Zone in western Nepal, it was found that rural incomes are not terribly unequal. Depending on the village, wages 10 per cent above the mean would put households in the 60–80th percentile of the wage distribution (Nepal Bank Limited, 1985). Though there are certainly more than two wage levels in rural Nepal, it is believed that the bi-modal distribution captures the most important features of the distribution: most people are 'poor', and being 'rich' does not mean a dramatically higher wage.

Given this wage distribution, total village forest biomass harvests (H_t) are the sum of harvests (measured in kilograms) of fuelwood (H_t^E) and fodder (H_t^f) of each of the two wage-earning groups. Logistic growth functions $G(X_t^E)$ and $G(X_t^f)$ that depend on the stocks of each type of biomass are assumed to capture the dynamics of forest growth. The superscripts *f* and *E* refer to fodder and fuelwood energy respectively.

Given that growth and harvests occur simultaneously, the time path of the biomass is governed by (12), with the change in the overall biomass stock defined as the sum of these two equations

$$X_{t+1}^E - X_t^E = g(X_t^E) - H_t^E$$
$$X_{t+1}^f - X_t^f = g(X_t^f) - H_t^f \qquad (12)$$
$$S_t = bX_t^{-\psi}$$
$$0 < \psi < \infty \qquad (13)$$

The link between this changing biomass stock and the availability of forest products (defined as the time required to gather one kilogram of fuelwood) is made in (13). This form was chosen because it is continuous and convex, which is probably close to the actual relationship between stock levels and time costs, and it also maps extreme values of X_t into S_t in a sensible fashion; in particular, as X_t approaches zero S_t nears infinity and as X_t approaches infinity S_t goes to zero.

Creating the analytical separation between wood and leaf biomass types described in (12) allows more distinct analyses of the time paths of each resource and also allows growth rates to differ. It also incorporates the reality that demands for fodder and fuelwood are relatively independent.[9]

[9] Such a specification also admits the possibility that there can be living trees made up exclusively of leaf or wood biomass. Such a case is unlikely if prices and parameter values are reasonable, because deforesting behavior is determined by the *overall* state of forests.

As already noted, linking the demand for fuelwood and fodder with the *overall* biomass stock through S_t also partially captures the reality that leaves on branches cut for fuelwood are used for fodder and not simply discarded. Defining the endowment of forest products in time $t + 1$ (X_{t+1}) as the sum of wood and leaf biomass, using (12) and (13) we can also define S_{t+1} in terms of X_t, forest growth and current harvests of fodder and fuelwood.

5. Simulations of the effects of price and technology policy on forest biomass stocks

An explicit form of the household model, as well as the technological parameters, prices, and starting endowment levels used for the simulations, are presented in the appendix to this paper. The behavioral model was solved analytically in terms of the exogenous variables and combined with the model of forest growth to analyze the dynamics of the agroforestry system.[10] One period is assumed to be a maize cultivation season.

With a few exceptions, parameters and prices were either computed directly or estimated econometrically using data from the 1982/83 Nepal Energy and Nutrition Survey (NENS) conducted by the Agricultural Projects Services Center (APROSC) of Kathmandu and the International Food Policy Research Institute (IFPRI) of Washington DC. These data are cross sectional for 120 households in three villages in north-central Nepal, and the typical village simulated is a composite of these three villages. Initial endowments of fuelwood and fodder are taken from the work of Soussan *et al.* (1991) in eastern Nepal. Forest growth parameters are computed using Southwick (1976) and Ricklefs (1983).

The model was calibrated such that at the start of the base case simulation the value of S_t was exactly at the mean of the NENS data for the maize season. Fuelwood and fodder collections were both greater than biomass growth. Fodder collections were 40 per cent greater than leaf biomass replacement and fuelwood collections were 20 per cent more than wood growth. With these initial conditions, the household optimizes. The labor supply pattern emerging from this maximization problem, of course, has implications for forests, because it includes an allocation for fuelwood and fodder collection. Forest stocks change in response to those pressures, altering the variable S_{t+1} and influencing the labor supply pattern in period $t + 2$. The simulations were conducted in this manner for a representative village having the income distribution discussed above.

In Figures 1–3, simulations are presented that compare the base case with one in which the State intervenes by subsidizing kerosene such that the one-third of the population enjoying 10 per cent higher wages finds optimal a shift to purchased fuels. *It is found that a subsidy of 80 per cent*[11] *is required to cause high-wage households to shift to kerosene.* This result is, of course, dependent on the assumption that 'high-wage' is defined as a wage 10 per cent above that of the 'poor'. For example, if the 'rich' had access to higher wages than assumed, subsidy needs would be lower. Though

[10] Reduced-form solutions are available from the author.

[11] From Rs.67 to Rs.13 per liter fuelwood equivalent.

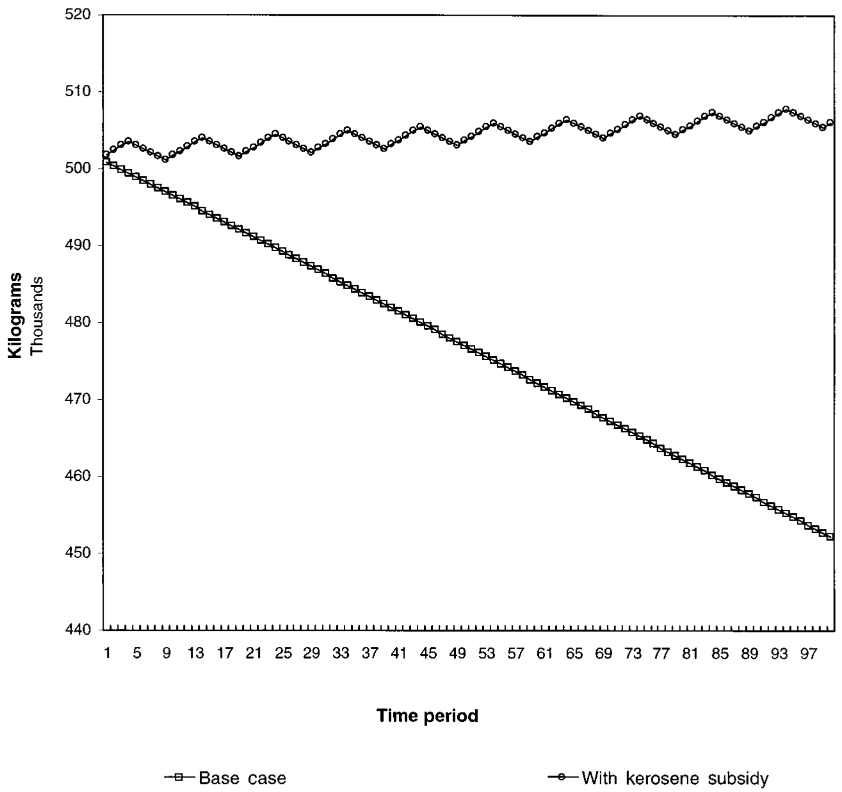

Figure 1 *Wood biomass stock: base case and with kerosene subsidy*

case specific, the result does suggest that given current policies, for most people living in the hills of Nepal the energy transition is perhaps not imminent.

In figure 1 we see that compared with the base case a kerosene subsidy substantially improves 70 per cent of the biomass that is wood. In fact, wood biomass actually *increases* over the 50-year horizon. Without the subsidy the stock of wood declines by 10 per cent, a result that corresponds rather well with the estimates for forested area quoted in section 2 that forests have been relatively stable over the past 15 years.

Figure 2 shows that the improvement occurs because total village fuelwood collections oscillate between the consumption level associated with the base case and an amount one-third lower. This cycle occurs, because once kerosene is cheaper than fuelwood, high-wage households withdraw their labor from fuelwood collections and move it off-farm where there are no diminishing returns.[12] Forests therefore regenerate, ultimately reducing

[12] It may be questioned whether, given the inconveniences of cooking with wood, high-wage households would ever cook with fuelwood. Leach (1992) notes that urban households in Pakistan with annual incomes as high as $18,000 used wood because it was so cheap and accessible. In the city of Kathmandu fuelwood use is also quite common.

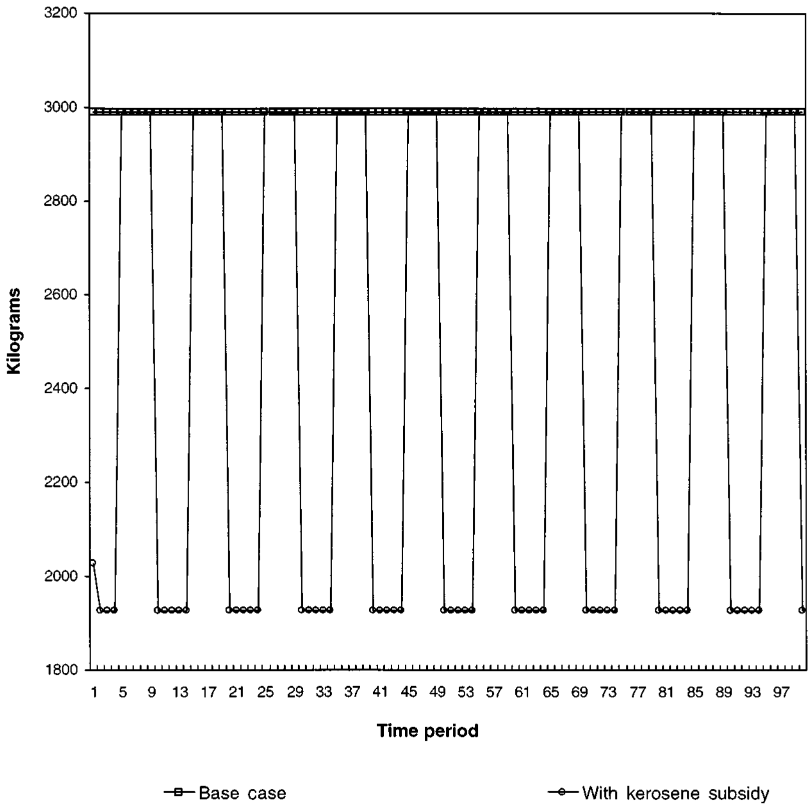

Figure 2 *Total village fuelwood collections: base case and with kerosene subsidy*

S_t to the point that the condition for fuel purchase is no longer satisfied. The predicted frequency is 12 periods.

Figure 3 shows that with the kerosene subsidy over time the forest biomass stays approximately stable. But this result is very sensitive to the definition of 'high wage', and if the high-wage group was smaller, pressure on the forest might be reduced only marginally, causing degradation to continue, albeit at a slower rate than without the kerosene subsidy.

This pattern of withdrawal and re-entry by high-wage households creates an improved forest environment that indirectly benefits the 'poor' who continue to depend on forests for fuelwood, and who are also more involved with animal raising than those with access to higher wages. The improved status of forests reduces their costs of fodder collection and will cause them to raise more animals in equilibrium. Increased animal holdings by the two-thirds of all households who are poor then adversely impacts leaf biomass stocks.

Figures 4–5 show the effects of a policy to promote stoves that allow the cooking of 35 per cent more food with a given amount of fuelwood.[13] It is

[13] Using the notation from table 1 in the appendix, this intervention is modeled as an increase in the parameter a_2 from 0.14 to 0.19.

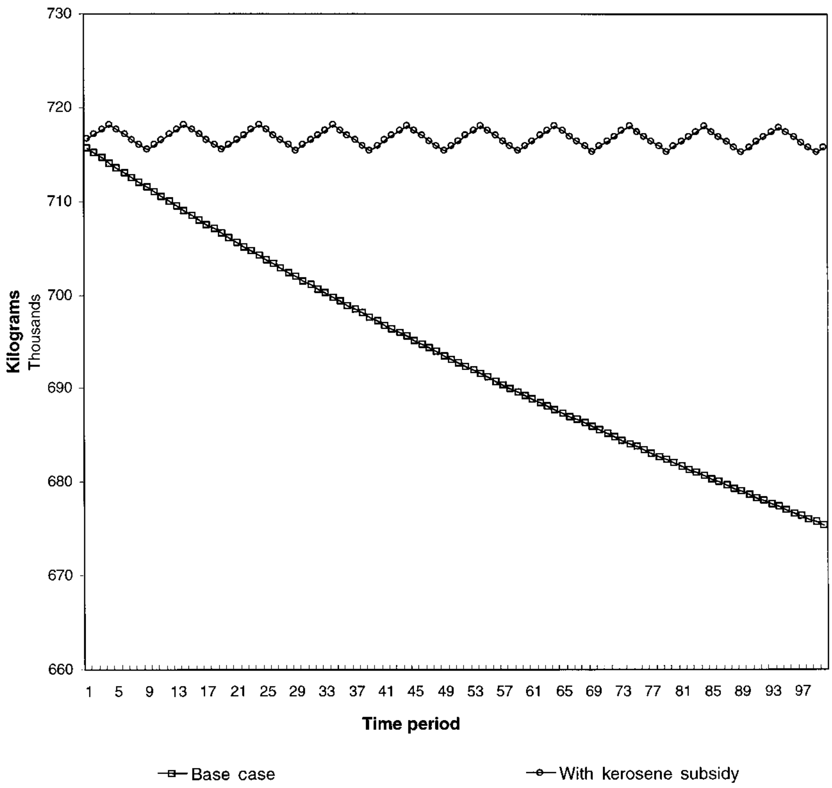

Figure 3 *Total forest biomass: base case and with kerosene subsidy*

assumed that the State fully subsidizes the program. Households enjoy the benefits of the improved technology in terms of increased food consumption and, as shown in figure 4, a 25 per cent lower level of fuelwood collections. With collections reduced, the wood biomass stock rejuvenates, ending in the final season with approximately 6 per cent more biomass than under the base case (figure 5). A reduced fuelwood demand of this magnitude then causes the time path of the forest biomass to be virtually flat rather than downward sloping. This result is virtually the same as in the kerosene subsidy case.

With the overall forest biomass stable over time, the time price of forest products also remains constant. Fodder collections therefore do not decline and the time path of the leaf biomass is everywhere lower than in the base case. This indirect effect is expected to be relatively small, however, with a predicted leaf biomass stock in the final period 10 per cent lower than in the base case.

The improved stove results are quite similar to those of the kerosene subsidy, but the way this policy works is quite different, because it is essentially technical progress that increases households' labor endowments. This is different than price policies that induce reallocations of labor out of deforesting activities. Put in other terms, technology policy is an

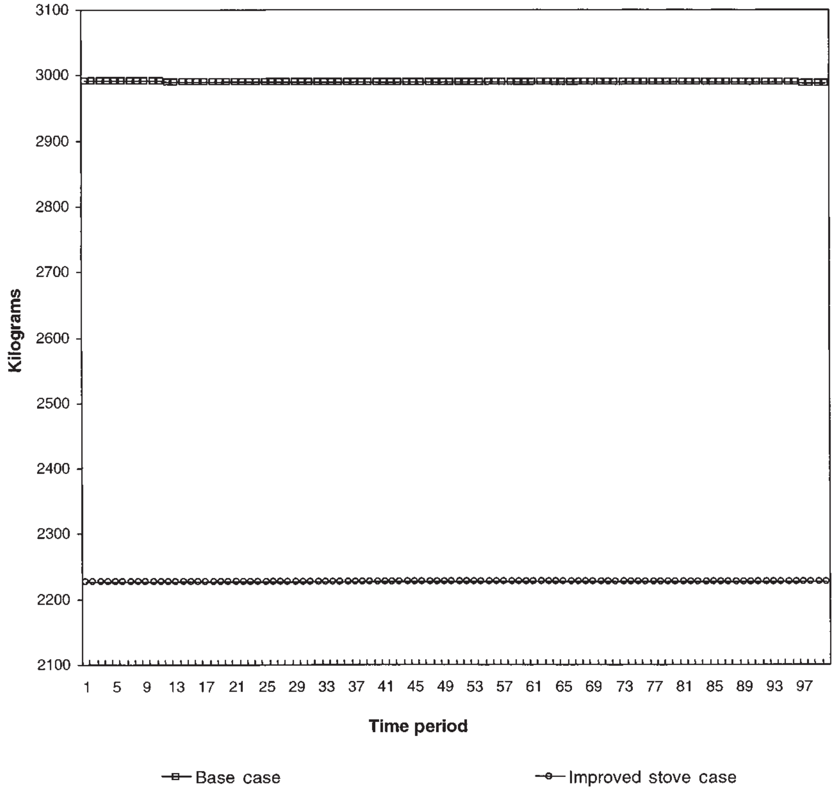

Figure 4 *Total village fuelwood collections: base case and with improved stove subsidy*

incomes instrument and price changes are *switching* policies. Price policy therefore carries with it the usual distortions. Because households allocate increased labor endowments to highest value uses, there should be no particular price distortions associated with technology policies. The efficacy of technology policy therefore rests primarily on three criteria: (1) achievement of ecological objectives compared with alternative instruments; (2) acceptability of technologies; and (3) level of subsidies necessary and the opportunity cost of public funds. In the next section a currently available stove, the *New Magan Chulo,* is evaluated on these three bases.

6. Evaluation of potential policies with particular reference to promotion of the *New Magan Chulo*

The purpose of this section is to compare the economic costs of the two policies discussed above. As illustrated in the simulations, the effects of price and technology policies on forest stocks in Nepal are predicted to be quite similar. Both cause labor to shift out of fuelwood collection and into off-farm work, and increase herd sizes. Both policies increase real incomes in rural areas and help conserve forest biomass. Offsite benefits (e.g., erosion control) may also exist in some areas.

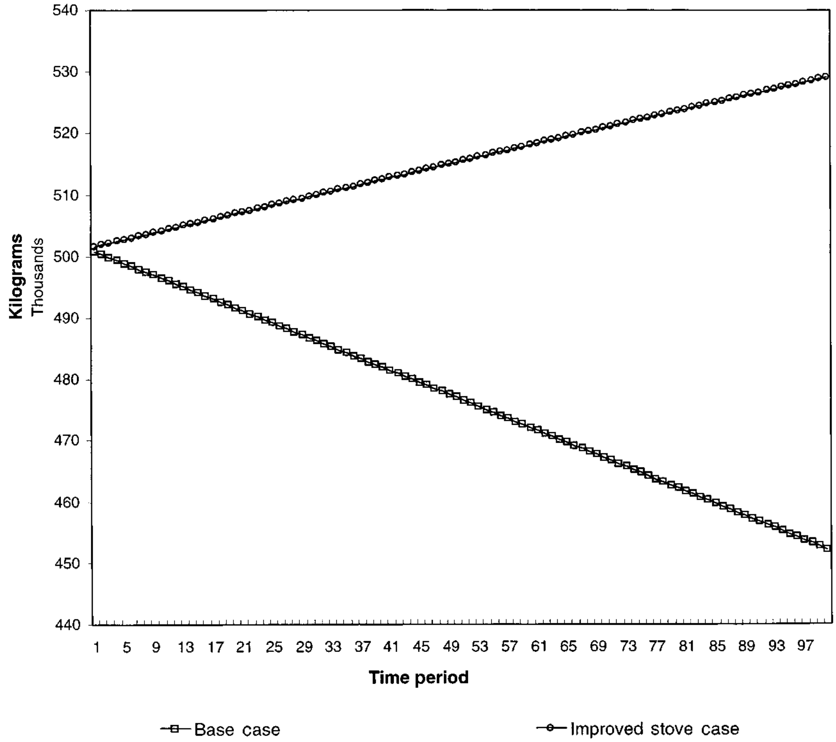

Figure 5 *Wood biomass stock: base case and with improved stove subsidy*

The economic costs of intervening in kerosene markets are likely to be much higher, however, because kerosene may have to be subsidized on the order of 80 per cent to cause richer households to switch fuels. This means it will cost approximately $160 per year, or 80 per cent of average annual per capita income, to subsidize one household.[14] With a subsidy of that magnitude denominated in dollars, and given the difficulty of limiting the subsidy to rural households, it is indeed questionable whether any welfare gain will occur from such a policy. Also, there are distributional problems associated with such subsidies, because it will be high wage earning, high opportunity cost households, probably living in urban areas, who will be the first to switch from fuelwood to kerosene.

How does this seemingly high-cost policy compare with the use of technology policy? To answer this question, the performance of the *New Magan Chulo* was evaluated using the results of a June 1989 survey of 43 improved stove-using households located in three middle altitude villages in Salyan District.[15] Mean household size in the sample, defined as the number of individuals eating from one stove, was approximately eight people and 84 per cent of all interviews included women. All households received a *New*

[14] Assuming usage of 390 liters per household per year and a cost of $0.50 per liter.
[15] A copy of the survey is available from the author.

Magan Chulo in 1984 or 1985 either through purchase or free distribution by the Government of Nepal.

By 1989, over half those surveyed were no longer using their stoves, largely because the ceramic inserts had cracked, but over half of those who abandoned their stoves used them more than two years. The mean stove lifetime was approximately two and one-half years.[16] Sixty-five per cent of those interviewed purchased fuelwood in the local wood market and the remainder collected it themselves. Two-thirds used the stoves for all household cooking.

The *New Magan Chulo* indeed saves wood. Users reported reduced wood consumption averaging 1,530 kilograms per household per year. This is equivalent to a 37 per cent average savings compared with traditional stoves, an estimate that is very similar to those quoted in Joshee (1986) and Wallace (1987), and also similar to estimates from Kenya. Interviewees were also surveyed regarding the advantages and disadvantages of the stoves. A significant minority of respondents (28 per cent) cited no disadvantages. Most of the majority that did see disadvantages focused on the small firebox, which not only limited the amount of wood used, but also slowed cooking and made grilling of breads difficult. Nearly all those surveyed perceived advantages either in terms of reduced fuelwood consumption or improved indoor air quality, because of chimneys that were distributed with stoves.[17]

Almost two-thirds pointed to the smokeless feature as being most important. That this percentage was so high and also relatively constant whether households collected or purchased fuelwood suggests that indoor air quality is considered a very serious problem.[18] It is also a somewhat difficult issue to address in Nepal, where gender issues are important. Whereas women mainly bear the costs of air pollution in kitchens, money is often controlled by men. That most households did not cite wood savings as most important also perhaps suggests that households may undervalue wood savings because time and monetary costs are perceived as low.

Direct program costs to fully subsidize improved cookstove adoption are relatively low. A program that, for example, produces and installs 250 stoves per year would have an annual budget of about $2,250. This figure is made up of a full subsidy at $4.00 per stove, $700 per year for a program manager, $2.00 per stove for transportation and $50 per year for advertising. Each stove would then need to be replaced on average every 2.1 years, which was the mean lifetime of stoves provided free of charge in Salyan during 1984–5.

[16] Stoves provided to villagers free of charge appear to have had systematically shorter lifetimes than those that were purchased. The mean difference in lifetimes was about 25 per cent.

[17] Including such benefits as reduced respiratory and ocular irritation, cleaner house, and cleaner clothes from the reduced smoke.

[18] This situation is not peculiar to Nepal. It is estimated by the World Health Organization that acute respiratory infections kill 4–5 million children every year (Kammen, 1995; Chege, 1993).

At a cost of approximately $9.00 per stove, it is therefore possible to reduce wood consumption by about 386,000 kilograms per year or 811,000 kilograms over the lifetimes of those 250 stoves; this amount is significant, and is approximately equivalent to a forest endowment for five rural families (Soussan *et al.*, 1991). The cost per metric ton of fuelwood saved is about $2.77, which is a small fraction of the market value. These results suggest that appropriately designed improved cookstove programs in Nepal can potentially provide very good value for the money.

Compared with the kerosene subsidy policy, promoting improved cookstoves indeed looks positively cost free. Just the direct costs of subsidizing kerosene consumption by 14 currently fuelwood-gathering, Nepali households would cost about as much as the 250-household improved cookstove promotion program discussed above, but *improved stoves would save approximately six times as much fuelwood.*

7. Conclusion

The fundamental causes of forest degradation in countries where there is an intimate linkage between rural households and forests typically include open access, rural poverty, and excessive population growth. Overcoming all three 'failures' is at best slow, and the argument here is that under such circumstances complementary policies should be seriously considered. This paper focused on identifying and evaluating potential second-best economic instruments for reducing fuelwood use in poor developing countries. It was asserted that in such cases demand-side instruments are quite limited, which at least partially explains why the problem of forest degradation in countries like Nepal seems so intractable, and why subsidies have been preferred. Indeed, subsidies are likely to be the most useful interim policies.

Two candidate policies, non-wood fuel subsidies and improved cookstove promotion, were considered. Model simulations revealed that technology and price policies can be expected to have very similar environmental effects in that both reduce fuelwood collections, stabilize forest stocks with the parameters and prices used, and increase fodder and grazing demands. Both policies are at least in principle also compatible with slow-moving first-best measures that attempt to directly address open access problems, increase rural incomes, and limit population growth. The direct economic costs of the two policies were then compared, and it was found that technology policy is likely to be superior to non-wood fuel subsidies, because costs are lower. Price policies also rely heavily on income threshold effects, with participation largely determined by income level. Technology policies, on the other hand, operate quite differently, with all income groups having similar incentives to participate. This feature makes them much more equitable tools than price policies.

An important omission from the model was the issue of intra-household distribution. In countries such as Nepal, particularly gender issues are very important. Explicitly incorporating these factors into household-oriented models of rural agro-forestry systems is therefore an extremely important area for continuing research. Despite the attention given by survey respondents to indoor air quality, this issue was left out of the model. The potential for improved cooking stoves to reduce indoor air pollution was not truly considered, and the benefits of that policy were therefore understated.[19] The formal incorporation of this perhaps most important benefit could potentially yield useful insights.

References

Acharya, M. and L. Bennett (1983), 'Women and the subsistence sector: economic participation and household decisionmaking in Nepal', Staff Working Paper No. 526, World Bank.

Amacher, G., W. Hyde, and B.R. Joshee (1991), Joint Production and Consumption in Traditional Households: Fuelwood and Crop Residues in Two Districts in Nepal, personal correspondence.

Bluffstone, R. (1989), Improved Cookstove Promotion and the Proper Public Role: A Case Study of Salyan, Nepal, USAID / Nepal: Kathmandu, Nepal.

Bluffstone, R. (1993), 'Reliance on forests: household labor supply decisions, agricultural systems and deforestation in rural Nepal', Ph.D. Dissertation, Boston University, Boston, Massachusetts.

Bluffstone, R. (1995), 'The effect of labor market performance on deforestation in developing countries under open access: an example from rural Nepal', *Journal of Environmental Economics and Management*, **29**: 42–63.

Catterson, T. and T.N. Bhattarai (1988), 'Technical Analysis: Forestry Development Project 367-058', USAID, Washington DC.

Chege, N. (1993), 'Cooking up a more efficient stove', *Worldwatch*, November–December, 34–36.

Dasgupta, P. (1992), 'The population problem', Beijer Discussion Paper Series No. 11, Beijer International Institute of Ecological Economics.

Dasgupta, P. (1995), 'Poverty, population, and the environment' in Susan Hanna and Mohan Munasinghe, eds., *Property Rights and the Environment: Social and Ecological Issues*, Beijer International Institute of Ecological Economics and the World Bank, Washington DC.

Dasgupta, P. (1996), 'The economics of the environment', Paper Presented at the Annual Conference of the European Association of Environmental and Resource Economists, Lisbon, Portugal.

Dasgupta, P. and K. Maler (1993), 'Poverty, institutions, and the environmental-resource base', Beijer Discussion Paper Series No. 27, Beijer International Institute of Ecological Economics.

Deacon, R. (1992), 'Controlling tropical deforestation: an analysis of alternative policies', Working Paper, University of California, Santa Barbara.

Deacon, R. (1995), 'Assessing the relationship between government policy and deforestation', *Journal of Environmental Economics and Management*, **28**: 1–18.

Field, T. (1993), 'Wood-starved and footsore: global fuelwood shortage', *World Forests*, **99**: 49.

Fox, J. (1993), 'Forest resources in a Nepali village in 1980 and 1990: the positive influence of population growth', *Mountain Research and Development*, **1**: 89–98.

Gilmour, D. (1988), 'Not seeing the trees for the forest: a re-appraisal of the deforestation crisis in two hill districts of Nepal', *Mountain Research and Development*, **8**(4): 343–350.

Gregersen, H., S. Draper, and E. Dieter (1989), *People and Trees: The Role of Social Forestry in Sustainable Development*, Washington DC: World Bank.

[19] I thank one of the reviewers of the paper for this insight.

Hahn, R. and R. Stavins (1992), 'Economic incentives for environmental protection: integrating theory and practice', *American Economic Review*, **2**: 464–468.

Hanna, S., C. Folke and K.G. Maler (1995), 'Property rights and environmental resources', in Susan Hanna and Mohan Munasinghe, eds., *Property Rights and the Environment: Social and Ecological Issues*, Beijer International Institute of Ecological Economics and the World Bank, Washington DC.

Hosier, R. and M. Bernstein (1992), 'Woodfuel use and sustainable development in Haiti', *Energy Journal*, 13: 129–159.

Hotchkiss, D. and S. Kumar (1988), 'Consequences of deforestation for women's time allocation, agricultural production, and nutrition in hill areas of Nepal', International Food Policy Research Institute, Washington DC.

Jodha, N.S. (1990), 'Rural common property resources: contributions and crisis', Working Paper, International Center for Integrated Mountain Development, Kathmandu.

Joshee, B.R. (1986), 'Improved stoves in minimization of fuelwood consumption in Nepal', Forest Research Paper No. 7, Winrock Institute for International Development, Morrilton, Arkansas.

Kammen, D. (1995), 'Cookstoves for the developing world', *Scientific American*, July, 72–75.

Larson B. and D. Bromley (1990), 'Property rights, externalities and resource degradation: locating the tragedy', *Journal of Development Economics*, **33**: 235–262.

Leach, G. (1992), 'The energy transition', *Energy Policy*, February.

Mahar, D. (1989), *Government Policies and Deforestation in Brazil's Amazon Region*, Washington DC: World Bank.

Metz, J. (1991), 'A reassessment of the causes and severity of Nepal's environmental crisis,' *World Development*, **19**: 805–820.

Nepal Bank Limited (1985), 'Household incomes survey', Unpublished, 1984–85.

Ostrom, E. (1990), *Governing the Commons: The Evolution of Institutions for Collective Action*, New York: Cambridge University Press.

Ostrom, E. (1995), 'Designing complexity to govern complexity', in Susan Hanna and Mohan Munasinghe, eds., *Property Rights and the Environment: Social and Ecological Issues*, Beijer International Institute of Ecological Economics and the World Bank, Washington DC.

Perrings, C. (1989), 'An optimal path to extinction? Poverty and resource degradation in the open agrarian economy', *Journal of Development Economics*, **30**: 1–24.

Pitt, M. (1985), 'Equity, externalities and energy subsidies: the case of kerosene in Indonesia', *Journal of Development Economics*, **17**: 201–207.

Pradhan, A. and P. Parks (1995), 'Environmental and socioeconomic linkages of deforestation and forest land use change in Nepal', in Susan Hanna and Mohan Munasinghe, eds., *Property Rights in a Social and Ecological Context: Case Studies and Design Applications*, Beijer International Institute of Ecological Economics and the World Bank, Washington DC.

Repetto, R. and M. Gillis (1988), *Public Policies and the Misuse of Forest Resources*, World Resources Institute, Washington DC.

Ricklefs, R. (1983), *The Economy of Nature*, Chiron Press.

Runge, C.F. (1981), 'Common property externalities: isolation, assurance and depletion in a traditional grazing context', *American Journal of Agricultural Economics*, November, 595–606.

Seabright, P. (1993), 'Managing local commons: theoretical issues in incentive design', *The Journal of Economic Perspectives*, **4**: 113–134.

Schreier, H., S. Brown, M. Schmidt, P. Shah, B. Shrestha, G. Nakarmi, K. Subba, and S. Wymann (1994), 'Environmental auditing. Gaining forests but losing ground:

a GIS evaluation in a Himalayan watershed', *Environmental Management*, **18**(1): 139–150.
Shrestha, R.L. (1986), 'Socioeconomic factors leading to deforestation in Nepal', Winrock Institute for International Development, Morrilton, Arkansas and USAID / Nepal.
Simmons, I.G. (1989), *Changing Face of the Earth: Culture, Environment and History*, Oxford: Basil Blackwell.
Smith, K., S. Gu, K. Huang, and D. Qiu (1993), 'One hundred million improved cookstoves in China: how was it done?', *World Development*, **21**: 941–961.
Soussan, J., E. Gever, K. Ghimire, and P. O'Keefe (1991), 'Planning for sustainability: access to fuelwood in Dhanusha district, Nepal', *World Development*, **10**: 1299–1314.
Soussan, J., E.E. Mercer, and P. O'Keefe (1992), 'Fuelwood policies for the 1990s', *Energy Policy*, February, 137–144.
Southwick, C. (1976), *Ecology and the Quality of Our Environment*, 2nd edn., New York: D. Van Nostrand.
Sulpya, K.M. (1989), *A Study of the Impact and Effectiveness of Insert Stoves in the Terai*, FAO.
Swallow, B. and D. Bromley (1995), 'Institutions, governance and incentives in common property regimes for African rangelands', *Environmental and Resource Economics*, **2**: 99–118.
Virgo, K.J. and K.J. Subba (1994), 'Land-use changes between 1978 and 1990 in Dhankuta district, Koshi Hills, Eastern Nepal', *Mountain Research and Development*, **14**(2): 159–170.
Wallace, M.B. (1987), *Forest degradation in Nepal: Institutional Context and Policy Alternatives*, Winrock Institute for International Development, Morrilton, Arkansas and USAID / Nepal.
World Bank (1996), *World Development Report 1996*, New York: Oxford University Press.
World Resources Institute (1996), *World Resources 1996–97*, New York.
Xinhua News Agency (1986), 'Regional [FAO] workshop on improved stoves held in Kathmandu', 25 June 1986.

APPENDIX Explicit form of the household model used for simulations

Because of the low income levels and limited participation in markets in the hills of Nepal, it is assumed that household utility is equivalent to food consumption.

$$U = F \tag{14}$$

The constraints to the maximization are as follows:

$$F = Min[a_1(g_t + G_t), a_2(E(T_t^E, S_t) + e_t)] \tag{15}$$

$$E_t = \frac{T_t^E}{S_t} \tag{16}$$

$$G_t = (T_t^G)^{\phi}(M_t)^{\rho} \tag{17}$$

$$m = \sigma M \tag{18}$$

$$M = \gamma f \tag{19}$$

$$f = \delta \frac{T_t^A}{S_t} \tag{20}$$

$$wT_t^L = P^e e_t + P^g g_t - \frac{(\gamma\sigma\delta)P^m T_t^A}{S_t} \tag{21}$$

$$T = T_t^G + T_t^E + T_t^L + T_t^A \tag{22}$$

Edible food (F) is produced using fixed proportions (15).[20] This technology is assumed because of the limited substitutability of grains and fuels. It also seems plausible that if substitutability exists, changes would be in terms of food quality rather than quantity. The production function for fuelwood (16) is linear in T_t^E and proportional to the reciprocal of S_t. It is also an identity given that S_t is defined as the time required to gather one kilogram of fuelwood. Production of grains (17) is Cobb–Douglas in the two arguments, agricultural labor (T_t^G) and the number of cattle equivalents held (M).

Milk production is linear in the number of cattle raised (18), and cattle herd size is linear in fodder collected (19); linearity implies that each animal requires a constant amount of fodder.[21] In (20), fodder is a linear function of time in animal raising (T_t^A) and proportional to the reciprocal of the time price of forest products (S_t). The linear functions in (16) and (20) imply that in both fodder and fuelwood collections households not only suppose their actions do not affect forests between periods (i.e., they take S_t as given), but at any point in time also do not directly observe diminishing returns to fodder and fuelwood collection effort. This explicit form falls out of the assumption that households are small gatherers of forest products within open access environments, and as was discussed in the previous section, there will therefore be two mutually exclusive fuel regimes.

Table 1. *Base case simulation technology*

Technology
Cooking: $a_2 =$ 0.14 kg. grains per kg. fuelwood*
Output elasticity of agricultural labor: *phi* = 0.634**
Output elasticity of agricultural labor: rho = 0.27**
Milk production parameter: sigma = 3.0 liters per animal per period***
Fodder production parameter: delta = 0.888*****
Fodder consumption parameter: gamma = 0.0008 milk animals per kg. of fodder per period****

Source: Author's calculations summarized in Bluffstone (1993) Based on IFPRI / APROSC 1982 / 83 Nepal Energy and Nutrition Survey (NENS).
* Calibrated to generate annual per capita consumption of 550 kg of fuelwood.
** From a six equation model of the agricultural system estimated using 3SLS.
*** NENS mean of 24.03 liters with a standard deviation of 28.6. Milk production deliberately de-emphasized because of this high standard deviation.
**** Mean value of NENS data.
***** From OLS estimation of equation (19) after substituting in equation (20).

[20] Assuming utility maximization, the following two equations replace the 'min' function as constraints to the maximization: $F_t = a_2\,(E_t + e_t)$ and $F_t = a_1\,(g_t + G_t)$.

[21] Lack of diminishing returns is perhaps reasonable when animals are generally under-fed, as is often the case in the hills of Nepal.

Table 2. *Base case simulation endowments*

Endowments

Labor (T): 527.8 days per household*

Wood biomass (70% of forest) (X_t^E): 167,100 kg. per household**

Leaf biomass (30% of forest) (X_t^f): 71,614.3 kg. per household**

Forest growth and link with S_t

Intrinsic rates of growth (r^E, r^f) in the logistic growth function: 0.01 (1.0%) per period***

S_t Function exponent (psi): 0.9****

S_t Function scaling parameter (b): 3738.4****

Sources: Author's Calculations Based on IFPRI / APROSC NENS Data; Sources Cited Below

* Mean of NENS sample (3.8 working members)

** From Soussan *et al.* (1991). Assumes maximum sustainable yield initial stock level.

*** From estimates of net ecosystem production (NEP) (*Quercus* and *Pinus* forests) by Southwick (1976) applied to yield estimates of Ricklefs (1983).

**** Generates elasticity $\{(dS_t / dX_t)(X_t / S_t)\}$ of 1.09.

Table 3. *Base case simulation prices*

Prices

Price of milk (P^m): Rs. 10 per liter

Wage rate: Rs. 5.9 per day*

Price of kerosene (P^e): Rs. .67 per liter fuelwood equivalent**

Price of grains (P^g): Rs. 22 per kilogram***

Price of forest products (S_t):.0201 days per kg. fuelwood****

Source: Author's Calculations Based on IFPRI / APROSC NENS data.

* Set below NENS mean, but within one standard deviation. See Bluffstone (1993) for discussion.

** Set using Gregersen *et al.* (1989) conversion factor of 0.0905 liters kerosene per kg. fuelwood and assumed 1982 retail price of Rs. 7.5 per liter.

*** Perhaps twice the actual market price. Due to lack of price data, technological parameter estimates derived from production rather than labor supply functions and therefore were not estimated incorporating variation in prices. Because the price of maize is exogenous and therefore not a policy variable, it was used to calibrate the behavioral portion of the model.

**** Mean value of NENS data.