Forest Degradation and Economic Growth in Nepal 2003-2010

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Abstract

We investigate the relation between economic growth, household firewood collection and forest conditions in Nepal between 2003 and 2010. Co-movements in these are examined at the household and village levels, combining satellite imagery and household data from the Nepal Living Standard Measurement Survey. Projections of the impact of economic growth based on Engel curves turn out to be highly inaccurate: forest conditions remained stable despite considerable growth in household consumption and income. Firewood collections at the village level remained stable at the village level, as the effects of demographic growth were offset by substantial reductions in per-household collections and households substituted firewood by alternative energy sources, particularly when livestock and farm based occupations declined in importance. Engel curves specifications which explicitly include household productive assets (a proxy for occupational patterns) provide much more accurate predictions, in line with the observed changes. The results suggest the need to incorporate structural changes accompanying economic growth in understanding accompanying changes in forest conditions.

Keywords: Deforestation ; Growth ; Environmental Kuznets Curve ; Nepal

JEL codes: O1, D12, Q2

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1 Introduction

Deforestation in South Asia and Sub-Saharan Africa poses serious development and ecological problems. Many households in developing countries rely on forests for fuel, timber and fodder, and spend a large amount of time collecting these products (see for instance Angelsen et al. (2014)). Deforestation and forest degradation have immediate consequences for the local population in terms of increased fuel scarcity and a reduced supply of fodder and leaf-litter manure. Increased scarcity affects agricultural operations by reducing the time available for other farm activities. Forest degradation may induce lower levels of schooling and child health as children play an important role in collections (Dasgupta, 1995; Kumar and Hotchkiss, 1988). Finally, a reduced production of heat in the household may increase incidence of diseases for all members of the family (Amacher et al., 2004). At a broader scale, the ecological problems brought about by deforestation pertain to increased soil erosion, water salinity, siltation in rivers, and increased likelihood of landslides and floods which affect large areas.[1,2] Deforestation contributes to climate change as natural forests absorb a substantial fraction of greenhouse gases in the earth's atmosphere. Accordingly, arresting deforestation is an important goal adopted by the 2015 Paris Agreement on Climate Change.[3]

The extent to which deforestation may be caused by economic growth in developing countries is central to evaluating the sustainability of currently ongoing development patterns, and the need for corrective policies. To investigate this issue, we focus on the Himalayan forests located in the Hills and the Mountains of Nepal combining household level data for 2003 and 2010 and collected as part of the Nepal Living Standard Survey (NLSS) together with satellite imagery constructed at the village level over the period in question.

The Hills and Mountains region of rural Nepal was selected for this analysis for several reasons, besides the availability of rich data. First, the Himalayas, one of the largest mountain ranges in the world, has been subject to serious deforestation and soil erosion in the last century, with forest cover declining at an estimated annual rate of 1.9% over the 1980s and the 1990s (UNEP, 2011). The resulting erosion causes siltation of the rivers, one of the main factor behind the large scale floods observed in the Ganga and Bramahpoutra river basins. Moreover, over the period examined, income grew at an annual rate of 5.5% in Nepal (GDP per capita, PPP, The World Bank) and poverty fell dramatically, with a head count

[1]For detailed references concerning these problems, see Arrow et al. (1995), Dasgupta and Mäler (1995), Dasgupta et al. (2000) and various references cited in Baland et al. (2010b)

[2]Wood fuel extraction is the main driver of biomass removal in most countries, such as India, China, Democratic Republic of Congo, Ethiopia or Nigeria. Industrial roundwood production is dominant in only a limited set of developing countries including Brazil, Indonesia and Malaysia.

[3]See Article 5 of the Paris Agreement.

ratio dropping from 46% in 2003 to 15% in 2010 (computed at 1.90$ a day, The World Bank), much faster than in neighbouring areas of India and China. Finally, in the Hills and the Mountains of Nepal, firewood is by far the main source of energy for the households (93% of the households report wood as their main cooking fuel in our sample), both for cooking and heating.[4]

We find that forest conditions (measured by forest cover and biomass) remained quite steady over the past 15 years, in contrast to reports of declining trends (cited above) prior to 2000. We also find a negative cross-sectional relationship between firewood collections at the village level in 2003 and 2010 and subsequent changes in neighbouring forest cover, providing support for the hypothesis that firewood collection is an important determinant of deforestation (see e.g. Baland et al. (2014, pp.209-210)). Total village level collections remained essentially stable between 2003 and 2010 and accounted for at most 2% of the forest biomass, which roughly corresponds to its natural regeneration rate – a result consistent with the observed steadiness in forest biomass. The stability of village level collections occurred despite substantial growth in village population, thanks to a 8% decline in per-household collections. This decline occurred despite a 59% rise in per household consumption expenditures. Clearly, at the household level, rising living standards in rural Nepal were **not** accompanied by rising firewood collections. Instead, the reverse happened.

In an effort to understand possible explanations for the observed decline in collections, we focus in the rest of the paper on correlates of firewood collection at the household level. We start by estimating Engel curves using cross-sectional and temporal variations across households in our sample.[5] Contrary to the overall trends described above, we find that per household collections were rising with consumption levels. Since household consumption levels grew substantially between 2003-10 for the bottom half of the distribution, the estimated Engel curve would predict considerable growth in per household collections, contrary to the observed decline.

The rest of the paper explores possible reasons for the weak predictive power of the Engel curve owing to omitted variable bias and measurement errors. To address these we add household level controls concerning ownership of productive assets such as livestock, farmland, education, non-farm business assets, household size and composition besides others described below. The estimated regression coefficient of household consumption then becomes very small, indicating omitted variable bias in specifications that exclude such household controls. The estimated

[4]We exclude the low-level Terai regions as they are subject to completely different agro-climatic and ecological conditions and do not require heating energy, in contrast with the higher altitude villages. See Table A3 for more numerical details on these differences.

[5]The subsample of households included in both rounds is too small to permit precise inferences from the corresponding household panel.

regression coefficients of household assets turn out to be statistically significant, and robust with respect to the specification (e.g., irrespective whether consumption is included in the regression). Moreover, the regression with included household controls succeeds in predicting the observed changes between 2003 and 2010 in per household collections quite accurately.

The underlying explanation is consistent with Baland et al. (2010b) and echoes the work of Narain et al. (2008): during the period in question, livestock, farmland owned and household size per household fell, while education and non-farm business assets rose. The former set of household characteristics are positively related to firewood collection, while the latter have a significant negative association.[6] This reflected a shift in occupational patterns, away from farm and livestock based occupations that are complementary to firewood collection, towards non-farm occupations that are substitutes. Non-farm occupations necessitate going away from the village and neighbouring forest areas to nearby semi-urban areas, raising the shadow cost of time for collecting firewood. Consistent with this explanation, we find a significant negative relationship between collections and median collection time (per bundle of firewood) within the village.

We provide supplementary evidence corroborating the hypothesis of occupational shifts which encouraged substitution of firewood by alternate energy sources.[7] Household fuel expenditures (i.e., on firewood alternatives) rose substantially between 2003 and 2010. In the cross-section, they exhibit similar correlations with various household assets as firewood but with the signs reversed. Nevertheless, the absence of suitable instruments for various household assets or consumption do not permit more definitive assessments. Unless better data becomes available, causal inferences are unlikely to be feasible. We do, however, include village-level controls for likely sources of endogeneity bias, such as incidence of the Maoist conflict, the presence of biogas installations or the existence of a Community Forest User Group (CFUG), which might have affected firewood collections as well as household assets, consumption and firewood collection times at the same time. The results are robust to inclusion of these controls, as well as village (and year) fixed effects.

Finally, at the household or village level, forest conditions are often measured through imperfect proxies, such as the time taken to collect firewood at the time of the survey. The recent availability of high definition satellite imagery allows for a much more precise assessment of forest conditions, and their relation with collection times. In a final section, we therefore explore the connections between collections, collection times and forest conditions. We are the first in the eco-

[6]The large positive significant coefficients of consumption when these household assets are dropped owe to a positive correlation between consumption on the one hand and farmland, livestock and household size on the other in the cross-sectional data.

[7]Amacher et al. (1996); Baland et al. (2010b); Baland and Platteau (1996); Bluffstone (1995)

nomic literature to provide an explicit attempt at relating collection times to forest biomass measures. We find that, as expected, the time taken to collect one bundle of firewood decreases with biomass availability or average forest cover in the village, but the estimated effects are small. We also find that household collections increase with forest biomass or forest cover though, again, the effects of these are dwarfed by those of household assets. Hence variations in forest biomass or forest cover are likely to be of second order importance relative to household occupational patterns in explaining variations of firewood collections.[8]

In the literature, various competing hypotheses relating deforestation and income growth have been proposed. Some scholars argue that poverty is the major factor that drives households to rely on forest firewood rather than modern fuels; hence declining poverty made possible by economic growth will reduce the pressure on forests. This view, commonly referred to as the Poverty-Environment hypothesis (PEH), is based on the presumption that the factors moderating firewood collection will dominate those raising household energy demands along the process of growth.[9] Another popular view based principally on cross-country evidence is expressed by the Environmental Kuznets Curve (EKC), according to which environmental degradation first intensifies with growth in living standards until a threshold is reached, and is moderated thereafter as living standards grow beyond the threshold.[10] The first part of the EKC, through which economic growth accelerates deforestation, is based on the idea that rising living standards are accompanied by rising energy needs for cooking and heating, a large fraction of which are met by collecting firewood from forests.[11] On the other hand, a rise in income also increases the opportunity cost of time and thereby the costs of firewood collection for the household, which reduces firewood collections. Moreover, as incomes rise, the demand for land intensive consumption goods (Alix-Garcia et al., 2013), for cleaner and more practical energy sources (the "energy ladder" model) and awareness of the need for forest preservation and eco-system services may also increase. Falling household size and increases in out-migration can also reduce pressure on forests. The net impact depends on the relative strength of these various effects, and is therefore difficult to predict *a priori*. Data limitations make it difficult to assess the validity of these various statements regarding causal impacts of economic growth on firewood use, owing to concerns about endogeneity, unobserved heterogeneity and measurement errors. These limitations underlie the weak econometric basis of EKCs, which are typically estimated at

[8] With the exception of Foster and Rosenzweig (2003), we are not aware of any study analysing the changes in forest biomass and relating these to local energy use based on a household survey.

[9] Barbier (1998, 2010); Barbier et al. (1997); Duraiappah (1998); Jalal (1993); Lele (1991); Lopez (1998); Maler (1998)

[10] Barbier (1997); Grossman and Krueger (1995); Stern (2004); Yandle et al. (2002)

[11] World Economic Forum 2006 Summit Report, Word Bank (2000)

the cross-country level (for a comprehensive assessment, see, e.g., Stern (2004)). Our initial estimates of Engel curves are at a substantially higher level of disaggregation (households rather than countries), but are nevertheless still subject to problems of simultaneity and omitted variables. In a sense, this paper examines the robustness of correlation-based results with respect to the level of disaggregation, adding controls for proxies of unobserved variables at the household and village level, and using variables to measure socio-economic status subject to less measurement error.

The paper is organized as follows. In Section 2, we describe the major trends in forest conditions and collection of firewood in Nepal between 2003 and 2010. In Section 3, we investigate how changes in forest conditions are related to total firewood collection at the village level. We then present Engel curves and their reduced form counterparts in Section 4. In Section 5, we examine more closely the relations between forest biomass, collections and collection time. Section 6 discusses the existing literature and concludes the paper.

2 Major Economic Trends and Deforestation in Nepal: Context and Descriptive Statistics

The World Bank Living Standards Measurement Survey (LSMS) for Nepal interviewed 3912 households in 2003-4 and 5998 households in 2011-12 concerning their production and consumption activities in the preceding one year.[12] We focus on the villages located in the Hills and Mountains of Nepal, which share a similar agro-ecological system and a comparable reliance on forest resources. Table A3 in the Appendix compares the Terai and the Hills and Mountains, which indicates a very different pattern of firewood use and energy needs between those two regions. We end up working with a total sample of 3590 households (1474 in 2003 and 2116 in 2010), located in 301 villages. Tables A5 - A7 in the Appendix provides a description of the main household level variables used in our analysis.

In this region, almost all households collect and consume firewood, which is the primary source of cooking fuel and heat. The quantities of firewood exchanged on the market are negligible and a small fraction of households report such pur-

[12]Note that the 2002-3 LSMS was effectively administered in 2003 and part of 2004. To avoid confusion, we refer to the year of that particular survey as 2003, and to the other as 2010. Another Nepal LSMS was also administered in 1995 and has been analyzed in Baland et al. (2010b). Unfortunately, the satellite imagery data available in the 90s do not provide the relevant information necessary for our research. We have therefore decided to drop this additional dataset in our main presentation, and provide some robustness checks on our main estimates using the larger sample including the 1995 data in Table A2 in the Appendix.

chases.[13] Each household collects on average 81.75 bharis of firewood (headloads corresponding to about 30 kg of wood) per year, and spends 3.75 hours to collect one such bhari. Between 2003 and 2010, the amount of firewood collected per household fell by 8%, while collection time increased by about 12%. Overall, annual fuel expenditures (that exclude firewood collected, but include purchases of fuelwood, sawdust, kerosene, LPG, logwood,...) amount to 2,086 NPR (from 1,379 NPR in 2003 to 2,578 NPR in 2010) and represent 2% of all expenditures.

Household living standards (measured by the value of annual consumption expenditures at 2010 prices) were equal on average to 101,000 NPR, and increased substantially (by about 60%) during this period. The number of migrants also doubled over the period, from 0.4 to 0.8 individuals per household. Households are mostly engaged in farming as they spend on average 76% of their working time in agricultural occupations.[14] This dependence on farming decreased substantially between 2003 and 2010, as the proportion of time spent on agricultural activities fell from 0.82 to 0.72. Changes in the structure of productive assets owned by the households reflect this evolution. Thus, between 2003 and 2010, the number of livestock heads per household fell from 3.53 to 3.15, the amount of land owned from 0.68 to 0.61 hectares and household size from 5.02 to 4.79 individuals. By contrast, average adult education increased from 2.41 to 3.16 years of schooling and the proportion of households owning non-farm business assets rose from 0.22 to 0.28.

The Forest User Group program was launched in 1993. Its objective has been to transfer the management of accessible forests to local communities, via Community Forest User Groups (CFUGs). These groups are empowered to control access to the forests, taxing forest products, hiring forest guards and launching plantation programmes.[15] Income generated by forest-related activities can be used to finance local projects such as roads, schools and temples. Most of the villages have at least one forest user group (87% in 2003 and 95% in 2010) and the area controlled by CFUGs increased substantially over the period, from 14% to 20% of the total village area as defined by administrative boundaries.

Another important event during the study period was a Civil War between

[13]Unfortunately, we do not have precise information on purchases of firewood, which in the survey are grouped together with construction wood and sawdust into a single expenditure category. In 2003, less than 10% of the households report such an expenditure, and the amounts reported are less than one fifth the amounts spent on other types of fuel, such as kerosene or LPG. The absence of active markets differentiates our work from studies of fuelwood demand in developed countries (Couture et al., 2012) or urban areas where the market for fuelwood is thicker and relies on explicit prices.

[14]This is measured as the proportion of the total adult working time in the household spent on farm activities.

[15]Certain legal restrictions are set for the use of these funds. For example, 25% of revenue must be reinvested in projects aimed at developing the forest.

government forces and Maoist rebels, which started in 1996 and ended in 2006. The civil war culminated in 2003 and 2004 with the Maoist rebels controlling a large part of the countryside. In this paper, we use the Informal Service Center (INSEC) dataset which provides the most reliable data source on conflict intensity, reporting the number of conflict related casualties, with the date of the event and its geo-localization. Using the centroid of each village in our data set, we computed the total number of conflict related deaths since the start of the conflict within a 20 km radius around the center of the village.[16] At the village level, we will also systematically control for environmental and climatic conditions using remote sensing information. Snow cover and cooling degree days (CDD) determine the demand for firewood. Growing Degree Days are computed for each monsoon season to capture one of the important determinants of biomass growth over the year. We control for rainfall z-score, the village median altitude and within village altitude variance. The appendix describes each variable used, presents the satellite data sources and the computational details for these variables.

Finally, we consider the rapid expansion of biogas installations in Nepal over the period considered. To this end, we use the census of biogas installations for each village in Nepal, which is provided by the Alternative Energy Promotion Center (AEPC). According to this census, over the period considered, the proportion of village households equipped with biogas doubled, from 2 to 4%. We control for this at the village level. The past decade has also seen the promotion of improved cookstoves in Nepal, which are more efficient in terms of cooking energy needs and produce less indoor air pollution. Unfortunately, the rates of adoption remain low (see Nepal et al. (2011)).

Three different measures of forest biomass in a village are used. All remote-sensing measures suffer from non-trivial measurement errors observed at the micro-level, which justifies the use of various alternative measures (see e.g. Glenn et al. (2008)). In our approach, they are averaged over the village territory, using administrative boundaries of the survey villages to identify the relevant pixels.[17] We first define the leaf area index, LAI, which corresponds to the share of an area which is covered by leaves, and is therefore closely related to the more traditional measure of crown cover, but in a finer way as it takes into account the differences between pine and broadleaved trees. Given the seasonality in the density of leaves

[16] More details on this variable are available in Libois (2016). According to Do and Iyer (2010), the Nepal civil war was concentrated in geographic locations favoring insurgents, such as mountains and forests, and in areas of greater poverty owing to the need of the insurgents to recruit soldiers (see also Bohara et al. (2006) and Hatlebakk (2010). Since the location of conflicts is not random, we are not able to draw reliable estimates of the effects of the civil war on firewood collections.

[17] LAI and FPAR pixels have a $1km \times 1km$ resolution while NDVI is more precise with a $250m \times 250m$ resolution

in those areas, we use the 90 percentile of the measure in a year (we avoided using the maximum as the latter is more subject to measurement errors). Our main results are based on this particular measure.[18]

The second measure of forest condition is the Fraction of absorbed Photosynthetically Active Radiation, FPAR, which indicates the photosynthesis capacity of standing vegetation. It captures the growth potential and carbon storage capacity of the biomass. There again, because of seasonality, we will use the 90^{th} percentile. The third measure of forest condition is the Normalized Difference Vegetation Index (NDVI), for which we computed the village-wise average of the November-December maximum of each pixel. This methodology follows the bimonthly production algorithm which report for every 16 days the maximum of the ratio $\frac{Near\ Infra\ Red\ -\ Visible\ Red}{Near\ Infra\ Red\ +\ Visible\ Red}$. It proxies the amount of radiation captured by chloroplast, which are green because they absorb all visible colours but green. The closer to one the ratio is, the denser is the vegetation cover of the pixel. We focus on November and December to limit the greening of pixels due to agricultural standing crops and capture as much as possible the canopy.[19]

These three measures of forest condition vary a lot across villages, but remain remarkably stable between 2003 and 2010. In Figure 1 below, we report for the villages surveyed in the Nepal LSMS the evolution of our three measures of biomass between 2001 and 2013. We also report separately the evolution of biomass in the low-lying Terai villages, since the latter appear to follow a completely different process. While there is some fluctuations between years, there are no discernible trends in the Hills and the Mountains along any of those measures, except perhaps a slight increase in NDVI over the decade. In the Terai by contrast, forest conditions seem to be improving, starting from a much lower initial level.

[Insert figure 1 here]

3 Forest Conditions and Firewood Collections

Before proceeding to our analysis of household collection patterns, we examine how the evolution of local forest conditions as measured on the basis of satellite data, related to (ground survey evidence on) firewood collection levels by residents of neighboring villages. According to the FAO, woodfuel extraction represents the major share of total wood production in Nepal. This share is fairly stable, and varied between 90 and 95% of total forest production over the past 50 years

[18] We used the LAI measure provided by NASA, for which the initial LAI measure is multiplied by 30 to normalize it on a scale from 0 to 100.

[19] For more details on NDVI products using MODIS data, see Solano et al. (2010). For LAI and FPAR products using MODIS data, see also Myneni et al. (2002).

(FAO, 2016). Using our data set, we examine how total village collections at time t were related to changes in neighboring forest biomass between $t-1$ and $t+1$[20]. We first define the total amount of fuelwood removed per unit area, using the administrative boundaries of the village.[21] In a village j at time t, $C_{jt} = \frac{\bar{C_{jt}} \times N_{jt}}{A_j}$, where $\bar{C_{jt}}$ denotes per-household village average annual collections (as measured in the survey), N_{jt} the number of households (obtained from the Nepal census), and A_j the area of the village. The change in forest biomass in a village is equal to the natural growth of biomass minus the amounts collected. We therefore estimate the following equation:

$$\Delta B_{jt} = B_{jt+1} - B_{jt-1} = \alpha + \varphi C_{jt} + \sigma B_{jt-1} + \sum_{z=1}^{Z} \rho_z V_{zjt} + \varepsilon_{jt} \quad (1)$$

where B_{jt} is a measure of biomass at time t and V_{zjt} represent various village controls. We expect φ to be negative while σ measures the effect of the existing biomass on its growth.

[Insert table 1 here]

Table 1 reports the estimation of this regression for each of our three forest measures, controlling for a number of relevant village variables.[22] As argued above, village collections are measured as densities, i.e. annual total collection per unit area, since biomass is also measured as an average per unit area. The first columns (col. 1, 4 and 7), follow exactly the specification given in equation (1). For each biomass measure, robustness checks are provided in the second and third column (cols. 2, 3, 5, 6, 8 and 9). In the second specification, we additionally control for the stock in $t-2$ and its square, while in the third specification, the dependent variable is measured as the change between the year $t-2$ and year $t+1$, controlling for the stock in $t-2$ and its square.

The results show a negative correlation between annual village collection levels and changes in village biomass. The results are consistent across the three measures of biomass. Using the estimated coefficient in column (1), total collections

[20] Because of the seasonality in forest cover, by $t+1$ we mean the leaf cover peak following the household level data collection. By $t-1$, we mean the leaf cover peak preceding the response of households. To reduce measurement error and simultaneity bias, we do not consider year t when household data are collected. Indeed, most of the questionnaire is framed around the household behaviour over the last 12 months and this period spans over a leaf cover peak.

[21] The various biomass index used are averages per pixel, and are therefore measures of biomass per unit area. Hence the need to define village collections in terms of density per unit area.

[22] To be precise, the biomass stock at time t-1 refers to the stock over the first 12 of the 24 months that precede the date of the survey in the village, since collections were reported "over the last 12 months".

in a village correspond to a 1.7% reduction in LAI (0.000129*3276.17/25.5). The estimated coefficient for FPAR are smaller in relative terms, as total collections correspond to a fall of about 0.8% in FPAR. The larger estimates obtained with the LAI measure comes from the fact that LAI is based on the density of leaves, and a lot of firewood is collected through cutting branches (lopping) instead of trees (Baland et al., 2010a). Hence our regression results conform the prior expectation that LAI would be more sensitive to collections than the other two biomass measures.[23]

These estimates suffer from a number of problems, however. First, they are imprecise owing partly to the low number of observations (301) and measurement errors in biomass. The biomass measures are constructed as averages over the whole administrative area of a village and therefore only imperfectly capture villagers' access to forest products. The latter goes to specific forest patches which are not well captured by a village average. Moreover, these patches may be located in neighbouring administrative villages, since administrative boundaries do not match perfectly the areas in which collection of forest products take place. Second, these estimates may suffer from serial correlation in errors: for instance, a larger forest stock may imply a slower growth rate while simultaneously inducing larger collections in the village. The inclusion of quadratic terms is an admittedly imperfect attempt to control for possible non-linearity between biomass growth and the stock of biomass. We also control in columns (2), (5) and (8) for the stock in t-2, to capture possible trends. It was however not possible to control for longer trends as most of the biomass measures are available only in the end of year 2000 and collections are available only for the two years 2003 and 2010. This also explains why our analysis does not include the 1995 LSMS round.

4 Firewood Collection and Living Standards

In this section we focus on the relationship between per-household consumption and firewood collections, in order to test commonly held views such as PEH or EKC concerning the link between growth in living standards and firewood collections. The analytical framework in Baland et al. (2010b) addresses some of the key conceptual problems involved in estimating Engel curves in this context. More than 90% of households collect all the firewood they use, so the cost of firewood

[23]An alternative assessment of these estimates is to compare them to a rough calculation based on the stock of wood in Nepalese forests (Oli and Shrestha, 2009). The average above ground stock in forest is estimated to be around 200 tons per hectare and per year, while village collections represent a removal of about 2.5 ton per hectare and per year (30 kgs per bharis * 3276 bharis per square kilometres * 0.40 forest per unit area), which amounts to a 1.25% decrease in the stock of wood, which is reassuringly close to our own estimates.

reflects collection times and the opportunity cost of time, both of which can vary across households. Higher household living standards could affect firewood demand directly through a pure income effect, as well by altering their collection costs. We examine first the total effect of higher living standards, and then attempt to separately estimate the income and collection cost effects. Concerns for reverse causality are unlikely, as estimates of Baland et al. (2010b) using the 1995 and 2003 rounds of the LSMS indicate that the shadow cost of time spent collecting firewood accounted for less than 2% of annual consumption expenditures. However, the effects estimated below are potentially subject to bias owing to unobserved heterogeneity and errors in measuring consumption.

We first provide cross-sectional estimates of the relation between household annual consumption expenditure and annual firewood collections, pooling the two waves of the survey. Controlling for village dummies and focusing on intra-village variations in a cross-sectional analysis helps control for the bias resulting from unobserved village heterogeneity, but does not allow us to estimate the effects of collection times which do not vary as much within a village. Moreover, there could be concerns about potential reverse causality at the household level if we were to rely on household-level measures of collection time. Hence we use the median collection time per bhari at the village level, and rely on across-village variations in collection times to estimate the collection cost effect, while controlling for observed village characteristics, besides belt-zones dummies to control for regional characteristics. A belt-zone is defined administratively as a region of roughly similar geographical characteristics (usually, low plains, hills and mountains correspond to three different ecological belts). We distinguish between 22 belt-zones in the Hills and the Mountains, which include on average 2.5 districts or 13.7 villages. The use of belt-zones allows for more variability across villages, but the results are robust to the use of district fixed effects, with some loss in significance.

Table 2 presents estimated Engel relationships using a varying sets of controls using a quadratic or a logarithmic specification.[24] Consumption is measured by annual household recurrent expenditures valued at 2010 prices. In the first column, we control for village and year dummies, in the second column, we control for a belt-zone dummy and for the median collection time per bhari in the village (which was absorbed by the village dummy in column 1).[25] In column (3), we add other village level controls, including the share of forest managed by community forest groups, the distance to a paved road in walking hours, the number of conflicts related deaths within 20 km of the village, the presence of biogas installations and

[24] Higher order polynomials were also tested, with little impact on the estimates. While not reported here, all the results discussed are robust to using income instead of consumption expenditures as the measure of living standards.

[25] The use of individual self-reported collection time per bhari, while arguably more endogenous, does not affect our conclusions.

various topographic and climatic controls. Column (4) presents the logarithmic specification, with the same set of village controls. In column (5), we follow the specification adopted in column (1), controlling for household size.

All the estimates indicate an increasing and concave relationship between firewood collections and consumption. In the quadratic specifications, the estimated turning points are located near or above 300,000NPR, corresponding to consumption levels above the 99th percentile. The coefficient of collection time is significant but relatively small, as one more hour needed to collect one bhari (a 27% increase) is associated with a fall of at most 4.3 bharis per year collected, which corresponds to an average elasticity of about -20%.

[Insert table 2 here]

[Insert figure 2 here]

We next explore the robustness of the preceding results with respect to the functional form assumed between collections and consumption. Figure 2 provides semi-parametric estimates of the Engel curve. To estimate this curve, we use the estimator proposed by Baltagi and Li (2002) which allows consistent estimates in a semi-parametric panel regression.[26] The estimation controls for belt-zone fixed effects and the village controls. The first panel presents the semi-parametric estimate between firewood collections and consumption expenditures, while the second panel is obtained using a logarithmic specification. We again find an increasing relation between firewood collections and consumption, which flattens at the top of the distribution and closely follows a quadratic shape. The right hand panel of Figure 2 reports the distribution of annual consumption across all households (in '000 NPR).

[Insert table 7 here]

The evidence is consistent with the upward sloping part of an Environmental Kuznets Curve, suggesting that income effects dominate collection cost effects. Based on this, one might expect deforestation to accompany rising living standards in rural Nepal. In Table 7, we generate the predicted change in firewood collections between 2003 and 2010, based on the estimated Engel curve and observed changes in household consumptions in different deciles. The estimated Engel curve predicts

[26] Baltagi and Li (2002) suggests eliminating the fixed-effects by first differencing the model over time, assuming that the non-parametric part of the regression has the same functional form in both periods. Combined with the use of sufficiently flexible splines, this assumption allows estimating consistent parameters which will be used to partial out the non-parametric part of the model from its parametric components. The partialled-out residuals will then be used to draw the non-parametric part of the regression. For more details, see Libois and Verardi (2013).

a rise of about 8 bharis (or 10%) in firewood collections per household and per year as a result of the 44,000 NPR increase in annual consumption. However, this is exactly the opposite of what actually happened: we have already seen that collections fell over this period by about 7 bharis per year.

This prediction failure could be the result of econometric biases in the Engel curve estimates and measurement errors in living standards, reflecting an excessively narrow representation of economic growth relying solely on household consumption expenditures or income. The econometric complications are discussed in detail in Baland et al. (2010b), who argue for incorporation of household productive assets as a way of addressing endogeneity concerns and lowering measurement errors. In a rural setting where households collect their own firewood and spend large amounts of time doing so, firewood collections are determined by labour allocation decisions, which depend in turn on productive assets owned by the household. Stocks and composition of household assets represent occupational patterns which are deeper underlying determinants of household consumption, incomes and opportunity cost of time. Rising living standards could be associated with increasing collection costs owing to changing occupational patterns, which would lower the growth in firewood collections. This motivates a specification in which assets are explicitly incorporated. An added argument for such an approach is that these assets are less prone to systematic measurement errors than consumption or income that lead to both bias and reduced precision in the estimation of the EKC. Measurement errors, if random, lead to a downwards bias in the estimation, which suggests that the "true" coefficients attached to consumption are in fact larger. However, measurement errors for consumption could be systematic, e.g. recall errors may lead to downward biases, whence the estimated coefficient would be biased upwards. Hence it is difficult to speculate regarding the direction of bias resulting from measurement errors in consumption.

In addition there is a need to control for demographic factors. Economic growth may be accompanied by changes in household size owing to changing fertility and migration patterns. Larger households are likely to have higher energy needs, and incur lower shadow cost of collecting firewood (owing to the opportunity to share collection tasks among household members). The age and gender composition of households is also likely to matter for similar reasons.

In Table 4 below, we report the main changes in productive assets and household demographics observed between 2003 and 2010. Consumption growth was accompanied by a large fall in livestock and in farm-based occupations, which are complementary to firewood collection (such as fodder collection or livestock grazing). Household size fell, while the age and gender composition did not change much. The proportion of adult working time spent on farming fell from 82 to 72%. Non-farm occupations require household members to work set hours, usually in a semi-urban location outside the village, which create pressures for households to reduce collections and switch to alternative fuels. We also see a rise in education and in the number of out-migrants. Rising education and mobility could enhance access to non-firewood fuel substitutes, and promote awareness of harmful smoke effects associated with firewood fuels. All of these factors are likely to lower firewood collections over time.

[Insert table 4 here]

In Table 5, we re-estimate the Engel curve by incorporating into the set of regressors household occupation or household assets and demographics, which include household size, the proportion of children, the proportion of female adults and the number of migrants. The first two columns report the estimated coefficients when controlling for the proportion of working time in the family spent on farming, with village controls (Col.(1)) or village fixed effects (Col.(2)). Columns (3) and (4) report the estimated coefficients with household assets and demographics instead. We also re-estimated the Engel curve separately for 2003 and 2010 in columns (5) and (6) respectively. Column (7) reports the estimation results on household assets without consumption, resulting in a pure reduced form specification.

As expected, we find a strong association between collections and the time spent on agricultural occupations, which indicates the important role played by occupational patterns. The contrasting role of farm based assets (livestock and agricultural land) and non-farm assets is particularly striking, and suggest the importance of occupational effects operating through the shadow cost of collection. Rising farm-based assets raise collections as expected, while rising non-farm assets lower collections possibly owing to rising collection costs outweighing the direct income effects. The coefficient on household size is positive and signficant, as expected; household age and gender composition seem less important. The coefficient of the number of migrants is sensitive to the specification, while the coefficient of collection time has the expected negative sign.

[Insert table 5 here]

It is worth noting that the coefficient on consumption is vastly reduced, by about two thirds, compared to the simple Engel curve estimates. It is also less precisely estimated and less stable. This indicates the simple Engel curve estimation suffered from a classic omitted variable bias, generated by positive correlation of consumption with livestock, land and household size. Table 6 reports regression estimates of annual consumption expenditures and the proportion of adult work-time allocated to agriculture, on household assets and demographics. Columns

(1) and (3) include a village fixed effect, while the usual village level controls are included in the two other columns. Clearly, living standards and occupational patterns are closely related to all productive assets and household demographics in the expected way.

[Insert table 6 here]

[Insert table 7 here]

Since rising non-farm occupations are associated with rising consumption expenditures, we expect total household energy demand to also rise; hence the fall in firewood collection is likely to have been accompanied by a rise in expenditures on alternate fuels. To check this, we conduct a similar analysis using annual fuel expenditures instead of firewood as the dependent variable. These expenditures relate mostly to liquefied petroleum gas (LPG), coal, charcoal and kerosene. Table 7 presents the estimated coefficients using the same specifications as in Table 5. The results closely mirror those obtained for firewood: fuel expenditures increase with income and collection times. Fuel expenditures decrease with agricultural occupations and farm-based assets (in particular livestock) but increase in non-farm based assets. Fuel expenditures are therefore used by households as a substitute to firewood collections when collection costs are high or occupations and asset ownership are less based on farming.

Using the estimated coefficients of column (3) and column (7) of Tables 5 and 7, we can predict the changes in annual household collections and fuel expenditures between 2003 and 2010 associated with the observed changes in household assets and other variables and compare these prediction with the observed changes. We report these predictions in Table 8 below. In terms of firewood collections, with an observed change in collection of -6.9 bharis per household, we predict a total change between -6.4 and -8.3 bharis, depending on whether we include changes in consumption levels in addition to asset changes. Among these, the main changes come from the changes in livestock (-1.0), household size (-1.6) and education (-1.6). The rise in collection time per bhari correspond to a fall in collections by 1.7 bharis. For annual fuel expenditures, the observed change is equal to 1199, and our predicted changes vary between 298 and 1066 NPR.

[Insert table 8 here]

5 Firewood Collection and the Local Ecology

In this section we explore variations in household firewood collections arising from changes in the nature of the neighboring forests. We have seen above that household collections decrease with the time taken to collect wood; in turn collection times depend on biomass in neighbouring forests. We have also seen that higher collections are associated with a faster depletion of forest conditions. To the extent these reflect causal impacts, forest stocks could follow a self-correcting dynamic process: high levels of collection today will lower forest stock and thus raise collection times in the future, which will tend to lower future collections. Is there any evidence of such a process operating in Nepal? Could it have played a role in lowering per household collections between 2003 and 2010?

We first provide a simple model corresponding to our estimation strategy. Let the amount of firewood collected by household i in village j and year t be denoted by C_{ijt}. Under the reduced form specification, this is a function of various household assets X_{kijt}, the time taken to collect one unit of firewood T_{jt} and various village characteristics V_{zjt}. In the preceding section we have estimated the following specification:

$$C_{ijt} = \sum_{k=1}^{K} \beta_k X_{kijt} + \phi T_{jt} + \sum_{z=1}^{Z} \gamma_z V_{zjt} + \varepsilon_{ijt} \tag{2}$$

The amount of firewood available in a village depends on forest conditions, as measured by forest biomass, B_{jt}. The more biomass is available in a village, the lower the time necessary to collect one bhari of firewood. Given the possibility of simultaneity biases, we assume that the collection time at time t depends on the biomass available at time $t-1$. We therefore have:

$$T_{jt} = \xi B_{jt-1} + \sum_{z=1}^{Z} \eta_z V_{zjt} + \epsilon_{jt} \tag{3}$$

which can be directly estimated. As collection times depend on forest biomass, equation (1) can also be rewritten in a reduced form way as:

$$C_{ijt} = \sum_{k=1}^{K} \beta_k X_{kijt} + \zeta B_{jt-1} + \sum_{z=1}^{Z} \mu_z V_{zjt} + \nu_{ijt} \tag{4}$$

Combined with equation (1), this generates a dynamic process for the evolution of the forest bio-mass.

We now turn to the estimation of equation (3). Table 9 reports the regression results for the village median collection time per bhari on forest biomass, where the three different measures of biomass will be used in turn: LAI, FPAR and NDVI. (We provide in the Appendix A4 a similar estimation based on individual collection times.) Columns (1), (4) and (7) present the simple correlation between these two variables and columns (2), (5) and (8) correspond to the specification proposed in equation (3) above, where various village controls are added. In the remaining three columns, we allow for the possibility that current total collections in a village have an impact on contemporaneous collection times; we therefore use the densities in household assets (total assets owned in the village divided by the area) to control for these.

As expected, forest biomass has a negative, robust and significant correlation with median collection time per bhari in a village. The coefficients estimated are relatively small in magnitude, as a one standard deviation increase in LAI (+7.37 or about 30%) results in a fall of only 0.22 hours (6%) in collection times (using column (2) estimate). These small effects may partly be due to measurement errors. As explained above, biomass measures, which are constructed as averages over the administrative boundaries of the village, do not correspond to the actual collection points in the forest. By contrast, collection times are directly measured relative to the actual place of collection.

[Insert table 9 here]

Also, the time needed to collect firewood increases with the presence of forest user groups (measured by the proportion of village area managed by a CFUG) by about 1.3 hours per bhari. This is plausibly related to the restricted access but also to the improved collection and lopping practices implemented by CFUGs. However, as CFUGs are created voluntarily by villages, it is difficult to estimate their causal impact on firewood collections. Their creation and the time at which they were created are likely to be affected by prior pressures of deforestation as well as various unobserved political and economic factors. At the household level, membership in a CFUG is also voluntary. Hence the right to collect from a community forest is not exogenous, even when one controls for village characteristics. Given our data, we therefore refrain from drawing any inferences regarding the role of the CFUGs in forest conservation or regeneration.[27] Most of the asset densities and the other village variables are insignificant, with the exception of the altitude variability within a village, which measures ruggedness and is associated with longer collection times.

[Insert table 10 here]

In table 10, we report the correlation between forest biomass and household collections. Columns (2), (5), and (8) correspond to the specification given in equation (4) above. In columns (1), (4) and (7), we replace village controls by a village fixed effect, while in columns (3), (6) and (9), we additionally control for collection time. The estimated coefficient for forest biomass is positive, robust but small. Thus, a one SD increase in LAI is associated with an increase in

[27] For various attempts at identifying the impact of community forest management in Asia, we again refer to Edmonds (2002), Somanathan et al. (2009) and Baland et al. (2010a).

collections by about 4.5 bharis per year (7.37*0.615, from col.(2)). The alternative specifications and the other biomass measures provide somewhat larger estimates. For instance, a one SD increase in NDVI corresponds to an increase in collections by 7.7 bharisper year (887*.0087, from col.(8)).[28] Introducing collection times as an additional control slightly reduces the estimated coefficient which remains significant. This implies that forest biomass is correlated with firewood collections, independently of its relation with collection times. Forest biomass may be related to the easiness in collections, or to the collection of associated forest products that influence positively the collection of firewood, and these effects are not fully captured by collection times.

Household assets display very consistent and similar estimates to those obtained in the reduced form specification presented in Table 5. Also, Community Forest User Groups are correlated with reduced collections (of about 13 bharis) even if the coefficient is imprecisely estimated. When controlling for collection times, the coefficient is systematically lower and looses significance, which supports the idea that CFUGs increase collection times. It remains negative, which may be related to the improved collection or changing cooking and heating practices that may accompany the creation of a CFUG. CFUGs may also play a role in promoting alternative energy sources. Firewood collections also decrease with the presence of biogas installations in the village. In the Appendix (Table A1), we report the estimations obtained with fuel expenditures as the dependent variable, following the same specifications as in Table 10. The results there closely follow the previous results. Fuel expenditures decrease in villages with more abundant forest biomass, lower collection times or farm-based assets, while they increase with education and non-farm business assets.

This last set of estimates allows us to explore whether collections, when excessive, would fall fast enough in the subsequent periods, through their impact on forest biomass and collection times. In other words, the question is whether the possible feedbacks effects on collections are large enough for a stable equilibrium in collections, biomass and collection times to appear.[29] For the sake of the argument, consider that collections caused a 20% reduction in biomass, i.e. a fall of 5 units in LAI. According to Table 9 (col. 3), collection times should then increase by 0.18 hours per bhari. Using the estimates in table 10 (col. 3), firewood collections should then fall by 3.2 bharis per year or 4%, (1% through the increase in collection time, and 3% through the fall in biomass). These estimations indicate relatively weak feedback effects of a degraded biomass on collections. This may be due to the low sensitivity of collections to a degrading forest biomass, either

[28] These values can be compared to the average annual collection of 82 bharis per household.

[29] Since the overall forest biomass remained essentially stable over the period considered, this question remains essentially hypothetical in our context.

directly or indirectly through increasing collection times. This may also be due to the various measurement errors in these estimates, which tend to bias downwards our estimates.

6 Concluding Comments and Relation to Existing Literature

Our main results may be summarized as follows. First, aerial satellite images indicate absence of significant deforestation in the non-Terai regions of rural Nepal between 2003-10. This occurred despite substantial growth in consumption expenditures of households in neighbouring villages. Per household firewood collections fell, offsetting effects of growth in the number of households. These facts provide strong evidence against pessimistic assessments of threats posed by economic growth to forest sustainability. Second, we provide evidence consistent with household substitution of firewood by alternate fuels, a process accompanied (and possibly caused) by changing occupational patterns away from livestock and farm-based occupations, and declining household size - two mechanisms in which migration may play an important role. Third, inferences concerning the size of income effects associated with growth in living standards on the basis of standard EKC-style Engel estimations are highly unreliable and upward biased, owing to omission of relevant household assets as controls.

We now mention some issues neglected in the paper. One point concerns possible problems with measures of deforestation. Aerial satellite image based measures provide estimates of forest cover and biomass, but ignore the quality or composition of the forest. Trees can be heavily lopped. Köhlin and Parks (2001) also discuss the implications of tree species choice in reforestation campaigns in India where plantations can target trees producing fodder and firewood or belonging to species producing good timber but that are not useful as household fuel. Differences in the quality of the wood biomass can actually have non trivial impact in terms of respiratory health for households as explained by Jagger and Shively (2014) in Uganda. The fact that collection times rose 12% in Nepal could reflect a process of deforestation which is not picked up by aerial satellite images or by a progressive change in tree species, something hard to measure by large spectrum remote sensing. More detailed on-the-ground studies are needed to evaluate this possibility. Some of the rise in collection times can however be explained by the growing role of community forest groups. Note also that this issue does not affect the second and third main findings described above.

Concerning related literature, the only longitudinal study on deforestation in South Asia that we are aware of is Foster and Rosenzweig (2003). They used a panel of 250 Indian villages over the last three decades of the 20th century. The satellite imagery data showed evidence of reforestation, while the household data showed increased demand for wood and wood products accompanying the rise in their living standards. They argue that the increasing demand for wood products induced reforestation. Our analysis pertains to a different country and period. In particular, the hilly and mountainous regions of Nepal differ from India in a number of important characteristics: (1) forests are abundant relative to the population, (2) forests are still of an open access nature (though possibly regulated by the CFUG), which implies that households collect according to their needs; and (3) the demand for heating energy in the winter constitutes an important and relatively inelastic component of the demand for firewood in Nepal, for which few substitutes are available.[30] Nevertheless, our paper shares with theirs a common finding of evidence against the pessimistic hypothesis of forest sustainability threats posed by economic growth, and emphasis on accompanying adaptation mechanisms that explain reforestation or absence of deforestation.

Our results are consistent with numerous cross-section studies set in Nepal and rural India which suggest that firewood is a normal good for all but the wealthiest households (see in particular Adhikari et al. (2004); Arnold et al. (2006); Baland et al. (2006); Gundimeda and Kohlin (2008); Heltberg et al. (2000)). The switch of high income households to higher quality but more expensive substitutes (gas or kerosene) is known as the 'energy-ladder' hypothesis, and is often viewed as an important mechanism behind the EKC (see Arnold et al, 2003). Recent evidence from China suggests that firewood is becoming an inferior good in China, with coal emerging as a superior alternative (Démurger and Fournier, 2011). Chaudhuri and Pfaff (2003) find evidence of an EKC in indoor air pollution, using a cross-sectional analysis of the Pakistan World Bank LSMS after controlling for village dummies. While richer households tend to consume more energy, they switch to cleaner and more efficient fuels (kerosene) which reduces the amount of indoor pollution. This is also consistent with an increasing awareness of environmental issues among wealthier households. According to the review of Dinda (2004), this mechanism may be more salient for local pollutants. Baland et al. (2006) also find the demand for firewood in Indian Himalayas is sensitive to the price of kerosene. These earlier findings are consistent with our estimations of the Engel curves for fuelwood, as well as for expenditures on other fuels. However, the evidence concerning EKC in earlier literature has been based on cross-sectional analyses, without checks for robustness with respect to unobserved heterogeneity, functional form or measurement error. More importantly, the role of occupation patterns accompanying growth has not been examined in this literature. Closest

[30] In the same vein, Nepal et al. (2011) show that improved cookstoves had little impact on firewood collections in Nepal. This finding supports the idea of an inelastic demand for firewood.

to our analysis is Baland et al. (2010b), which was based on a cross section Nepal LSMS of 1995, and argued that the structure of productive assets was a major determinant of firewood collections.[31] The findings of that paper are strengthened by the results of this paper, thereby providing additional evidence supporting findings reported in the review of Cooke et al. (2008).

Our results on CFUGs tend to support the findings of Somanathan et al. (2009) and, to a lesser extent, of Baland et al. (2010a), who showed that the impact of community forestry in Northern India on the state of the forest was quite limited. While the presence of a CFUG is associated with higher collection times and lower collections, they do not seem to affect forest biomass in our estimates. Our results are also consistent with those obtained by Edmonds (2002) who found that the creation of CFUGs in Nepal tends to reduce fuelwood extraction from forests (see also the recent surveys by Kanel (2008) and Shyamsundar and Ghate (2011)). The methodology used in those studies deals explicitly with the possibility of a selection bias in the creation of the CFUGs, a problem that we could not satisfactorily address with the present data set. For this reason we avoid drawing any inferences regarding the causal impact of CFUGs.

At a methodological level, our finding that estimated Engel curve relationships are not robust to the inclusion of relevant controls suggests this weakness may affect other cross-sectional analyses of the EKC as well. Projections focusing on wealth effects alone on the basis of simple EKCs can yield very misleading conclusions about the sustainability of economic development. We showed the importance of widening conceptions of economic growth from rising living standards to accompanying structural changes in occupational patterns and household demographics that induce various substitution effects that help relieve environmental pressures.

[31] See Bluffstone (1995) for similar cross-sectional evidence concerning the role of occupational structure in firewood collections.

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References

Adhikari, B., Di Falco, S., and Lovett, J. C. (2004). Household characteristics and forest dependency: evidence from common property forest management in Nepal. *Ecological Economics*, 48(2):245–257.

Alix-Garcia, J., McIntosh, C., Sims, K. R. E., and Welch, J. R. (2013). The Ecological Footprint of Poverty Alleviation: Evidence from Mexico's Oportunidades Program. *The Review of Economics and Statistics*, 95(2):417–435.

Amacher, G., Ersado, L., Grebner, D. L., and Hyde, W. (2004). Disease, Microdams and Natural Resources in Tigray, Ethiopia: Impacts on Productivity and Labour Supplies. *Journal of Development Studies*, 40(6):122–145.

Amacher, G. S., Hyde, W. F., and Kanel, K. R. (1996). Household fuelwood demand and supply in Nepal's tarai and Mid-Hills: Choice between cash outlays and labor opportunity. *World Development*, 24(11):1725 – 1736.

Angelsen, A., Jagger, P., Babigumira, R., Belcher, B., Hogarth, N. J., Bauch, S., Borner, J., Smith-Hall, C., and Wunder, S. (2014). Environmental Income and Rural Livelihoods: A Global-Comparative Analysis. *World Development*, 64(S1):12–28.

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

Arrow, K., Bolin, B., Costanza, R., Dasgupta, P., Folke, C., Holling, C. S., Jansson, B.-O., Levin, S., Mäler, K.-G., Perrings, C., and Pimentel, D. (1995). Economic growth, carrying capacity, and the environment. *Science*, 268:520–521.

Baland, J.-M., Bardhan, P., Das, S., and Mookherjee, D. (2010a). Forests to the people: Decentralization and forest degradation in the Indian Himalayas. *World Development*, 38(11):1642 – 1656.

Baland, J.-M., Bardhan, P., Das, S., Mookherjee, D., and Sarkar, R. (2006). Managing the environmental consequences of growth: Forest degradation in the Indian Mid-Himalayas. *Indian Policy Forum*, 3(1):125–277.

Baland, J.-M., Bardhan, P., Das, S., Mookherjee, D., and Sarkar, R. (2010b). The environmental impact of poverty: Evidence from firewood collection in rural Nepal. *Economic Development and Cultural Change*, 59(1):23–61.

Baland, J.-M., Das, S., and Mookerjee, D. (2014). *Environment and Development Economics: Essays in Honour of Sir Partha Dasgupta*, chapter Forest Degradation in the Himalayas: Determinant and Policy Options, pages 202–240. Oxford University Press.

Baland, J.-M. and Platteau, J.-P. (1996). *Halting degradation of natural resources - Is there a role for rural communites.* Oxford: Oxford University Press.

Baltagi, B. H. and Li, D. (2002). Series estimation of partially linear panel data models with fixed effects. *Annals of Economics and Finance*, 3(1):103–116.

Barbier, E. B. (1997). Introduction to the environmental Kuznets curve special issue. *Environment and Development Economics*, 2(04):357–367.

Barbier, E. B. (1998). *The economics of environment and development: Selected essays*, chapter The concept of sustainable economic development and natural capital and the economics of environment and development. Edward Elgar.

Barbier, E. B. (2010). Poverty, development, and environment. *Environment and Development Economics*, 15:635–660.

Barbier, E. B., Sanchez, P., Thomas, R., and Wagner, A. (1997). The economic determinants of land degradation in developing countries [and discussion]. *Philosophical Transactions: Biological Sciences*, 352(1356):891–899.

Bluffstone, R. A. (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(1):42–63.

Bohara, A. K., Mitchell, N. J., and Nepal, M. (2006). Opportunity, democracy, and the exchange of political violence: A subnational analysis of conflict in Nepal. *Journal of Conflict Resolution*, 50(1):108–128.

Chaudhuri, S. and Pfaff, A. S. (2003). Fuel-choice and indoor air quality: a household-level perspective on economic growth and the environment. Technical report, Columbia University.

Cooke, P., Köhlin, G., and Hyde, W. F. (2008). Fuelwood, forests and community management: evidence from household studies. *Environment and Development Economics*, 13(1):103–135.

Couture, S., Garcia, S., and Reynaud, A. (2012). Housheold energy choices and fuelwood consumption: an econometric approach unsing french data. *Energy Economics*, 34:1972–1981.

Dasgupta, P. (1995). The population problem: Theory and evidence. *Journal of Economic Literature*, 33(4):1879–1902.

Dasgupta, P., Levine, S., and Lubchenco, J. (2000). Economic pathways to ecological sustainability. *Bioscience*, 50(4):339–345.

Dasgupta, P. and Mäler, K.-G. (1995). Poverty, institutions, and the environmental resource-base. In Behrman, J. and Srinivasan, T., editors, *Handbook of Development Economics*, volume 3, Part 1, chapter 39, pages 2371 – 2463. Elsevier.

Démurger, S. and Fournier, M. (2011). Poverty and firewood consumption: A case study of rural households in northern China. *China Economic Review*, 22(4):512–523.

Dinda, S. (2004). Environmental kuznets curve hypothesis: A survey. *Ecological Economics*, 49(4):431 – 455.

Do, Q.-T. and Iyer, L. (2010). Geography, poverty and conflict in Nepal. *Journal of Peace Research*, 47(6):735–748.

Duraiappah, A. K. (1998). Poverty and environmental degradation: A review and analysis of the nexus. *World Development*, 26(12):2169–2179.

Edmonds, E. V. (2002). Government-initiated community resource management and local resource extraction from Nepal's forests. *Journal of Development Economics*, 68(1):89–115.

FAO (2016). FAOSTAT database collections.

Foster, A. and Rosenzweig, M. (2003). Economic growth and the rise of forests. *Quarterly Journal of Economics*, 118(2):601–637.

Glenn, E. P., Huete, A., Nagler, P. L., and Nelson, S. G. (2008). Relationship between remotely-sensed vegetation indices, canopy attributes and plant physiological processes: What vegetation indices can and cannot tell us about the landscape. *Sensors*, 8:2136–2160.

Grossman, G. M. and Krueger, A. B. (1995). Economic growth and the environment. *The Quarterly Journal of Economics*, 110(2):353–77.

Gundimeda, H. and Kohlin, G. (2008). Fuel demand elasticities for energy and environmental policies: Indian sample survey evidence. *Energy Economics*, 30(2):517–546.

Hatlebakk, M. (2010). Maoist control and level of civil conflict in Nepal. *South Asia Economic Journal*, 11(1):99–110.

Heltberg, R., Arndt, T. C., and Sekhar, N. U. (2000). Fuelwood consumption and forest degradation: A household model for domestic energy substitution in rural India. *Land Economics*, 76(2):213–232.

Jagger, P. and Shively, G. (2014). Land use change, fuel use and respiratory health in Uganda. *Energy Policy*, 67:713 – 726.

Jalal, K. (1993). *Sustainable development, environment and poverty nexus*. Asia Development Bank.

Kanel, K. R. (2008). *Promise, trust and evolution*, chapter So far so good: Next steps in Community forestry, pages 370–390. Oxford: Oxford University Press.

Köhlin, G. and Parks, P. J. (2001). Spatial Variability and Disincentives to Harvest: Deforestation and Fuelwood Collection in South Asia. *Land Economics*, 77(2):206–218.

Kumar, S. K. and Hotchkiss, D. (1988). Consequences of deforestation for women's time allocation, agricultural production, and nutrition in hill areas of Nepal:. Research reports 69, International Food Policy Research Institute (IFPRI).

Lele, S. M. (1991). Sustainable development: A critical review. *World Development*, 19(6):607–621.

Libois, F. (2016). Households in times of war: Adaptation strategies during the Nepal civil war. Technical report, CRED, University of Namur.

Libois, F. and Verardi, V. (2013). Semiparametric fixed-effects estimator. *Stata Journal*, 13(2):329–336.

Lopez, R. (1998). *1997 Annual World Bank Conference in Development Economics*, chapter Where Development Can or Cannot Go: The Role of Poverty-Environment Linkages. Washington D.C.

Maler, K. G. (1998). *1997 Annual World Bank Conference in Development Economics*, chapter Environment, Poverty and Economic Growth. Washington D.C.

Myneni, R., Hoffman, S., Knyazikhin, Y., Privette, J., Glassy, J., Tian, Y., Wang, Y., Song, X., Zhang, Y., Smith, G., Lotsch, A., Friedl, M., Morisette, J., Votava, P., Nemani, R., and Running, S. (2002). Global products of vegetation leaf area and fraction absorbed PAR from year one of MODIS data. *Remote Sensing of Environment*, 83(1-2):214–231. The Moderate Resolution Imaging Spectroradiometer (MODIS): a new generation of Land Surface Monitoring.

Narain, U., Gupta, S., and van 't Veld, K. (2008). Poverty and the environment: Exploring the relationship between household incomes, private assets, and natural assets. *Land Economics*, 84(1):148–167.

Nepal, M., Nepal, A., and Grimsrud, K. (2011). Unbelievable but improved cookstoves are not helpful in reducing firewood demand in Nepal. *Environment and Development Economics*, 16(01):1–23.

Oli, B. N. and Shrestha, K. (2009). Carbon status in forest of Nepal: An overview. *Journal of Forest and Livelihood*, 8:63–67.

Shyamsundar, P. and Ghate, R. (2011). Rights, responsibilities and resources: Examining community forestry in South Asia. Working papers 59, The South Asian Network for Development and Environmental Economics.

Solano, R., Didan, K., Jacobson, A., and Huete, A. (2010). MODIS Vegetation Index user's guide: MOD13 Series. Technical report, The University of Arizona.

Somanathan, E., Prabhakar, R., and Mehta, B. S. (2009). Decentralization for cost-effective conservation. *Proceedings of the National Academy of Sciences of the United States of America*, 106(11):4143–4147.

Stern, D. I. (2004). The rise and fall of the Environmental Kuznets Curve. *World Development*, 32:1419–1439.

UNEP (2011). Forest management in Nepal. http://www.unep.org/ greeneconomy/ SuccessStories/ ForestManagementinNepal/ tabid/29869/Default.aspx. Accessed: 2015-08-27.

Word Bank (2000). *India: alleviating poverty through forest development.*

Yandle, B., Vijayaraghavan, M., and Bhattarai, M. (2002). *The environment Kuznets Curve: a primer.* Political Economy Research Center, Center for Free Market Environmentalism, Montana.

Figure 1: Evolution of biomass in surveyed villages in the 2000's

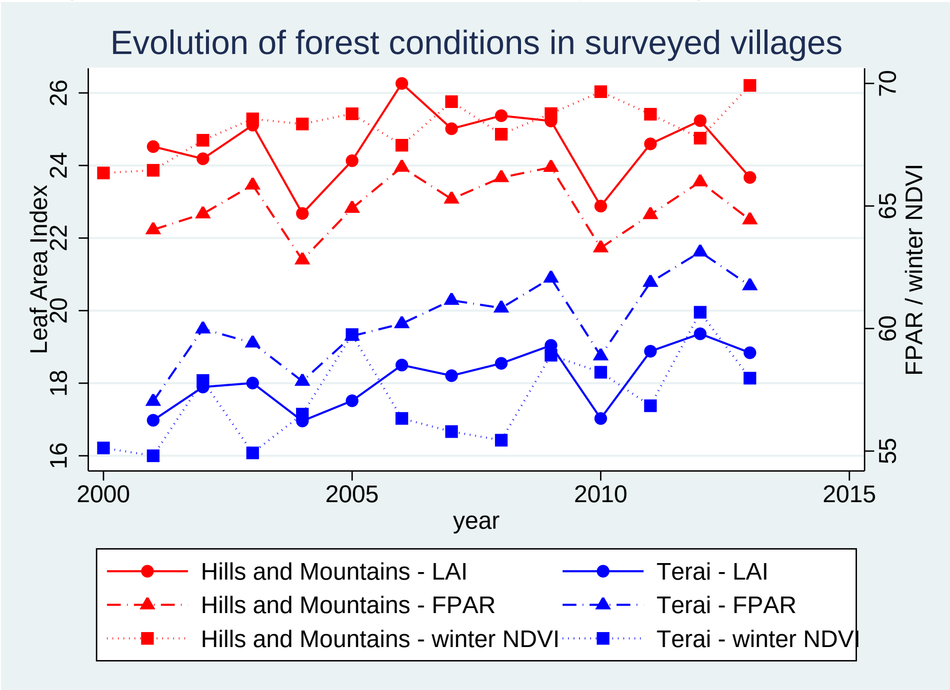
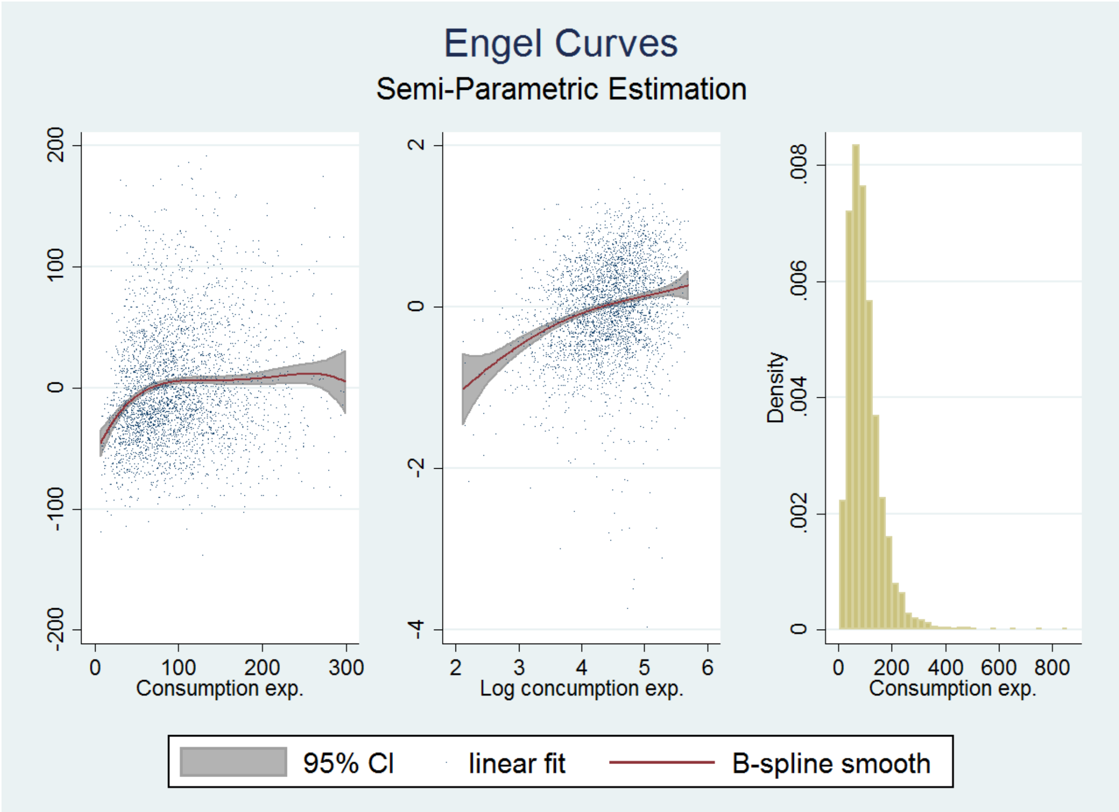


Figure 2: Annual firewood demand in bharis as a function of annual consumption



The semi-parametric estimation of the Engel curve includes controls for the share of the village area managed by community forest user groups, the number of biogas installations per household in the village, the median access time to road, the village median altitude and altitude standard deviation, number of people killed in the 20km around the village in the previous year, as well as previous year snow cover, rainfall deviation, cooling degree days and monsoon growing degree days. It also includes as belt-zone fixed effects. The estimation procedure relies on Baltagi and Li (2002) following the implementation of Libois and Verardi (2013). The top 1% of firewood collection and consumption expenditures have been trimmed.

Table 1: Degradation of forest and annual firewood collection

	Δ LAI 90^{th} percentile			Δ FPAR 90^{th} percentile			Δ NDVI winter max		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Collection densities	-0.000129	-0.000150*	-0.000205**	-0.000170*	-0.000176**	-0.000207**	-0.000113*	-0.0000955	-0.000102
	(-1.59)	(-1.94)	(-2.26)	(-1.94)	(-2.19)	(-2.27)	(-1.78)	(-1.61)	(-1.52)
LAI $90^{th} percentile_{t-1}$	0.0378	-0.312							
	(0.26)	(-1.31)							
LAI $90^{th} percentile^2_{t-1}$	-0.00384	-0.00223							
	(-1.37)	(-0.51)							
LAI $90^{th} percentile_{t-2}$		0.387	-0.0928						
		(1.63)	(-0.62)						
LAI $90^{th} percentile^2_{t-2}$		-0.00130	-0.00132						
		(-0.28)	(-0.46)						
FPAR $90^{th} percentile_{t-1}$				0.0743	0.825				
				(0.49)	(1.56)				
FPAR $90^{th} percentile^2_{t-1}$				-0.00173	-0.0106***				
				(-1.50)	(-2.64)				
FPAR $90^{th} percentile_{t-2}$					-0.760	-0.0692			
					(-1.47)	(-0.36)			
FPAR $90^{th} percentile^2_{t-2}$					0.00967**	-0.000602			
					(2.42)	(-0.41)			
$100\times$ NDVI winter $\max_{t-1}$							-0.0447	0.469	
							(-0.44)	(0.78)	
$100\times$ NDVI winter $\max^2_{t-1}$							0.00000838	-0.00788*	
							(0.01)	(-1.77)	
$100\times$ NDVI winter $\max_{t-2}$								-0.558	-0.0854
								(-0.92)	(-1.09)
$100\times$ NDVI winter $\max^2_{t-2}$								0.00837*	0.0000815
								(1.85)	(0.14)
Year fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Belt-Zone fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Village level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	301	301	301	301	301	301	301	301	301
Dep. variable: mean	-1.43		-.91	-1.59		-.53	.61		1.62
Dep. variable: std. dev.	2.93		3.24	3.65		3.66	2.1		1.98

Standard errors robust to heteroskedasticity – t-statistics in parentheses, $^{*}p < 0.1,^{**} p < 0.05,^{***} p < 0.01$

Village level controls include the share of the village area managed by community forest user groups, the number of biogas installations per household in the village, the median access time to road, village median altitude and altitude standard deviation, number of people killed in the 20km around the village in the previous ear, as well as previous year snow cover, rainfall deviation, cooling degree days and monsoon growing degree days.

Table 2: Engel curves

	(1) Wood	(2) Wood	(3) Wood	(4) lnwood	(5) Wood
Consumption exp.	0.372***	0.246***	0.271***		0.170***
	(8.03)	(5.23)	(6.02)		(4.03)
Consumption exp.^{2}	-0.000539***	-0.000429***	-0.000450***		-0.000291***
	(-4.37)	(-4.46)	(-4.50)		(-3.57)
Log. consumption exp.				0.283***	
				(12.09)	
Household size					5.950***
					(10.62)
Med. collection time		-3.123*	-4.382***	-0.0404**	
		(-1.96)	(-2.68)	(-2.32)	
Village controls	No	No	Yes	Yes	No
Year fixed-effects	Yes	Yes	Yes	Yes	Yes
Other fixed-effects	Village	Belt-Zone	Belt-Zone	Belt-Zone	Village
Observations	3590	3590	3590	3343	3590
Est. turning point	344.93	286.38	301.15	NA	292.32

Standard errors robust to heteroskedasticity – t-statistics in parentheses, $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

Village level controls include the share of the village area managed by community forest user groups, the number of biogas installations per household in the village, the median access time to road, village median altitude and altitude standard deviation, number of people killed in the 20km around the village in the previous year, as well as previous year snow cover,rainfall deviation, cooling degree days and monsoon growing degree days.

Table 3: Changes in annual firewood collections

Year	Wood collected in bharis per year	Frequent consumption exp. in $1000NPR_{2010}$ per year
2003	85.84	74.92
	(55.20)	(47.43)
2010	78.91	119.19
	(61.68)	(67.11)
Observed change	-6.93	+44.28
Predicted change in wood collection based on Δ consumption		
+8.51	*Semi-parametric estimation based on Figure 2, specification (1)*	
+7.44	*Parametric estimation based on Table 2, specification (3)*	
+4.38	*Parametric estimation based on Table 2, specification (5)*	
Predicted change in wood collection based on Δ consumption and Δ household size		
+2.97	*Parametric estimation based on Table 2, specification (5)*	

Table 4: Descriptive statistics: Main household variables

Variable / Survey wave	Mean 2003	Mean 2010
Big livestock	3.53	3.15
Land owned, ha	.68	.61
Household size	5.02	4.79
Prop. Female	0.35	0.37
Prop. Children	0.39	0.37
Avg. education (yrs)	2.41	3.16
Prop with Non-Farm Business	.22	.28
Number of migrants	0.40	0.80
Prop. agri. working time	.82	.72
Consumption exp. (1000NPR/yr)	74.9	119.2
Firewood (bharis/yr)	86	79
Collection time (hrs/bhari)	3.5	3.9
Fuel expenditures (NPR/yr)	1979	2578

Descriptive statistics for the repeated cross-sections of NLSS in rural villages.

All differences statistically different at the 5% threshold.

All monetary values expressed in NPR_{2010}.

Table 5: Annual firewood collection

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Wood	Wood	Wood	Wood	Wood	Wood	Wood
Consumption exp.	0.0957**	0.189***	0.0996**	0.174***	0.0815	0.101	
	(2.15)	(4.48)	(2.03)	(3.79)	(0.88)	(1.57)	
Consumption exp.^{2}	-0.000214***	-0.000312***	-0.000214***	-0.000286***	-0.000148	-0.000206**	
	(-2.86)	(-3.81)	(-2.65)	(-3.37)	(-0.48)	(-2.16)	
Prop. agri. worktime	26.19***	16.65***					
	(6.99)	(4.82)					
Big livestock			2.529***	2.171***	2.213***	2.887***	2.640***
			(4.73)	(4.11)	(3.08)	(3.97)	(4.94)
Land owned, ha			3.701*	0.479	6.013**	1.325	4.129**
			(1.96)	(0.26)	(2.29)	(0.58)	(2.20)
Household size	7.296***	5.991***	6.175***	5.440***	7.312***	5.176***	6.550***
	(12.03)	(10.76)	(8.35)	(7.74)	(8.74)	(4.89)	(10.96)
Prop. female			1.384	-5.726	-11.78*	0.516	1.362
			(0.26)	(-1.01)	(-1.75)	(0.07)	(0.25)
Prop. children			-3.119	-7.548	-5.314	-3.491	-3.008
			(-0.63)	(-1.47)	(-0.80)	(-0.49)	(-0.62)
Avg. education			-2.360***	-1.299***	-1.886***	-2.412***	-2.126***
			(-5.84)	(-3.01)	(-3.80)	(-4.65)	(-5.66)
= 1 if non-farm Bus.			-6.416***	-5.433**	-6.911*	-5.746**	-6.018***
			(-2.81)	(-2.58)	(-1.95)	(-2.15)	(-2.71)
# Migrants			-1.276	1.744*	3.825**	-1.480	-1.207
			(-1.22)	(1.75)	(2.08)	(-1.26)	(-1.15)
Med. collection time	-4.163***		-4.055***		-1.878	-6.625***	-4.083***
	(-2.87)		(-2.79)		(-1.09)	(-3.07)	(-2.83)
% of Vil. area in FUG	-9.149		-8.210		-41.43**	6.506	-7.630
	(-0.82)		(-0.74)		(-2.47)	(0.52)	(-0.69)
Biogas per household	-57.02*		-58.75*		-107.4	-34.21	-54.81
	(-1.66)		(-1.70)		(-1.45)	(-0.95)	(-1.61)
Year fixed-effects	Yes	Yes	Yes	Yes	2003	2010	Yes
Spatial fixed-effects	Belt-zone	Village	Belt-zone	Village	Belt-zone	Belt-zone	Belt-zone
Village controls	Yes	NA	Yes	NA	Yes	Yes	Yes
Observations	3590	3590	3590	3590	1474	2116	3590
Turning point	223.47	303.48	232.2	304.19	275.28	245.33	NA

Standard errors clustered at the village level, t-statistics in parentheses, $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

Village level controls include median access time to road, village median altitude and altitude standard deviation, number of people killed in the 20km around the village in the previous year, as well as previous year snow cover, rainfall deviation, cooling degree days and monsoon growing degree days.

Table 6: Consumption and occupational patterns: determinants

	Annual consumption exp.		Prop. agricultural worktime	
	(1)	(2)	(3)	(4)
Big livestock	1.658***	0.646	0.0187***	0.0223***
	(3.61)	(1.41)	(7.80)	(9.09)
Land owned, ha	14.71***	12.83***	0.0101	0.0263***
	(8.39)	(7.74)	(1.48)	(3.61)
Household size	9.882***	9.964***	-0.0110***	-0.0111***
	(13.93)	(13.88)	(-4.40)	(-4.51)
Prop. children	-13.69***	-16.16***	0.128***	0.150***
	(-2.75)	(-3.33)	(4.46)	(5.52)
Prop. female	-0.628	4.451	0.206***	0.194***
	(-0.11)	(0.78)	(5.92)	(5.85)
Avg. education	4.987***	6.500***	-0.0170***	-0.0227***
	(12.49)	(13.04)	(-7.79)	(-10.11)
= 1 if non-farm Bus.	9.914***	10.60***	-0.252***	-0.265***
	(4.41)	(4.55)	(-17.40)	(-19.90)
# Migrants	0.0148	-0.0631	0.0425***	0.0385***
	(0.01)	(-0.06)	(7.43)	(7.14)
Med. collection time		-0.470		0.00405
		(-0.42)		(0.72)
% of Vil. area in FUG		11.49		-0.0453
		(1.46)		(-1.08)
Biogas per household		64.18**		-0.322**
		(2.00)		(-2.06)
Year F.E.	Yes	Yes	Yes	Yes
Spatial fixed effects	Village	Belt-Zone	Village	Belt-Zone
Village controls	No	Yes	No	Yes
Observations	3590	3590	3590	3590

Standard errors clustered at the village level, t-statistics in parentheses, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Village level controls include median access time to road, village median altitude and altitude standard deviation, number of people killed in the 20km around the village in the previous year, as well as previous year snow cover, rainfall deviation, cooling degree days and monsoon growing degree days.

Table 7: Fuel expenditures in NPR_{2010} per year

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Fuel exp.	Fuel exp.	Fuel exp.	Fuel exp.	Fuel exp.	Fuel exp.	Fuel exp.
Consumption exp.	16.25**	12.94*	18.40**	13.99*	28.20***	20.20**	
	(2.21)	(1.83)	(2.31)	(1.86)	(3.86)	(2.11)	
Consumption exp.^{2}	0.00556	0.00860	0.00266	0.00712	-0.0412	0.00174	
	(0.24)	(0.40)	(0.11)	(0.32)	(-1.61)	(0.07)	
Prop. agri. worktime	-1695.2***	-1135.1***					
	(-5.24)	(-4.44)					
Big livestock			-158.7***	-86.94***	-105.6***	-213.6***	-140.2***
			(-3.70)	(-2.61)	(-3.09)	(-3.16)	(-3.20)
Land owned, ha			-355.5***	-138.6	-309.3**	-381.4**	-114.1
			(-3.27)	(-1.53)	(-2.28)	(-2.19)	(-1.13)
Household size	-137.9***	-80.46**	-57.44	-49.23	-28.26	-92.53	133.8***
	(-3.20)	(-2.04)	(-1.04)	(-0.98)	(-0.71)	(-1.08)	(2.79)
Prop. female			22.11	665.2*	749.2**	-369.3	87.91
			(0.06)	(1.89)	(2.56)	(-0.69)	(0.24)
Prop. children			-162.2	488.3	11.37	-198.9	-470.3
			(-0.42)	(1.32)	(0.03)	(-0.36)	(-1.19)
Avg. education			102.5***	80.24***	101.4**	74.39*	224.0***
			(3.28)	(3.15)	(2.45)	(1.91)	(6.48)
= 1 if non-farm Bus.			229.8	269.8*	768.6***	-69.58	419.0**
			(1.37)	(1.82)	(3.21)	(-0.35)	(2.50)
# Migrants			-167.5**	-60.45	-95.28	-170.0	-166.9**
			(-2.16)	(-1.02)	(-1.55)	(-1.60)	(-2.14)
Med. collection time	344.9**		336.0**		-86.83	501.5***	342.4**
	(2.57)		(2.56)		(-1.23)	(2.65)	(2.54)
% of Vil. area in FUG	895.7		867.2		291.3	671.0	1036.4
	(1.33)		(1.32)		(0.40)	(0.88)	(1.45)
Biogas per household	-5471.9**		-5601.0**		-4211.2	-6403.6**	-4244.9
	(-2.29)		(-2.32)		(-1.55)	(-2.46)	(-1.59)
Year fixed-effects	Yes	Yes	Yes	Yes	2003	2010	Yes
Spatial fixed-effects	Belt-zone	Village	Belt-zone	Village	Belt-zone	Belt-zone	Belt-zone
Village controls	Yes	NA	Yes	NA	Yes	Yes	Yes
Observations	3590	3590	3590	3590	1474	2116	3590
Turning point	-1462.05	-752.51	-3463.19	-982.64	342.17	-5796.01	NA

Standard errors clustered at the village level, t-statistics in parentheses, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Village level controls include median access time to road, village median altitude and altitude standard deviation, number of people killed in the 20km around the village in the previous year, as well as previous year snow cover, rainfall deviation, cooling degree days and monsoon growing degree days.

Table 8: Observed and predicted changes in annual firewood collections and fuel expenditures

Determinant	Change	Predicted effect			
		Firewood collection		Fuel expenditures	
		specification (3)	specification (7)	specification (3)	specification (7)
Consumption exp.	+44.27	+2.08		+843	
Big livestock	-.38	-.96	-1.00	+60	+53
Land owned, ha	-.08	-.28	-.32	+27	+9
Household size	-.24	-1.46	-1.55	+14	-32
Prop. female	+.02	+.02	+.02	+0	+2
Prop. children	-.02	+.05	+.05	+3	+8
Avg. education	+.74	-1.75	-1.58	+76	+166
= 1 if non-farm Bus.	+.06	-.39	-.36	+14	+25
# Migrants	+.40	-.51	-.48	-67	-67
Med. collection time	+.41	-1.66	-1.67	+137	+140
% of Vil. area in FUG	+.06	-.53	-.49	+56	+67
Biogas per household	+.02	-1.02	-.95	-97	-73
Total Predicted Change		-6.41	-8.33	+1066	+298
Observed Change		-6.93		+1199	

Table 9: Village median collection time per bhari

	Median village collection time in hours per bhari								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
LAI $90^{th} percentile_{t-1}$	-0.0400***	-0.0292**	-0.0351**						
	(-3.17)	(-2.01)	(-2.29)						
FPAR $90^{th} percentile_{t-1}$				-0.0344***	-0.0361***	-0.0378***			
				(-4.17)	(-2.73)	(-2.79)			
NDVI winter max $_{t-1}$							-0.000271**	-0.000305*	-0.000372**
							(-2.37)	(-1.90)	(-2.36)
% of Vil. area in FUG		1.402***	1.235**		1.388***	1.255**		1.507***	1.340**
		(2.64)	(2.40)		(2.62)	(2.41)		(2.84)	(2.59)
Biogas density		-1.684	-2.776		-1.755	-2.730		-1.390	-2.392
		(-0.85)	(-1.52)		(-0.90)	(-1.51)		(-0.70)	(-1.30)
Livestock density			-0.00215			-0.00183			-0.00172
			(-1.03)			(-0.90)			(-0.82)
Farm land density			-0.00143			-0.00113			-0.00254
			(-0.28)			(-0.22)			(-0.49)
Population density			0.00277**			0.00271**			0.00264**
			(2.19)			(2.16)			(2.10)
Prop. female density			-0.0132			-0.0116			-0.0106
			(-1.02)			(-0.91)			(-0.84)
Prop. child. density			-0.00375			-0.00506			-0.00809
			(-0.38)			(-0.50)			(-0.80)
Education density			-0.00147**			-0.00140**			-0.00138**
			(-2.08)			(-1.97)			(-1.99)
Non-farm business density			0.00420			0.00313			0.00477
			(0.75)			(0.55)			(0.83)
Out-migrant density			0.00897***			0.00839***			0.00807***
			(2.86)			(2.69)			(2.63)
Year fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Belt-Zone fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Village controls	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Observations	301	301	301	301	301	301	301	301	301

Standard errors robust to heteroskedasticity – t-statistics in parentheses, $^{*}p < 0.1,^{**} p < 0.05,^{***} p < 0.01$

Village level controls include median access time to road, village median altitude and altitude standard deviation, number of people killed in the 20km around the village in the previous year, as well as previous year snow cover, rainfall deviation, cooling degree days and monsoon growing degree days.

Table 10: Annual firewood collection

	Firewood collections in number of bharis per year								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
LAI $90^{th} percentile_{t-1}$	0.522***	0.615***	0.501**						
	(3.67)	(3.70)	(3.07)						
FPAR $90^{th} percentile_{t-1}$				0.235*	0.501**	0.364*			
				(2.36)	(3.07)	(2.26)			
NDVI winter max $_{t-1}$							0.00529***	0.00873***	0.00756***
							(4.45)	(4.22)	(3.62)
% of Vil. area in FUG		-12.98*	-7.588		-13.00*	-7.566		-15.60*	-9.835
		(-2.16)	(-1.22)		(-2.16)	(-1.22)		(-2.57)	(-1.56)
Biogas per household		-38.33	-45.55		-41.76	-49.08*		-41.91	-48.10*
		(-1.61)	(-1.92)		(-1.75)	(-2.07)		(-1.75)	(-2.02)
Med. collection time			-3.731***			-3.793***			-3.721***
			(-4.70)			(-4.76)			(-4.64)
Big livestock	2.952***	2.687***	2.646***	2.954***	2.652***	2.620***	2.870***	2.655***	2.619***
	(6.93)	(6.23)	(6.14)	(6.92)	(6.15)	(6.09)	(6.70)	(6.16)	(6.09)
Land owned, ha	4.613**	4.193**	3.960*	4.661**	4.154**	3.948*	4.639**	4.010*	3.791*
	(2.94)	(2.63)	(2.48)	(2.95)	(2.60)	(2.46)	(2.94)	(2.52)	(2.38)
Household size	6.341***	6.534***	6.561***	6.339***	6.531***	6.558***	6.345***	6.519***	6.548***
	(11.86)	(12.23)	(12.33)	(11.82)	(12.20)	(12.31)	(11.88)	(12.22)	(12.33)
Prop. female	0.501	2.696	2.455	-0.302	2.036	1.857	0.0935	2.692	2.519
	(0.09)	(0.50)	(0.46)	(-0.06)	(0.38)	(0.35)	(0.02)	(0.50)	(0.47)
Prop. children	-2.334	-2.560	-2.817	-2.460	-2.754	-2.980	-2.407	-2.247	-2.535
	(-0.50)	(-0.55)	(-0.61)	(-0.52)	(-0.59)	(-0.64)	(-0.51)	(-0.48)	(-0.55)
Avg. education	-2.211***	-1.956***	-2.038***	-2.263***	-1.981***	-2.066***	-2.217***	-1.902***	-1.986***
	(-6.83)	(-5.92)	(-6.20)	(-6.95)	(-5.98)	(-6.26)	(-6.84)	(-5.74)	(-6.02)
= 1 if non-farm Bus.	-6.337**	-6.288**	-6.103**	-6.194**	-6.088**	-5.948**	-5.966**	-6.097**	-5.942**
	(-3.00)	(-2.95)	(-2.87)	(-2.92)	(-2.85)	(-2.80)	(-2.81)	(-2.86)	(-2.80)
# Migrants	-1.379	-1.346	-1.221	-1.309	-1.232	-1.136	-1.365	-1.168	-1.067
	(-1.38)	(-1.36)	(-1.24)	(-1.31)	(-1.25)	(-1.16)	(-1.38)	(-1.18)	(-1.08)
Year fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Belt-Zone fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Village controls	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Observations	3590	3590	3590	3590	3590	3590	3590	3590	3590

Standard errors robust to heteroskedasticity – t-statistics in parentheses, $^{*}p < 0.1,^{**} p < 0.05,^{***} p < 0.01$

Village level controls include median access time to road, village median altitude and altitude standard deviation, number of people killed in the 20km around the village in the previous year, as well as previous year snow cover, rainfall deviation, cooling degree days and monsoon growing degree days.

A Appendix

Table A1: Annual fuel expenditures in NPR_{2010}

	Annual fuel expenditures in NPR_{2010}								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
LAI $90^{th} percentile_{t-1}$	-60.62***	-50.52***	-40.96***						
	(-5.74)	(-4.24)	(-3.38)						
FPAR $90^{th} percentile_{t-1}$				-43.09***	-47.50***	-36.23**			
				(-5.19)	(-4.30)	(-3.19)			
NDVI winter max $_{t-1}$							-0.575***	-0.760***	-0.662***
							(-4.77)	(-4.07)	(-3.50)
% of Vil. area in FUG		1486.7**	1033.0*		1479.3**	1030.1*		1711.3***	1229.5**
		(3.14)	(2.31)		(3.13)	(2.31)		(3.56)	(2.71)
Biogas per household		-5608.9***	-5001.7***		-5419.7***	-4815.0***		-5349.0***	-4832.8***
		(-4.39)	(-3.97)		(-4.30)	(-3.87)		(-4.19)	(-3.84)
Med. collection time			313.6***			313.6***			310.7***
			(5.08)			(5.09)			(5.15)
Big livestock	-161.2***	-144.1***	-140.7***	-158.8***	-140.8***	-138.2***	-152.6***	-141.3***	-138.3***
	(-5.09)	(-4.54)	(-4.49)	(-4.99)	(-4.42)	(-4.39)	(-4.79)	(-4.44)	(-4.39)
Land owned, ha	-93.21	-119.9	-100.3	-98.61	-113.2	-96.17	-96.37	-102.9	-84.53
	(-0.98)	(-1.24)	(-1.03)	(-1.04)	(-1.16)	(-0.99)	(-1.03)	(-1.06)	(-0.87)
Household size	137.8***	135.1***	132.9***	140.2***	135.2***	133.0***	137.0***	136.4***	133.9***
	(3.43)	(3.35)	(3.31)	(3.48)	(3.34)	(3.31)	(3.42)	(3.38)	(3.34)
Prop. female	24.28	-21.70	-1.407	126.1	23.88	38.65	73.71	-27.84	-13.43
	(0.07)	(-0.06)	(-0.00)	(0.37)	(0.07)	(0.12)	(0.22)	(-0.08)	(-0.04)
Prop. children	-468.8	-507.5	-485.9	-440.6	-491.8	-473.1	-461.6	-535.7	-511.7
	(-1.38)	(-1.50)	(-1.45)	(-1.30)	(-1.45)	(-1.41)	(-1.37)	(-1.59)	(-1.53)
Avg. education	211.5***	209.9***	216.8***	219.4***	211.0***	218.0***	212.4***	204.7***	211.7***
	(7.46)	(7.68)	(7.94)	(7.67)	(7.67)	(7.93)	(7.51)	(7.61)	(7.89)
= 1 if non-farm Bus.	476.0**	441.5**	425.9**	441.1**	423.6**	411.9**	436.8**	425.2**	412.3**
	(3.21)	(2.98)	(2.88)	(2.95)	(2.85)	(2.78)	(2.90)	(2.86)	(2.78)
# Migrants	-142.6*	-155.3*	-165.8**	-144.1*	-166.1*	-174.1**	-145.4*	-170.8**	-179.2**
	(-2.18)	(-2.41)	(-2.58)	(-2.21)	(-2.57)	(-2.71)	(-2.24)	(-2.66)	(-2.80)
Year fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Belt-Zone fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Village controls	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Observations	3590	3590	3590	3590	3590	3590	3590	3590	3590

Standard errors robust to heteroskedasticity – t-statistics in parentheses, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Village level controls include median access time to road, village median altitude and altitude standard deviation, number of people killed in the 20km around the village in the previous year, as well as previous year snow cover, rainfall deviation, cooling degree days and monsoon growing degree days.

Table A2: Main specifications including the 1995 survey wave

	Firewood collection			Fuel expenditures		Consumption	Prop. Agri worktime
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Consumption exp.	0.444***	0.465***	0.228***	11.91**	14.51**		
	(9.82)	(10.37)	(5.49)	(2.19)	(2.16)		
Consumption exp.^{2}	-0.000635***	-0.000656***	-0.000340***	0.00885	0.00524		
	(-4.87)	(-5.05)	(-3.90)	(0.46)	(0.25)		
Prop. agri. worktime		19.45***		-794.9***			
		(5.53)		(-3.55)			
Big livestock			2.564***		-70.03***	2.049***	0.0158***
			(6.17)		(-3.02)	(5.58)	(9.47)
Land owned, ha			-0.687		-56.46*	4.350***	0.00715***
			(-1.10)		(-1.73)	(3.65)	(2.70)
hhsize			5.131***		-37.84	9.049***	-0.00764***
			(9.15)		(-0.99)	(17.70)	(-3.94)
Prop. children			-5.318		107.5	-15.57***	-0.00367
			(-1.41)		(0.47)	(-4.86)	(-0.21)
Avg. education			-1.307***		65.89***	5.218***	-0.0193***
			(-3.50)		(3.11)	(15.33)	(-10.16)
= 1 if non-farm Bus.			-4.955***		178.4	9.593***	-0.258***
			(-2.61)		(1.41)	(4.94)	(-20.79)
# Migrants			1.662*		-35.75	0.990	0.0522***
			(1.79)		(-0.67)	(1.01)	(10.60)
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Village F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5047	5047	5047	5047	5047	5047	5047
Est. turning point	349.51	354.55	334.84	NA	NA	NA	NA

Standard errors clustered at the village level, t-statistics in parentheses, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table A3: Descriptive statistics: Hills and Mountains *versus* Terai

	Hills and Mountains					Terai			
Variable	Median	Mean	std. dev.	N		Median	Mean	std. dev.	N
Household level variables									
Wood collection in bhari/year	70.00	81.75	59.20	3590	***	25.00	42.00	52.98	2594
Collect any firewood last year	1.00	0.93	0.25	3590	***	1.00	0.65	0.48	2594
Wood collected cond. on collecting	72.00	87.79	56.86	3343	***	50.00	64.69	53.43	1684
Collection time in hrs per bhari	3.50	3.75	1.83	3344	*	3.00	3.85	2.35	1684
Main cooking fuel: wood	1.00	0.93	0.25	3590	***	1.00	0.58	0.49	2594
Main cooking fuel: dung	0.00	0.00	0.05	3590	***	0.00	0.26	0.44	2594
Main cooking fuel: advanced	0.00	0.05	0.21	3590	***	0.00	0.12	0.32	2594
Big livestock	3.00	3.30	2.72	3590	***	2.00	2.00	2.26	2594
Village level variables									
LAI $90^{th} percentile_t$	24.60	24.64	7.02	301	***	15.84	18.44	7.21	228
FPAR $90^{th} percentile_t$	67.15	65.88	9.95	301	***	59.96	60.40	7.05	228
NDVI winter max $_t$	70.97	69.59	9.14	301	***	55.20	56.90	9.90	228
% of Vil. area in FUG	0.13	0.18	0.18	301	***	0.00	0.07	0.14	228
Biogas per household	0.01	0.03	0.06	301		0.01	0.04	0.05	228
Distance to paved road	3.13	7.69	11.20	301	***	0.50	0.88	1.04	228
Cooling degree days (15° C)	9.32	161.49	494.12	301	***	0.00	31.88	113.27	228
Village elevation	1332.00	1465.47	789.93	301	***	110.00	154.18	146.91	228

$^{*}p < 0.10,^{**}p < 0.05,^{***}p < 0.01$, for difference in means between Hills & Mountains and Terai

Table A4: Individual collection time

	Individual collection time in hours per bhari								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
LAI $90^{th} percentile_{t-1}$	-0.0502***	-0.0418***	-0.0456***						
	(-4.78)	(-3.50)	(-3.84)						
FPAR $90^{th} percentile_{t-1}$				-0.0382***	-0.0476***	-0.0481***			
				(-5.38)	(-4.41)	(-4.45)			
NDVI winter max $_{t-1}$							-0.000329***	-0.000440***	-0.000435***
							(-3.73)	(-3.78)	(-3.36)
% of Vil. area in FUG		1.120***	1.016**		1.095***	1.030**		1.263***	1.162***
		(2.67)	(2.54)		(2.61)	(2.55)		(2.97)	(2.83)
Biogas density		-1.273	-2.300		-1.228	-2.167		-0.889	-1.689
		(-0.73)	(-1.44)		(-0.72)	(-1.37)		(-0.52)	(-1.06)
Livestock density			-0.00282			-0.00234			-0.00212
			(-1.61)			(-1.37)			(-1.20)
Farm land density			0.000854			0.00125			-0.000658
			(0.19)			(0.27)			(-0.14)
Population density			0.00219**			0.00212*			0.00202*
			(1.98)			(1.92)			(1.81)
Prop. female density			-0.00390			-0.00165			-0.000340
			(-0.37)			(-0.16)			(-0.03)
Prop. child. density			0.00716			0.00524			0.000759
			(0.74)			(0.54)			(0.08)
Education density			-0.00188***			-0.00180***			-0.00170***
			(-3.04)			(-2.86)			(-2.83)
Non-farm business density			-0.000843			-0.00203			-0.000561
			(-0.19)			(-0.46)			(-0.13)
Out-migrant density			0.00787***			0.00699***			0.00681***
			(2.97)			(2.65)			(2.66)
Year fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Belt-Zone fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Village controls	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Observations	3344	3344	3344	3344	3344	3344	3344	3344	3344

Standard errors clustered at the village level – t-statistics in parentheses, $^{*}p < 0.1,^{**} p < 0.05,^{***} p < 0.01$

Village level controls include median access time to road, village median altitude and altitude standard deviation, number of people killed in the 20km around the village in the previous year, as well as previous year snow cover, rainfall deviation, cooling degree days and monsoon growing degree days.

Table A5: Descriptive statistics: household level variables

Variable	Median	Mean	Std. Dev.	Minimum	Maximum	Observations
Wood	70.00	81.75	59.20	0.00	500.00	3590
Collection time	3.50	3.75	1.83	0.02	12.00	3344
Fuel expenditures	844.63	2086.10	3920.95	0.00	57266.64	3590
Consumption exp.	87.52	101.01	63.65	6.98	860.77	3590
Prop. agri. worktime	0.91	0.76	0.30	0.00	1.00	3590
Big livestock	3.00	3.30	2.72	0.00	25.00	3590
Land owned, ha	0.46	0.64	0.71	0.00	10.38	3590
Household size	5.00	4.88	2.20	1.00	17.00	3590
Prop. female	0.33	0.36	0.19	0.00	1.00	3590
Prop. children	0.40	0.38	0.24	0.00	1.00	3590
Avg. education	2.33	2.85	2.89	0.00	17.00	3590
= 1 if NFBus	0.00	0.26	0.44	0.00	1.00	3590
# Migrants	0.00	0.64	0.88	0.00	8.00	3590

Descriptive statistics for the repeated cross-sections of NLSS in rural villages.

All monetary values expressed in NPR2010

Table A6: Descriptive statistics: household level variables in 2003

Variable	Median	Mean	Std. Dev.	Minimum	Maximum	Observations
Wood	72.00	85.84	55.20	0.00	360.00	1474
Collection time	3.00	3.53	1.71	0.02	12.00	1383
Fuel expenditures	812.14	1379.62	2613.21	0.00	57266.64	1474
Consumption exp.	64.10	74.92	47.43	6.98	449.37	1474
Prop. agri. worktime	0.97	0.82	0.27	0.00	1.00	1474
Big livestock	3.00	3.53	2.92	0.00	25.00	1474
Land owned, ha	0.48	0.68	0.76	0.00	9.81	1474
Household size	5.00	5.02	2.24	1.00	17.00	1474
Prop. female	0.33	0.35	0.19	0.00	1.00	1474
Prop. children	0.40	0.39	0.24	0.00	1.00	1474
Avg. education	1.67	2.41	2.70	0.00	13.67	1474
= 1 if NFBus	0.00	0.22	0.42	0.00	1.00	1474
# Migrants	0.00	0.40	0.67	0.00	6.00	1474

Descriptive statistics for the repeated cross-sections of NLSS in rural villages.

All monetary values expressed in NPR2010

Table A7: Descriptive statistics: household level variables in 2010

Variable	Median	Mean	Std. Dev.	Minimum	Maximum	Observations
Wood	60.00	78.91	61.68	0.00	500.00	2116
Collection time	4.00	3.91	1.90	0.50	10.00	1961
Fuel expenditures	884.47	2578.22	4554.36	0.00	52486.48	2116
Consumption exp.	106.29	119.19	67.11	9.05	860.77	2116
Prop. agri. worktime	0.86	0.72	0.32	0.00	1.00	2116
Big livestock	3.00	3.15	2.56	0.00	20.00	2116
Land owned, ha	0.43	0.61	0.66	0.00	10.38	2116
Household size	5.00	4.79	2.16	1.00	16.00	2116
Prop. female	0.33	0.37	0.19	0.00	1.00	2116
Prop. children	0.40	0.37	0.24	0.00	1.00	2116
Avg. education	2.67	3.16	2.98	0.00	17.00	2116
= 1 if NFBus	0.00	0.28	0.45	0.00	1.00	2116
# Migrants	1.00	0.80	0.97	0.00	8.00	2116

Descriptive statistics for the repeated cross-sections of NLSS in rural villages.

All monetary values expressed in NPR2010

Table A8: Descriptive statistics: village level variables

Variable	Median	Mean	Std. Dev.	Minimum	Maximum	Observations
Collection densities	2740.10	3276.17	2471.27	42.41	22515.49	301
ΔLAI p90_{t-1}^{t+1}	-1.28	-1.40	2.94	-14.50	6.80	301
$\Delta FPAR$ p90_{t-1}^{t+1}	-1.67	-1.59	3.68	-13.13	9.89	301
ΔLAI p90_{t-2}^{t+1}	-0.82	-0.94	3.21	-11.57	10.68	301
$\Delta FPAR$ p90_{t-2}^{t+1}	-0.52	-0.57	3.65	-11.07	11.33	301
$\Delta NDVI_{t-1}^{t+1}$	56.02	61.08	209.56	-615.46	765.33	301
$\Delta NDVI_{t-2}^{t+1}$	141.33	162.23	198.00	-488.65	769.82	301
LAI $90^{th} percentile_{t-1}$	25.50	25.39	7.38	1.72	50.43	301
LAI $90^{th} percentile_{t-2}$	25.05	24.94	7.26	1.69	45.00	301
FPAR $90^{th} percentile_{t-1}$	67.74	66.25	10.08	8.73	85.29	301
FPAR $90^{th} percentile_{t-2}$	66.90	65.23	9.93	8.50	83.86	301
NDVI winter max $_{t-1}$	7041.65	6897.94	888.24	1327.15	8491.89	301
NDVI winter max $_{t-2}$	6891.50	6796.80	887.66	1448.34	8377.78	301
Med. collection time	3.38	3.66	1.38	1.00	8.00	301
% of Vil. area in FUG	0.13	0.18	0.18	0.00	1.00	301
Biogas per household	0.01	0.03	0.06	0.00	0.40	301
Med. time to road	3.13	7.69	11.20	0.00	80.00	301
# killings 20km ar.	101.00	121.65	92.89	0.00	698.00	301
Vil. snow cover	0.37	2.93	8.51	0.00	62.11	301
Rainfall z-score	-0.45	-0.30	0.99	-2.32	1.53	301
Monsoon GDD	1326.64	1209.05	396.47	0.00	1815.29	301
Cooling Degree Days	9.32	162.07	493.28	0.00	4042.55	301
VDC area in km^2	25.60	45.23	88.95	2.36	815.01	301
Village # HH.	917.00	1076.16	705.14	125.00	4692.00	301

Descriptive statistics for the repeated cross-sections of NLSS in rural villages.

Table A9: Descriptive statistics: village level variables in 2003

Variable	Median	Mean	Std. Dev.	Minimum	Maximum	Observations
Collection densities	2700.06	3315.75	2436.23	42.41	15716.64	123
ΔLAI p90_{t-1}^{t+1}	-0.59	-0.72	2.98	-14.50	6.80	123
$\Delta FPAR$ p90_{t-1}^{t+1}	-0.07	-0.21	3.84	-12.78	9.89	123
ΔLAI p90_{t-2}^{t+1}	-0.50	-0.36	3.37	-9.60	10.68	123
$\Delta FPAR$ p90_{t-2}^{t+1}	0.78	0.74	3.91	-11.07	11.33	123
$\Delta NDVI_{t-1}^{t+1}$	41.92	52.97	181.53	-432.45	464.50	123
$\Delta NDVI_{t-2}^{t+1}$	152.83	170.25	191.57	-231.18	662.25	123
LAI $90^{th} percentile_{t-1}$	24.90	24.44	7.36	1.72	43.56	123
LAI $90^{th} percentile_{t-2}$	24.37	24.08	7.38	1.69	45.00	123
FPAR $90^{th} percentile_{t-1}$	66.00	64.34	10.67	8.73	83.78	123
FPAR $90^{th} percentile_{t-2}$	64.84	63.39	10.36	8.50	81.33	123
NDVI winter max $_{t-1}$	6945.72	6769.46	951.69	1327.15	8224.18	123
NDVI winter max $_{t-2}$	6846.12	6652.19	963.39	1448.34	8377.78	123
Med. collection time	3.00	3.42	1.27	1.00	8.00	123
% of Vil. area in FUG	0.10	0.14	0.14	0.00	0.64	123
Biogas per household	0.00	0.02	0.04	0.00	0.23	123
Med. time to road	5.00	10.65	14.47	0.08	80.00	123
# killings 20km ar.	56.00	78.67	64.98	0.00	354.00	123
Vil. snow cover	0.48	3.38	9.95	0.00	62.11	123
Rainfall z-score	0.72	0.60	0.63	-1.39	1.53	123
Monsoon GDD	1366.28	1248.64	373.85	27.85	1672.61	123
Cooling Degree Days	16.60	180.87	526.21	0.00	3836.66	123
VDC area in km^2	24.79	46.57	96.84	2.36	776.85	123
Village # HH.	837.00	970.89	557.06	125.00	3349.00	123

Descriptive statistics for the repeated cross-sections of NLSS in rural villages.

Table A10: Descriptive statistics: village level variables in 2010

Variable	Median	Mean	Std. Dev.	Minimum	Maximum	Observations
Collection densities	2745.60	3248.82	2501.67	55.91	22515.49	178
ΔLAI p90_{t-1}^{t+1}	-1.60	-1.86	2.84	-13.14	4.18	178
$\Delta FPAR$ p90_{t-1}^{t+1}	-2.41	-2.55	3.24	-13.13	7.12	178
ΔLAI p90_{t-2}^{t+1}	-0.90	-1.34	3.03	-11.57	5.75	178
$\Delta FPAR$ p90_{t-2}^{t+1}	-1.43	-1.48	3.17	-10.89	7.92	178
$\Delta NDVI_{t-1}^{t+1}$	68.03	66.68	227.25	-615.46	765.33	178
$\Delta NDVI_{t-2}^{t+1}$	129.43	156.69	202.66	-488.65	769.82	178
LAI $90^{th} percentile_{t-1}$	26.34	26.05	7.34	4.71	50.43	178
LAI $90^{th} percentile_{t-2}$	25.41	25.53	7.14	3.99	42.57	178
FPAR $90^{th} percentile_{t-1}$	68.91	67.57	9.45	14.11	85.29	178
FPAR $90^{th} percentile_{t-2}$	68.12	66.50	9.43	12.90	83.86	178
NDVI winter max $_{t-1}$	7115.30	6986.73	832.81	1976.44	8491.89	178
NDVI winter max $_{t-2}$	6986.38	6896.72	819.27	1857.98	8148.56	178
Med. collection time	3.50	3.83	1.43	1.00	8.00	178
% of Vil. area in FUG	0.15	0.20	0.19	0.00	1.00	178
Biogas per household	0.01	0.04	0.07	0.00	0.40	178
Med. time to road	2.50	5.65	7.61	0.00	40.00	178
# killings 20km ar.	126.50	151.35	97.69	0.00	698.00	178
Vil. snow cover	0.30	2.62	7.37	0.00	60.21	178
Rainfall z-score	-0.92	-0.93	0.65	-2.32	0.96	178
Monsoon GDD	1271.08	1181.70	410.19	0.00	1815.29	178
Cooling Degree Days	4.74	149.08	470.26	0.00	4042.55	178
VDC area in km^2	25.95	44.31	83.33	2.36	815.01	178
Village # HH.	945.50	1148.89	784.75	240.00	4692.00	178

Descriptive statistics for the repeated cross-sections of NLSS in rural villages.

B Description of variables

This paper uses a broad range of village level variables using remote sensing technology. This appendix aims at describing data sources, characteristics and treatment.

B.1 Biomass measures

The leaf area index (LAI) is a unitless ratio of the leaf area covering a unit of ground area. The measure of leaf area is adapted for the type of vegetation and takes into account the difference between leaves and needles. It is a good proxy of canopy cover, which is especially relevant in our context since fuelwood is often collected by lopping branches (Baland et al., 2010a). On top of being relevant for firewood collection, it is also relevant for biomass production since the canopy cover is one of the determinant of carbon storage in the woody biomass. To construct our variable, we use the MOD15A2 product multiply by a factor 30 to reduce decimals and as distributed by the NASA. This product, which uses measures of the Moderate-Resolution Imaging Spectroradiometer (MODIS) sensor on-board of the Terra satellite, is a eight-day measure of the LAI for every $1km \times 1km$ pixel. For every date of production, we first compute the average LAI for each Nepali village based on a central bureau of statistics shape file. For the main regression, we use the 90^th percentile within the last twelve months before the survey as a measure of the current LAI. We opt for the 90^th percentile to proxy the canopy cover peak in the last twelve months while limiting measurement errors. Another measure used in the appendix is the average LAI in November and December preceding the survey. This measure intends to focus on two months where the sky generally is clear and deciduous trees still have their leaves.

The Fraction of Absorbed Photosynthetically Active Radiation (FPAR) measures the share of radiation that a plant absorb for photosynthesis. The closer to one is the ratio, the highest the share of radiation in the 0.4-0.7nm spectral range absorbed by the vegetation for photosynthesis and therefore for growth. This information is also provided by the NASA in the MOD15A2 product. For our analysis, we process the FPAR variables in the same way than the LAI variables.

The Normalized Difference Vegetation Index (NDVI) is the third important variable capturing biomass in our study. This index is computed as the ratio $\frac{Near\ Infra\ Red - Visible\ Red}{Near\ Infra\ Red + Visible\ Red}$. A pixel covered by a dense forest would not reflect any visible red and the ratio would be close to one. To construct our variable, we use the MOD13A2 product distributed by the NASA on a 16-day basis for every $250m \times 250m$ pixel. The variable we use in regressions is the village average of the each pixel maximum over last November and December. This procedure is consistent with the NASA production algorithm which minimizes measurement by picking the maximum of each pixel over 16 days to construct the bi-monthly measure.

Within the three variables, the LAI is the best proxy of the canopy cover. The correlation between LAI on one hand and FPAR and NDVI on the other is relatively high but not perfect. FPAR and NDVI saturate more rapidly in relatively green environment (Myneni et al., 2002). For most of our villages, values of FPAR and NDVI are in the saturation range while LAI varies more. FPAR and NDVI are highly correlated. FPAR takes into account the whole range of photosynthetically active radiation while NDVI is based only on visible red and infra red. FPAR is therefore computationally more intensive. NDVI has already been used in previous studies in economics. In this study, we focus on NDVI in November and December to avoid the monsoon greening which is also affected by crops and grass. November corresponds to the beginning of harvest, a period in which grass and crops are less green while trees still have their leaves. November and December are also cloud free month in Nepal which minimize measurement errors.

B.2 Additional variables

We also use a broad set of environmental controls derived from satellite imagery. We retrieve information on snow cover, temperatures and altitude from the NASA, through the related MOD10A2, MOD11A2 and ASTER GDEM products. Snow cover is then computed as the share of village area covered by snow during 12 months before the survey. Temperature data allows us to construct a correlate of biomass growth, namely the Growing Degree Days during the monsoon and a correlate of fuel demand, namely the Cooling Degree Days (also named heating degree days in the literature) over last year. Measures of altitude are standards. Rainfall information were computed based the Tropical Rainfall Measurement Mission (TRMM) dataset, the space standard for measuring precipitation over the last 17 years.

B.3 List of variables

Table B1: List of household level variables

Variable	Units	Description	Source
Wood	Bundles per year	Firewood collected, one bundle weights approximately 30kg	NLSS
Collection time	Hours per bundle	Firewood collection time	NLSS
Median collection time	Hours per bundle	Village median firewood collection time	NLSS
Consumption expenditures	Nepali Roupies 2010 per year	Household total food and frequent non-food expenditures	NLSS
Fuel expenditures	Nepali Roupies 2010 per year	Household expenditures for fuel	NLSS
Proportion agricultural working time	%	Share of adult working time spent in agricultural activities	NLSS
Big Livestock	Units	Number of bullocks, cows and buffaloes owned	NLSS
Land owned	Hectares	Land owned by the household	NLSS
Household size	Units	Number of members living in the household more than 6 months per year	NLSS
Proportion female	%	Share of adult female in the household ($\leq$ 16 years)	NLSS
Proportion children	%	Share of children in the household ($<$ 16 years)	NLSS
Average education	Years	Average education of adults in the household	NLSS
=1 if non-farm Business	Indicator	Dummy indicating whether the household runs a non-farm business	NLSS
# migrants	Units	Number of migrants sending remittances to the household	NLSS

NLSS: Nepal Living Standard Survey

Table B2: List of village level variables

Variable	**Units**	**Description**	**Source**
LAI $_{90^{th} percentile}$		Leaf Area Index - see subsection B3 for more details	MODIS
FPAR $_{90^{th} percentile}$	%	Fraction of Photosynthetically Active Radiation - see subsection B3 for more details	MODIS
NDVI $_{\text{Winter max.}}$		Normalized Difference Vegetation Index - see subsection B3 for more details	MODIS
Village area	Km^2	Village Development Committee (VDC) administrative area	CBS
Share of village area in FUG	%	Share of VDC administrative area managed by Community Forest User Groups	Dpt. of Forest
Number of households	Units	Number of households living in the VDC	CBS
Biogas per households	Units	Number of biogas installation in the VDC	AEPC
Distance to paved road	Hours	Median walking time between the village and the closest paved road	LSMS
# killings 20km	Units	Number of conflict related casualties in the 20km around the VDC over the last 12 months	INSEC
Village snow cover	%	Share of VDC area covered by snow, weighted by days	MODIS
Monsoon GDD	Degree	Monsoon Growing Degree Days, Sum of residuals degrees between $30 \circ C$ and $15°C$ during the monsoon	MODIS
Cooling Degree Days	Degree	Cooling Degree days, Sum of residuals degrees below $15°C$	MODIS
Rainfall Z-score	Millimetres	Deviation of the last 12 month rainfall compared to the 1998 - 2015 average	TRMM
Village elevation	Meters	Average altitude of the VDC	ASTER
Village elevation, deviation	Meters	Standard deviation of altitude in the VDC	ASTER

AEPC: Alternative Energy Promotion Center ; ASTER: Advanced Spaceborne Thermal Emission and Reflection Radiometer (NASA) ; CBS: Central Bureau of Statistics ; INSEC: Informal Sector Service Center ; MODIS: Moderate Resolution Imaging Spectoradiometer (NASA); NLSS: Nepal Living Standard Survey ; TRMM: Tropical Rainfall Measuring Mission (NASA & JAXA)