Forest degradation and the nature of growth in Nepal 2003-2010

Jean-Marie Baland*, François Libois†, Dilip Mookherjee‡

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Abstract

A combination of satellite imagery with household cross-sectional and panel data set is used to investigate the effects of economic growth on firewood collection in Nepal between 2003 and 2010, and their implications for the evolution of the forests. While the estimations of the Engel curve suggests strong income effects, we show that these estimates are not robust to the inclusion of household productive assets, that better capture the nature of the growth process. Simple approaches of the Environmental Kuznets curve can therefore provide very misleading conclusions, due to a classical omitted variable bias. We find that forest conditions have remained essentially stable over the last decade even though firewood collections affect them adversely. At the household level, the observed reduction in firewood collections is essentially due to a switch away from agricultural based activities that encourage substitution away from fuelwood to alternative energy sources. Finally, the presence of Forest User Groups, the village-based forest management decentralization scheme in Nepal, are associated with lower collections, longer collection times and larger expenditures on alternative fuels.

Keywords: Deforestation ; Growth ; Environmental Kuznets Curve ; Nepal

JEL codes: O1, D12, Q2

*CRED, University of Namur, Belgium, BREAD and CEPR. Email: jean-marie.baland@unamur.be

†Paris School of Economics, France and CRED, University of Namur, Belgium. Email: francois.libois@unamur.be

‡IED, Department of Economics, Boston University, USA and BREAD. Email: dilipm@bu.edu

1 Introduction

Deforestation in South Asia and Sub-Saharan Africa poses serious developmental and ecological problems. Large sections of neighbouring populations of developing countries rely on forests for household fuel, timber and fodder, and spend a large amount of time collecting these products. The ecological problems pertain to increased soil erosion, water salinity, siltation in rivers, and increased likelihood of landslides and floods which affect large non-neighbouring populations adversely.[1][2]

In this paper, we investigate the interactions between economic growth, firewood collections and deforestation in the context of the Hills and the Mountains of rural Nepal over the last decade.[3] To this end, we use the two large scale household surveys organized by the Central Bureau of Statistics of Nepal in collaboration with the World Bank in 2003 and 2010. We combine this data set with various measures of forest biomass based on satellite imagery, which we reconstructed at the village level over different periods.

We focus on firewood collection as it represents by and large the main driver of forest degradation in the Himalayas compared to encroachment or timber collection (see e.g. Baland et al. (2014, pp.209-210)). Nepal is an appropriate context to study since it has been subject to serious deforestation in the last century, with forest cover declining at an estimated annual rate of 1.9% over the 1980s and the 1990s (UNEP, 2011). We first find that forest conditions have remained essentially stable over the past 15 years, in contrast to the declining trends that preceded. We also find that village firewood collections reduce forest biomass and canopy measures. However, they remained essentially constant at village level between 2003 and 2010 and account for at most 2% of the forest biomass; which corresponds to its natural regeneration rate.

We then explore the determinants of firewood collections at the level of the household. Over this period, collections fell by 8% while living standards, as measured by consumption expenditures, increased substantially by 59%.[4] These changes can be rationalized in a number of ways. Some scholars indeed 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

[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]We therefore exclude the low-level Terai regions as they are subject to completely different agro-climatic and ecological conditions.

[4]According to the censuses, village populations increased by roughly the same magnitude than the decline in household collections during this period, which explains the stability in village total collections

reduce the pressure on forests. This view, commonly referred to as the Poverty-Environment hypothesis (PEH), is compatible with the changes described above.[5]. These changes can also be *explained* as the declining part of the Environmental Kuznets Curve (EKC), which states environmental degradation will intensify with growth in living standards until a threshold, beyond which it will fall[6]. By contrast, another common view, expressed for instance by the World Bank, believes that income growth will increase the demand for household energy, thereby putting additional pressure on forests (the principal source of household fuel).[7].

The differences between these hypotheses stem from alternative assumptions regarding the nature of the wealth effects (i.e., whether firewood is a normal or an inferior good) and their strength relative to substitution effects. We estimate Engel curves and find that, contrary to the overall trends described above, collections are essentially rising with consumption levels. Hence growth in living standards *per se* tends to accelerate the pressure on the forest for the vast majority of the population, which goes against the PEH. This result is robust to functional forms and a large range of household and village attributes.

These estimates however suffer from a serious omitted variable bias. We then propose to incorporate household productive assets, so as to better approach the process of growth itself. The observed fall in collections is essentially explained by the substantial fall in farm based traditional assets compared to non-farm assets, and the corresponding changes in occupational patterns. The impact of consumption levels becomes very small, pointing to a large omitted variable bias in our simple Engel curves estimates. While a key question frequently debated by scholars[8], media[9] and policy-making community[10] concerns the likely effect of economic growth on environmental degradation in these countries, we therefore find that it is not so much growth itself but the nature of the growth process that matters. We also find that collections are sensitive to collection times, but the effects are not large. Finally, we find that the presence of a Community Forest User Group (CFUG) is associated with longer collection times and lower collection levels. Collection activities are also not directly affected by the regional differences in the intensity of the civil war in Nepal during this period. All these findings are con-

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

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

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

[8]Arrow et al. (1995); Dasgupta et al. (2000)

[9]*The Economist*, July 8 2004; *The Economist*, September 23 2010

[10]For instance, the World Bank report on deforestation in India stated: *"urbanization, industrialization and income growth are putting a tremendous demand pressure on forests for products and services. The shrinking common property resource base, the rapidly increasing human and livestock population, and poverty are all responsible for the tremendous degradation pressure on the existing forest cover"*(Word Bank, 2000, Summary section, page xx)

sistently mirrored in our estimates of expenditures on alternative fuels, suggesting important substitutions away from traditional fuels[11]

Despite the importance of the issue, there are very few explicit attempts in the literature at analysing the relationship between economic growth, fuel choices and forests conditions at a micro-economic level. Moreover, 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 local forest biomass. We find that collection times are sensitive to forest conditions, but the estimated effects are small. We also find that household collections increase with forest conditions in a village though, again, changing household assets and occupations play a major role.[12]

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

2 Major economic trends and deforestation in Nepal

The World Bank Living Standards Measurement Survey (LSMS) for Nepal interviewed 3912 households concerning their production and consumption activities for the year 2002-3 and 5988 in 2010-11.[13] 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, and therefore have a total sample of 3590 households (1474 in 2003 and 2116 in 2010), located in 301 villages. Tables A3 -

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

[12] 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.

[13] 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, and instead check the consistency of our new findings, with those already highlighted in this previous paper.

A5 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 heating source. The quantities of firewood exchanged on the market are negligible[14]. Each household collects on average 81.75 bharis of firewood (headloads corresponding to about 30 kg of wood), and spends 3.75 hours to collect one such bhari. Between 2003 and 2010, the amount of firewood collected fell by 8%, while collection time increased by about 12%. Overall, fuel expenditures (that exclude firewood collected) amount to 2,086 NPR (from 1,379 NPR in 2003 to 2,578 NPR in 2010), which represents 2% of all expenditures.

Household living standards (measured by value of annual consumption at 2010 prices) were equal on average to 101,000 NPR, and increased substantially (by about 60%) during this period. This change is partly related to the sharp increase in remittances received from migrants, with a rise in transfers (from 16201 NPR to 38691 NPR between 2003 and 2010), which parallels the mean increase in the number of migrants per household from 0.4 in 2003 to 0.8 in 2010. Households are mostly engaged in farming as they spend on average 76% of their time in agricultural occupations. This dependence on farming decreased substantially, as the proportion of time spent on agricultural activities fell from 0.82 to 0.72 between 2003 and 2010. Changes in the structure of productive assets owned by the households reflect this evolution. Thus, between 2003 and 2010, the number of livestock heads 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, the average adult education increased from 2.41 to 3.16 years of schooling and the proportion of households owning non-farm business assets 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.

Another important event during the study period was the Nepalese Civil War between government forces and Maoist rebels, which started in 1996 and ended in

[14]It differentiates our work from studies of fuelwood demand in developed countries (Couture et al., 2012) or urban area where the market for fuelwood is thicker and relies on explicit prices.

[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.

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 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 determinant of biomass growth over the year. We also control for rainfall z-score, the village median altitude and within village altitude variance. The appendix describes data sources and computational details for these variables.

We measure forest biomass in a village by three different approaches. 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 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 central estimations are based on this particular measure.

We also use the fraction of absorbed photosynthetically active radiation, FPAR, which measures the photosynthesis capacity of standing vegetation. It is a key parameter to understand the growth potential and carbon storage capacity of the biomass. There again, because of seasonality, we will use the 90 percentile. We will also make use of the more traditional 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

[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). As a result, we are not able to draw reliable estimates of the effects of the civil war on firewood collections, and our estimations results in this respect are disappointing.

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

$\frac{Near\ Infra\ Red\ -\ Visible\ Red}{Near\ Infra\ Red\ +\ Visible\ Red}$. 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.[18] These three measures 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 to support the idea that the latter 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]

According to the FAO, woodfuel production represents the major share of total wood production in Nepal. This share is essentially stable, and varied between 90 and 95% of total forest production over the past 50 years (FAO, 2016). Using our data set, we can first explore the possible impact of firewood collections on forest conditions at the level of the village, by investigating to what extent village collections at time t affect the change in forest biomass between $t-1$ and $t+1$. We first define the total amount of fuelwood removed per unit area.[19] In a village j at time t, C_{jt}, is equal to the sum of all individual collections divided by the area of the village, A_j, or to the average amount collected multiplied by the household density of the village, $\frac{N_{jt}}{A_j}$, where N_{jt} represents the number of households. We therefore have: $C_{jt} = \frac{\bar{C_{jt}} \times N_{jt}}{A_j}$. 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:

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

in which 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.

[18]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).

[19]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.

[Insert table 1 here]

Table 1 reports the estimations for each of our three forest measures, controlling for all the relevant village variables.[20]. As argued above, village collections are measured as densities, i.e. total collection per unit area, since biomass is also measured as an average per unit area. The first columns (col. 1, 3 and 5), follow exactly the specification given in equation (1). A robustness check is reported in the third column (cols. 2, 4 and 6), in which the change in biomass is measured as the change between the year $t-2$ and year $t+1$, controlling for the stock in $t-2$.

Overall, village collections reduce biomass, even though the coefficient is not always precisely estimated. Clearly, this is partly due to the low number of observations (301), but also to the measurement errors related to the use of biomass averages over the administrative boundaries of the village, which do not correspond to the actual collection points in the forest. However, the results are consistent across the three measures of biomass. Using the estimated coefficient in column (1), total collections in a village correspond to a 1.8% reduction in LAI (0.000139*3276.17/25.4). The estimated impact on FPAR are smaller in relative terms, as total collections correspond to a fall of about 0.8% in FPAR. These can be compared 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, while village collections represent a removal of about 2.5 ton per hectare (30 kgs per bharis * 3276 bharis per square kilometers * 0.40 forest per unit area), which corresponds to a 1.25% decrease in the stock of wood. 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). Collections should therefore have a larger impact on LAI than on the other two measures.

3 Firewood collection and living standards

In this section we focus on the relationship between household consumption and firewood collections, in order to test commonly held views such as PEH or EKC concerning the effect of growth in living standards on firewood collections. Conceptually this corresponds to estimating the nature of the income effect in the demand for firewood, and therefore requires to control for collection time, which

[20] To be precise, we took the average in the biomass 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'

is the main cost (price) associated with the consumption of firewood. We provide cross-sectional estimates of this relation, 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 to estimate the effects of collection times, which is constant in a village. Unless otherwise specified, in all the other estimations, we will use 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 specification[21]. Consumption is measured by annual household recurrent expenditures valued at 2010 prices. In the first column, we control for village and time dummies, in the second column, we control for a belt-zone dummy, and for the median collection time in the village (which was absorbed by the village dummy in column 1)[22]. In column (3), we add other village level controls, including the share of forest managed by CFUG, the distance to a paved road, the number of conflicts related deaths within 20 km of the village, and various topographic and climatic controls.

All the estimates indicate an increasing and concave relationship between firewood collections and consumption. The estimated turning point are located above 300,000NPR, corresponding to consumption levels above the 99th percentile.

[Insert table 2 here]

The effect 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 4.5 bharis collected, which corresponds to an average elasticity of about -20%.

[Insert figure 2 here]

We next explore the robustness of the results with respect to functional form of the relationship between collections and consumption. Figure 2 provides the semi-parametric estimations of the Engel curve. To estimate this curve, we use

[21]Higher order polynomials were also tested, with little impact on the estimates. We report on a semi-parametric specification below. While not reported here, all the results discussed are robust to using income instead of consumption expenditures as the measure of income.

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

the estimator proposed by Baltagi and Li (2002) which allows consistent estimates in a semi-parametric panel regression.[23] The estimation controls for belt-zone fixed effects and the village controls. We again find an increasing and concave relation between firewood collections and consumption, which closely follow a quadratic shape. The right hand panel of Figure 2 reports the distribution of consumption across all households in 2003 and 2010 (in '000 NPR).

[Insert table 6 here]

The evidence therefore firmly rejects the PEH but is consistent with the EKC. This suggests that positive income effects dominate substitution effects. As a result, economic growth should accelerate deforestation. In Table 6, 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 a rise of 7 units in firewood collections per household as a result of the 44,000 NPR increase in consumption. However, this is exactly the opposite of what happened, as collections actually fell over that period by about 7 bharis. The Engel curve therefore gives a completely misleading picture of the real effects of growth on collections.

We need to understand the process of growth better, and it is probably wrong to measure it solely in terms of growth of household consumption. 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 themselves depend on the household productive assets. This motivates an analysis in which assets are explicitly incorporated in the analysis. An added argument for such an approach is that these assets are less prone to measurement errors than consumption.

In Table 7 below, we report the main changes in productive assets that we observe over the period. We see that growth in Nepal 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). We also see a fall in household size together with a rise in education and transfers (essentially remittances). Non-farm occupations require household members to work set hours, usually in a semi-urban location, which makes firewood collection much more difficult. Moreover, the value of leisure time increases with income, and all these

[23] 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).

factors create strong pressures for households to reduce collections and switch to alternative fuels.

[Insert table 7 here]

In Table 4, we reestimate the Engel curve by incorporating household assets and demographics. Column (1) reports the estimated coefficients with the usual village controls, while column (2) uses village fixed effects. We also re-estimated the Engel curve separately for 2003 and 2010 in columns (3) and (4) respectively. Column (5) reports the estimation results on household assets without consumption, in a reduced form approach. As expected, farm based assets (livestock and agricultural land) and household size increase collections, as the effect of income and occupation complement each other. With respect to household size, we also expect an additional positive effect as energy use, particularly in terms of heating, is essentially a public good within the household. By contrast, education, non-farm business and transfer payments all reduce collections. In separate estimates (not reported here), we find a very strong correlation between collections and the time spent on agricultural occupations, again stressing the important role played by occupational patterns[24]

[Insert table 4 here]

It is worth noting that the role of consumption is vastly reduced, by about two thirds than in the simple Engel curve estimates. It is also less precisely estimated and less stable. The simple Engel curve estimation suffered from a classic omitted variable bias, generated by the positive correlation of consumption with livestock, land and household size (see Table A1 in the Appendix).

[Insert table 5 here]

We now turn to a similar analysis using fuel expenditures instead of firewood. These expenditures relate mostly to LPG, coal, charcoal and kerosene. Table 5, present the estimated coefficients using the same specifications as in Table 4. 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

[24]In the Appendix, Table A1 reports the regression estimations of consumption expenditures and the proportion of adult worktime allocated to agriculture on household assets and demographics. Columns (1) and (3) include a village fixed effect, while various village level controls are included in the two other columns. Clearly, living standards and occupational patterns are closely related to all productive assets in the expected way.

firewood collections when collection costs are high or occupations and asset ownership less based on farming. Using the estimated coefficients of column (1) and column (5) of Tables 4 and 5, we can predict the changes in 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 6 below. In terms of firewood collections, with an observed change in collection of -6.9 bharis per household, we predict a total change between -5.3 and -7.3 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 (-1.5). The rise in collection time reduce collections by 1.6 bharis. For fuel expenditures, the observed change is equal to 1199, and our predicted changes vary between 487 and 1204 NPR.

[Insert table 6 here]

4 Firewood collection and the local ecology

We first provide a simple model corresponding to our estimation strategy. Let the amount of firewood collected by household i in village j at time 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 firewood. To avoid simultaneity biases, we assume that the collection time at time t depends on the biomass available at time $t-1$. We therefore have:

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

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

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

We now turn to the estimation of these three equations. Table 8 reports the results of regression of collection time on forest biomass, where the three different measures of biomass will be used alternatively: LAI, FPAR and NDVI. To our knowledge, this is the first attempt to explicitly relate collection times to biomass measures in the economics literature. 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, and 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 robust and significant negative impact on median collection times in a village. The coefficients estimated are relatively small in magnitude, as a one standard deviation increase in LAI (+7.37) results in a fall of only 0.20 hours in collection times (using column (2) estimate). These small effects may partly be due to measurement errors. In particular, biomass measures, which are constructed as averages over the whole administrative area of a village, only imperfectly capture villagers' access to forest products. On the one hand, the latter go to specific forest patches which are not well captured by a village average. On the other hand, these patches may be located in neighbouring administrative villages, so that the administrative boundaries do not match perfectly the areas in which collection of forest products take place. By contrast, collection times are directly measured relative to the actual place of collection.

[Insert table 8 here]

Also, the presence of forest user groups (measured by the proportion of village area managed by a CFUG) tend to increase the time needed to collect firewood, by about 1.3 hours. This is 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.[25] Most of the asset densities and the other village

[25] 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).

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 9 here]

In table 9, we report the impact of forest biomass on 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. Forest biomass has a robust, positive but small impact on household collections. Thus, a one SD increase in LAI results in an increase in collections by about 3.7 bharis (7.37*0.506). The alternative specifications and the other biomass measures provide somewhat larger estimates. For instance, a one SD increase in NDVI results in an increase in collections by 4.6 bharis (887*.0052). Introducing collection times as an additional control slightly reduces the estimated coefficient which remains significant. This implies that forest biomass has an impact on collections which is independent of its indirect impact through 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.

The effects of household assets are very consistent and similar to those obtained in the reduced form estimations presented in Table 4. 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. In the Appendix (Table A2), we also report the estimations obtained with fuel expenditures as the dependent variable, following the same specifications as in Table 9. The results there closely follow the previous results. Fuel expenditures decrease in villages with more abundant forest biomass or lower collection times. Agricultural assets decrease those expenditures, while education and non-farm business assets increase them by a substantial amount. The importance of CFUGs in the village also increase fuel expenditures.

These last set of estimates alllow us to explore whether collections would fall fast enough when excessive, through their impact on forest biomass and collection times. 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 8 (col. 3), such a fall increases collection times by 0.14 hours. Using the estimates in table 9 (col. 3), these changes should reduce firewood collection by 3.3 bharis or 4%, (0.6% through the increase in collection time, and 3.4% through the direct impact of biomass on collections). These return effects of a degraded biomass on collections are therefore very small. This may be due to the low sensitivity of collections to a degrading forest biomass, either 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. Finally, let us again stress the fact that over the period analysed, the overall forest biomass remained essentially stable, so that this question remains essentially hypothetical in this context.

5 Relation to existing literature and concluding comments

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 results are broadly consistent with theirs, despite pertaining to a different country and period of analysis. In particular, the hilly and mountainous regions of Nepal do differ from India in a number of important characteristics: (1) the forests are abundant relative to the population, (2) the forests are still of an open access nature (though possibly regulated by the CFUG), which involves that households collect according to their needs, and, most importantly, (3) the demand for heating energy in the winter constitutes an important and relatively inelastic component of the demand for firewood, for which few substitutes are available.[26]

Numerous cross-section studies on Nepal and rural India 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 incomes 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 being used 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 while controlling for village dummies. While richer house-

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

holds tend to consume more energy, they switch to cleaner and more efficient fuels (kerosene) which reduces the amount of indoor pollution. Baland et al. (2006) also find the demand for firewood in Indian Himalayas to be sensitive to the price of kerosene. These earlier findings are consistent with our estimations of the Engel curves for fuelwood but also 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 nature of growth has not been examined in this literature. Closest to our analysis, our previous paper Baland et al. (2010b), based on a cross section Nepal LSMS of 1995, argued that the structure of productive assets was a major determinant of firewood collections[27]. Our earlier findings there are strengthened by our main results above.

Our results on CFUGs tend to support the findings of Somanathan et al. (2009) and, to a lower extent, of Baland et al. (2010a), who showed that the impact of community forestry in India on the state of the forest was quite limited. While the presence of 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.

At a methodological level, we have shown that our estimates of the Engel curves were not robust to the inclusion of relevant controls, and this weakness probably affects most cross-sectional analysis of the EKC as well. Focussing on wealth effects alone, as in simple approaches of the EKC, can yield very misleading conclusions about the sustainability of economic development. We showed here the importance of addressing explicitly the process of economic growth, and not just the increases in living standards, as various substitutions effects come into play that help to adapt to a shrinking environmental resource base.

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

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

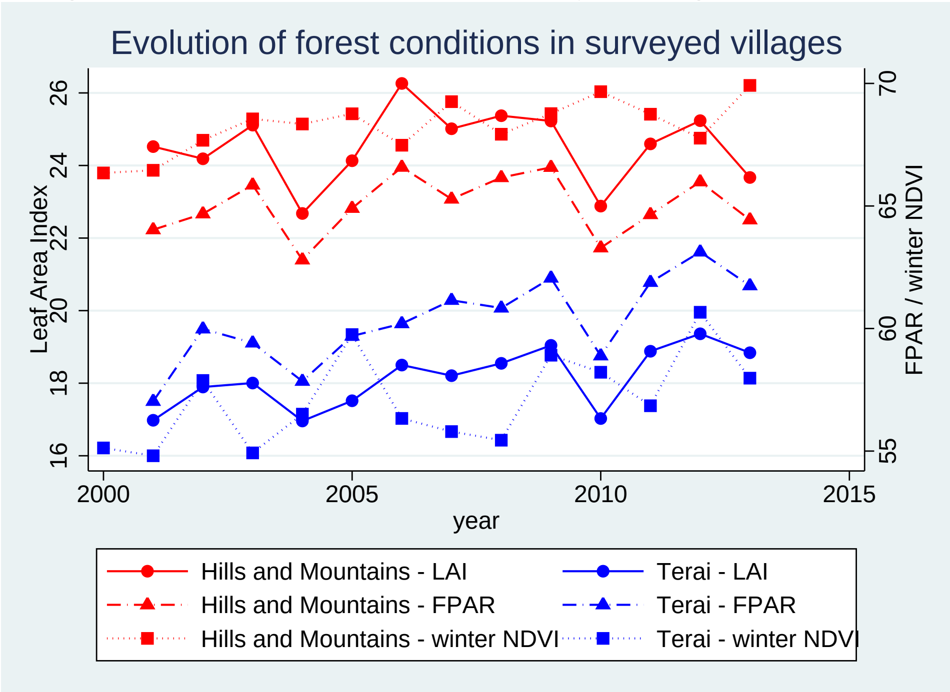
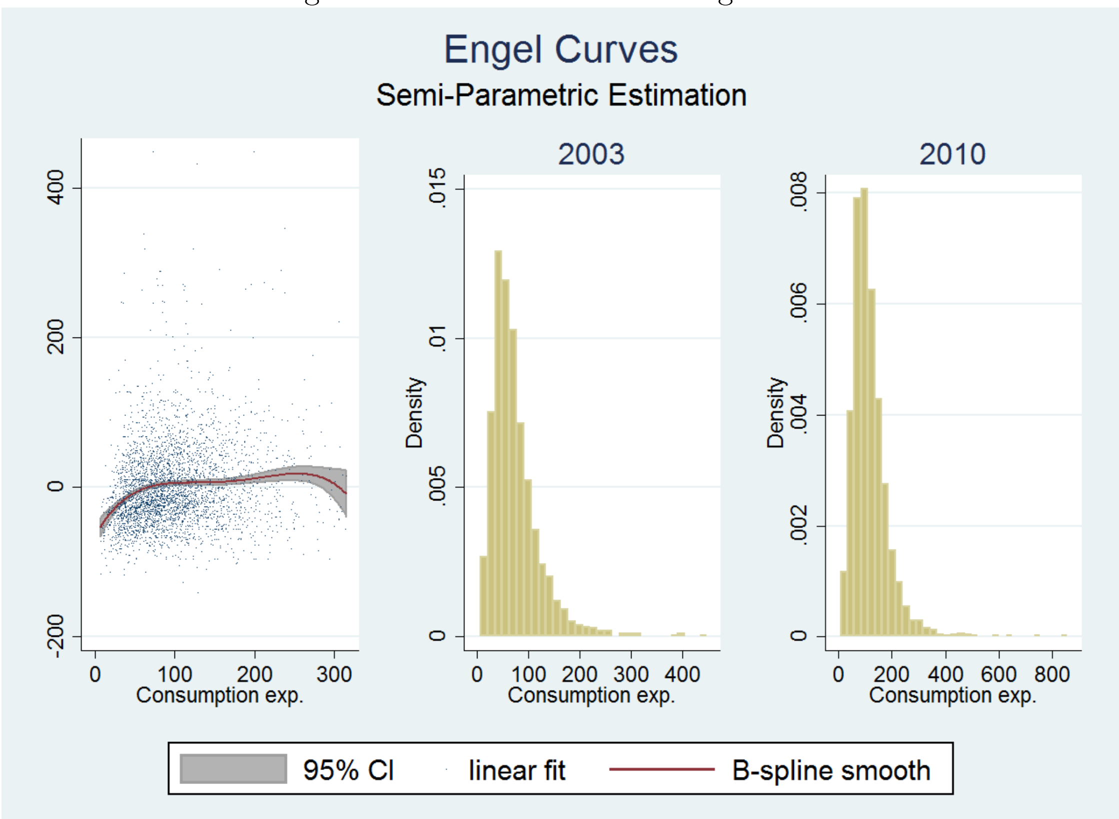


Figure 2: Firewood demand: Engel curve



The semi-parametric estimation of the Engel curve includes controls for the share of the village area managed by community forest user groups, 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)

Table 1: Degradation of forest and firewood collections

	Δ LAI 90^{th} percentile		Δ FPAR 90^{th} percentile		Δ NDVI winter max	
	(1)	(2)	(3)	(4)	(5)	(6)
Collection densities	-0.000139*	-0.000222**	-0.000151*	-0.000222**	-0.000106*	-0.000108*
	(-1.79)	(-2.55)	(-1.86)	(-2.58)	(-1.66)	(-1.74)
LAI $90^{th} percentile_{t-1}$	-0.171***					
	(-5.36)					
LAI $90^{th} percentile_{t-2}$		-0.157***				
		(-4.93)				
FPAR $90^{th} percentile_{t-1}$			-0.152***			
			(-4.40)			
FPAR $90^{th} percentile_{t-2}$				-0.143***		
				(-4.30)		
100$\times$ NDVI winter $\max_{t-1}$					-0.0455	
					(-1.50)	
100$\times$ NDVI winter $\max_{t-2}$						-0.0741***
						(-2.97)
Year fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes
Belt-Zone fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes
Village level controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	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, 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 2: Engel curves

	(1)	(2)	(3)
	Wood	Wood	Wood
Consumption exp.	0.372***	0.246***	0.273***
	(8.03)	(5.23)	(6.04)
Consumption exp.^{2}	-0.000539***	-0.000429***	-0.000456***
	(-4.37)	(-4.46)	(-4.55)
Med. collection time		-3.123*	-4.506***
		(-1.96)	(-2.82)
Village controls	No	No	Yes
Year fixed-effects	Yes	Yes	Yes
Other fixed-effects	Village	Belt-Zone	Belt-Zone
Observations	3590	3590	3590
Est. turning point	344.93	286.38	299.54

Standard errors clustered at the village level, 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, 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 firewood collections based on Engel Curves

Year	Wood collected	Frequent consumption exp. in $1000NPR_{2010}$
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		
Parametric estimation	**+7.14**	
Semi-parametric estimation	**+8.25**	

Table 4: Firewood collection

	(1) Wood	(2) Wood	(3) Wood	(4) Wood	(5) Wood
Consumption exp.	0.0977*	0.180***	0.0701	0.107	
	(1.93)	(3.88)	(0.75)	(1.63)	
Consumption exp.^{2}	-0.000211***	-0.000293***	-0.000117	-0.000210**	
	(-2.60)	(-3.43)	(-0.37)	(-2.18)	
Big livestock	2.574***	2.214***	2.278***	2.882***	2.678***
	(4.77)	(4.20)	(3.18)	(3.96)	(4.96)
Land owned, ha	3.872**	0.697	6.524**	1.442	4.277**
	(2.05)	(0.38)	(2.45)	(0.63)	(2.28)
hhsize	6.191***	5.402***	7.395***	5.107***	6.555***
	(8.32)	(7.80)	(8.90)	(4.82)	(11.05)
Prop. children	-3.569	-5.103	-0.467	-3.621	-3.449
	(-0.77)	(-1.12)	(-0.08)	(-0.56)	(-0.75)
Avg. education	-2.298***	-1.288***	-1.916***	-2.376***	-2.075***
	(-5.76)	(-3.00)	(-3.77)	(-4.68)	(-5.53)
= 1 if NFBus	-6.554***	-5.804***	-7.807**	-5.330*	-6.154***
	(-2.87)	(-2.75)	(-2.19)	(-1.96)	(-2.80)
Income from transfers	-0.0187**	-0.0138*	0.00392	-0.0187**	-0.0168**
	(-2.48)	(-1.75)	(0.16)	(-2.24)	(-2.19)
Med. collection time	-3.906***		-2.153	-5.957***	-3.943***
	(-2.72)		(-1.31)	(-2.89)	(-2.77)
% of Vil. area in FUG	-9.139		-40.71**	3.444	-8.526
	(-0.82)		(-2.45)	(0.27)	(-0.76)
Year fixed-effects	Yes	Yes	2003	2010	Yes
Spatial fixed-effects	Belt-zone	Village	Belt-zone	Belt-zone	Belt-zone
Village controls	Yes	NA	Yes	Yes	Yes
Observations	3590	3590	1474	2116	3590
Turning point	231.13	306.9	299.04	255.28	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 5: Fuel expenditures

	(1) Fuel exp.	(2) Fuel exp.	(3) Fuel exp.	(4) Fuel exp.	(5) Fuel exp.
Consumption exp.	16.41**	13.25*	26.71***	17.92*	
	(2.05)	(1.73)	(3.70)	(1.86)	
Consumption exp.^{2}	0.00546	0.00796	-0.0375	0.00474	
	(0.24)	(0.36)	(-1.44)	(0.19)	
Big livestock	-151.8***	-90.63***	-102.4***	-204.0***	-138.2***
	(-3.65)	(-2.84)	(-3.09)	(-3.07)	(-3.29)
Land owned, ha	-379.4***	-151.0*	-313.5**	-402.4**	-157.2*
	(-3.59)	(-1.76)	(-2.26)	(-2.40)	(-1.70)
hhsize	-36.56	-47.11	-26.68	-62.27	143.1***
	(-0.68)	(-0.96)	(-0.66)	(-0.75)	(3.00)
Prop. children	-136.7	185.2	-317.4	-6.744	-464.4
	(-0.42)	(0.60)	(-1.03)	(-0.01)	(-1.33)
Avg. education	102.8***	76.26***	97.74**	78.61**	214.8***
	(3.32)	(3.02)	(2.43)	(2.02)	(6.33)
= 1 if NFBus	289.7*	289.8**	779.1***	-11.24	472.0***
	(1.79)	(1.97)	(3.37)	(-0.06)	(2.88)
Income from transfers	2.132	1.896	1.696	1.858	3.072
	(1.17)	(0.94)	(0.90)	(0.94)	(1.50)
Med. collection time	346.6***		-69.92	502.7***	349.6***
	(2.62)		(-1.01)	(2.64)	(2.60)
% of Vil. area in FUG	606.4		165.1	373.5	774.8
	(0.90)		(0.22)	(0.48)	(1.08)
Year fixed-effects	Yes	Yes	2003	2010	Yes
Spatial fixed-effects	Belt-zone	Village	Belt-zone	Belt-zone	Belt-zone
Village controls	Yes	NA	Yes	Yes	Yes
Observations	3590	3590	1474	2116	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 6: Observed and predicted changes in firewood collections and fuel expenditures

Determinant	Change	Predicted effect			
		Firewood collection		Firewood collection	
		specification (1)	specification (5)	specification (1)	specification (5)
Consumption exp.	+44.27	2.03		+786	
Big livestock	-.37	-.97	-1.01	+57	+52
Land owned, ha	-.08	-.30	-.33	+29	+12
Household size	-.24	-1.46	-1.55	+9	-33
Prop. children	-.02	+.06	.06	+2	+8
Avg. education	+.74	-1.70	-1.53	+76	+159
= 1 if NFBus	.06	-.39	-.37	+17	+28
Income from transfers	+22.49	-.42	-.38	+48	+69
Med. collection time	+.41	-1.59	-1.61	+141	+142
% of Vil. area in FUG	+.06	-.59	-.55	+39	+50
Total Predicted Change		-5.33	-7.27	+1204	+487
Observed Change		-6.93		+1199	

Table 7: Descriptive statistics: Main household variables

Variable	Mean	Mean
	2003	2010
Big livestock	3.53	3.15
Land owned, ha	.68	.61
Household size	5.02	4.79
Avg. education (yrs)	2.41	3.16
Prop with Non-Farm Business	.22	.45
Prop. agri. working time	.82	.72
Consumption exp. (1000NPR)	74.9	119.2
Firewood (bharis/yr)	86	79
Collection time (hrs)	3.5	3.9
Fuel expenditures (NPR)	1979	2578

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

All monetary values expressed in NPR_{2010}

Table 8: Village median collection time

	Median village collection time in hours per bhari								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
LAI $90^{th} percentile_{t-1}$	-0.0404***	-0.0279**	-0.0275*						
	(-3.33)	(-2.07)	(-1.90)						
FPAR $90^{th} percentile_{t-1}$				-0.0344***	-0.0343***	-0.0338***			
				(-4.28)	(-2.76)	(-2.60)			
NDVI winter max $_{t-1}$							-0.000271**	-0.000296**	-0.000338**
							(-2.53)	(-2.10)	(-2.20)
% of Vil. area in FUG		1.385***	1.247**		1.370***	1.248**		1.488***	1.327**
		(2.63)	(2.31)		(2.60)	(2.30)		(2.81)	(2.46)
Livestock density			-0.0000704			-0.0000171			-0.0000102
			(-0.04)			(-0.01)			(-0.01)
Farm land density			-0.00259			-0.00196			-0.00315
			(-0.49)			(-0.37)			(-0.60)
Population density			0.000353			0.000431			0.000520
			(0.30)			(0.37)			(0.46)
Prop. child. density			0.00434			0.00319			-0.000317
			(0.39)			(0.29)			(-0.03)
Education density			-0.000792			-0.000780			-0.000771
			(-1.15)			(-1.14)			(-1.16)
Non-farm business density			0.00172			0.000990			0.00253
			(0.30)			(0.17)			(0.43)
Transfers density			0.0000443**			0.0000439**			0.0000414**
			(2.39)			(2.41)			(2.27)
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 9: Firewood collection

	Firewood collections in number of bharis per year								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
LAI $90^{th} percentile_{t-1}$	0.506***	0.654***	0.556***						
	(3.58)	(3.86)	(3.32)						
FPAR $90^{th} percentile_{t-1}$				0.225*	0.544**	0.423*			
				(2.27)	(3.28)	(2.56)			
NDVI winter max $_{t-1}$							0.00517***	0.00903***	0.00797***
							(4.34)	(4.35)	(3.80)
Med. collection time			-3.560***			-3.602***			-3.559***
			(-4.42)			(-4.46)			(-4.40)
Big livestock	2.950***	2.727***	2.696***	2.955***	2.696***	2.672***	2.871***	2.699***	2.671***
	(6.94)	(6.28)	(6.22)	(6.94)	(6.22)	(6.17)	(6.72)	(6.22)	(6.16)
Land owned, ha	4.645**	4.201**	3.978*	4.699**	4.163**	3.964*	4.667**	4.033*	3.821*
	(2.97)	(2.64)	(2.49)	(2.99)	(2.61)	(2.48)	(2.97)	(2.54)	(2.40)
Household size	6.367***	6.540***	6.564***	6.369***	6.538***	6.563***	6.375***	6.517***	6.544***
	(12.10)	(12.44)	(12.54)	(12.08)	(12.42)	(12.52)	(12.13)	(12.43)	(12.53)
Prop. children	-2.552	-3.715	-3.842	-2.309	-3.594	-3.715	-2.435	-3.378	-3.560
	(-0.62)	(-0.90)	(-0.93)	(-0.56)	(-0.87)	(-0.90)	(-0.59)	(-0.82)	(-0.86)
Avg. education	-2.156***	-1.929***	-2.009***	-2.200***	-1.950***	-2.034***	-2.160***	-1.880***	-1.963***
	(-6.73)	(-5.92)	(-6.20)	(-6.83)	(-5.98)	(-6.26)	(-6.73)	(-5.76)	(-6.04)
= 1 if NFBus	-6.254**	-6.273**	-6.111**	-6.117**	-6.067**	-5.941**	-5.884**	-6.100**	-5.962**
	(-2.98)	(-2.96)	(-2.88)	(-2.90)	(-2.85)	(-2.80)	(-2.79)	(-2.87)	(-2.81)
Income from transfers	-0.0201*	-0.0172*	-0.0162*	-0.0207*	-0.0174*	-0.0164*	-0.0199*	-0.0167*	-0.0157*
	(-2.48)	(-2.29)	(-2.18)	(-2.54)	(-2.32)	(-2.21)	(-2.48)	(-2.24)	(-2.13)
% of Vil. area in FUG		-13.50*	-8.531		-13.59*	-8.615		-16.32**	-10.99
		(-2.25)	(-1.37)		(-2.26)	(-1.38)		(-2.68)	(-1.74)
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 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.

A Appendix

Table A1: Consumption and occupational patterns: determinants

	Frequent consumption		Prop. agricultural worktime	
	(1)	(2)	(3)	(4)
Big livestock	1.594***	0.889**	0.0183***	0.0215***
	(3.58)	(2.16)	(7.73)	(8.96)
Land owned, ha	14.28***	12.15***	0.0137*	0.0300***
	(8.45)	(7.68)	(1.94)	(3.99)
Household size	9.923***	10.02***	-0.0135***	-0.0142***
	(14.06)	(14.07)	(-5.28)	(-5.69)
Prop. children	-13.09***	-17.21***	0.0239	0.0541**
	(-3.19)	(-4.08)	(1.06)	(2.51)
Avg. education	4.939***	6.200***	-0.0198***	-0.0246***
	(12.56)	(13.49)	(-8.94)	(-11.19)
= 1 if NFBus	10.32***	10.20***	-0.262***	-0.271***
	(4.50)	(4.58)	(-17.55)	(-19.76)
Income from transfers	0.0450***	0.0522***	0.000233*	0.000219**
	(2.74)	(3.32)	(1.94)	(2.07)
Med. collection time		0.00134		0.00233
		(0.00)		(0.41)
% of Vil. area in FUG		9.837		-0.0317
		(1.26)		(-0.74)
Year F.E.	No	Yes	No	Yes
Spatial Fixed effects	Village	Belt-Zone	Village	Belt-Zone
Village controls	No	Yes	No	Yes
Observations	3590	3590	3590	3590
Adj-R^2	0.528	0.454	0.425	0.354

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 A2: Fuel expenditures in NPR_{2010}

	Fuel expenditures in NPR_{2010}								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
LAI $90^{th} percentile_{t-1}$	-59.91***	-41.12***	-32.22**						
	(-5.87)	(-3.72)	(-2.84)						
FPAR $90^{th} percentile_{t-1}$				-42.98***	-38.40***	-27.57*			
				(-5.28)	(-3.67)	(-2.54)			
NDVI winter max $_{t-1}$							-0.567***	-0.666***	-0.572**
							(-4.86)	(-3.80)	(-3.20)
Med. collection time			321.6***			321.7***			316.5***
			(5.27)			(5.28)			(5.29)
Big livestock	-163.2***	-141.2***	-138.4***	-161.1***	-138.9***	-136.8***	-154.9***	-139.1***	-136.6***
	(-5.32)	(-4.66)	(-4.63)	(-5.22)	(-4.58)	(-4.57)	(-5.04)	(-4.58)	(-4.56)
Land owned, ha	-133.7	-163.9	-143.7	-139.0	-159.3	-141.5	-136.7	-148.8	-129.9
	(-1.56)	(-1.89)	(-1.66)	(-1.63)	(-1.84)	(-1.63)	(-1.62)	(-1.73)	(-1.51)
Household size	147.2***	145.9***	143.7***	148.9***	146.0***	143.8***	146.1***	147.6***	145.1***
	(3.72)	(3.66)	(3.63)	(3.75)	(3.66)	(3.63)	(3.70)	(3.70)	(3.67)
Prop. children	-449.1	-455.9	-444.5	-468.7	-460.7	-449.9	-465.1	-475.5	-459.3
	(-1.47)	(-1.49)	(-1.46)	(-1.53)	(-1.50)	(-1.48)	(-1.52)	(-1.55)	(-1.51)
Avg. education	203.2***	203.2***	210.5***	210.2***	204.0***	211.4***	203.8***	198.5***	205.9***
	(7.23)	(7.44)	(7.73)	(7.43)	(7.43)	(7.72)	(7.27)	(7.37)	(7.67)
= 1 if NFBus	517.5***	481.1**	466.5**	481.0**	467.4**	456.2**	478.2**	469.6**	457.3**
	(3.52)	(3.26)	(3.17)	(3.24)	(3.16)	(3.09)	(3.20)	(3.18)	(3.10)
Income from transfers	3.285	3.136	3.042	3.329	3.140	3.049	3.270	3.081	2.991
	(1.61)	(1.56)	(1.53)	(1.63)	(1.56)	(1.53)	(1.62)	(1.55)	(1.52)
% of Vil. area in FUG		1239.4**	790.6		1237.7**	793.4		1436.2***	961.9*
		(2.86)	(1.91)		(2.86)	(1.92)		(3.31)	(2.32)
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 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 A3: Descriptive statistics: household level variables

Variable	Median	Mean	Std. Dev.	Minimum	Maximum	Observations
Wood	70	81.75	59.2	0	500	3590
Collection time	3.5	3.75	1.83	.02	12	3344
Fuel expenditures	844.63	2086.1	3920.95	0	57266.64	3590
Consumption exp. ($1000NPR_{2010}$)	87.52	101.01	63.65	6.98	860.77	3590
Prop. agri. worktime	.91	.76	.3	0	1	3590
Big livestock	3	3.3	2.72	0	25	3590
Land owned, ha	.46	.64	.71	0	10.38	3590
Household size	5	4.88	2.2	1	17	3590
Prop. children	.4	.38	.24	0	1	3590
Avg. education	2.33	2.85	2.89	0	17	3590
= 1 if NFBus	0	.26	.44	0	1	3590
Income from transfers ($1000NPR_{2010}$)	0	29.46	95.22	0	3110.6	3590

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

All monetary values expressed in NPR2010

Table A4: Descriptive statistics: household level variables in 2003

Variable	Median	Mean	Std. Dev.	Minimum	Maximum	Observations
Wood	72	85.84	55.2	0	360	1474
Collection time	3	3.53	1.71	.02	12	1383
Fuel expenditures	812.14	1379.62	2613.21	0	57266.64	1474
Consumption exp. ($1000NPR_{2010}$)	64.10	74.92	47.43	6.98	449.37	1474
Prop. agri. worktime	.97	.82	.27	0	1	1474
Big livestock	3	3.53	2.92	0	25	1474
Land owned, ha	.48	.68	.76	0	9.81	1474
Household size	5	5.02	2.24	1	17	1474
Prop. children	.4	.39	.24	0	1	1474
Avg. education	1.67	2.41	2.7	0	13.67	1474
= 1 if NFBus	0	.22	.42	0	1	1474
Income from transfers ($1000NPR_{2010}$)	0	16.2	45.29	0	683.30	1474

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

All monetary values expressed in NPR2010

Table A5: Descriptive statistics: household level variables in 2010

Variable	Median	Mean	Std. Dev.	Minimum	Maximum	Observations
Wood	60	78.91	61.68	0	500	2116
Collection time	4	3.91	1.9	.5	10	1961
Fuel expenditures	884.47	2578.22	4554.36	0	52486.48	2116
Consumption exp. ($1000NPR_{2010}$)	106.29	119.19	67.11	9.05	860.77	2116
Prop. agri. worktime	.86	.72	.32	0	1	2116
Big livestock	3	3.15	2.56	0	20	2116
Land owned, ha	.43	.61	.66	0	10.38	2116
Household size	5	4.79	2.16	1	16	2116
Prop. children	.4	.37	.24	0	1	2116
Avg. education	2.67	3.16	2.98	0	17	2116
= 1 if NFBus	0	.28	.45	0	1	2116
Income from transfers ($1000NPR_{2010}$)	1	38.69	117.26	0	3110.6	2116

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

All monetary values expressed in NPR2010

Table A6: Descriptive statistics: village level variables

Variable	Median	Mean	Std. Dev.	Minimum	Maximum	Observations
Collection densities	2740.1	3276.17	2471.27	42.41	22515.49	301
ΔLAI p90_{t-1}^{t+1}	-1.28	-1.41	2.94	-14.5	6.8	301
$\Delta FPAR$ p90_{t-1}^{t+1}	-1.67	-1.57	3.63	-13.13	9.89	301
ΔLAI p90_{t-2}^{t+1}	-.81	-.93	3.22	-11.57	10.68	301
$\Delta FPAR$ p90_{t-2}^{t+1}	-.47	-.54	3.65	-11.07	11.33	301
$\Delta NDVI_{t-1}^{t+1}$	55.21	59.03	210.86	-615.46	765.33	301
$\Delta NDVI_{t-2}^{t+1}$	137.88	161.33	198.66	-488.65	769.82	301
LAI $90^{th} percentile_{t-1}$	25.5	25.39	7.35	1.72	50.43	301
LAI $90^{th} percentile_{t-2}$	24.86	24.91	7.26	1.69	45	301
FPAR $90^{th} percentile_{t-1}$	67.78	66.25	10.08	8.73	85.29	301
FPAR $90^{th} percentile_{t-2}$	66.86	65.23	9.94	8.5	83.86	301
NDVI winter max $_{t-1}$	7041.65	6898.67	887.96	1327.15	8491.89	301
NDVI winter max $_{t-2}$	6890.47	6796.36	887.65	1448.34	8377.78	301
Med. collection time	3.38	3.66	1.38	1	8	301
% of Vil. area in FUG	.13	.18	.18	0	1	301
Med. time to road	3.13	7.69	11.2	0	80	301
# killings 20km ar.	101	121.64	92.86	0	698	301
Vil. elevation: mean	1332	1465.47	789.93	119	5278	301
Vil. elevation: std. dev.	296.55	331.98	207.17	12.74	1520.83	301
Vil. snow cover * 1000	.37	2.92	8.51	0	62.11	301
Rainfall z-score	-.45	-.3	.99	-2.32	1.53	301
Monsoon GDD	1326.64	1209.43	396.61	0	1815.29	301
Cooling Degree Days	9.32	161.19	493.27	0	4042.55	301
VDC area in km^2	25.6	45.23	88.95	2.36	815.01	301
Village # HH.	917	1076.16	705.14	125	4692	301

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

Table A7: 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}	-.59	-.72	2.97	-14.5	6.8	123
$\Delta FPAR$ p90_{t-1}^{t+1}	-.07	-.18	3.79	-12.78	9.89	123
ΔLAI p90_{t-2}^{t+1}	-.5	-.34	3.4	-9.6	10.68	123
$\Delta FPAR$ p90_{t-2}^{t+1}	.9	.79	3.9	-11.07	11.33	123
$\Delta NDVI_{t-1}^{t+1}$	41.92	52.97	181.53	-432.45	464.5	123
$\Delta NDVI_{t-2}^{t+1}$	152.83	170.25	191.57	-231.18	662.25	123
LAI $90^{th} percentile_{t-1}$	24.92	24.44	7.28	1.72	39.33	123
LAI $90^{th} percentile_{t-2}$	24.33	24.05	7.39	1.69	45	123
FPAR $90^{th} percentile_{t-1}$	65.89	64.34	10.67	8.73	83.56	123
FPAR $90^{th} percentile_{t-2}$	64.79	63.38	10.39	8.5	83.33	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	3.42	1.27	1	8	123
% of Vil. area in FUG	.1	.14	.14	0	.64	123
Med. time to road	5	10.65	14.47	.08	80	123
# killings 20km ar.	56	78.65	64.86	0	354	123
Vil. elevation: mean	1336	1452.46	800.70	119	4835	123
Vil. elevation: std. dev.	290.03	329.76	206.23	12.74	1435.02	123
Vil. snow cover * 1000	.48	3.36	9.96	0	62.11	123
Rainfall z-score	.72	.6	.63	-1.39	1.53	123
Monsoon GDD	1366.28	1249.92	374.46	27.85	1673.1	123
Cooling Degree Days	16.6	178.68	526.18	0	3836.66	123
VDC area in km^2	24.79	46.57	96.84	2.36	776.85	123
Village # HH.	837	970.89	557.06	125	3349	123

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

Table A8: Descriptive statistics: village level variables in 2010

Variable	Median	Mean	Std. Dev.	Minimum	Maximum	Observations
Collection densities	2745.6	3248.82	2501.67	55.91	22515.49	178
ΔLAI p90_{t-1}^{t+1}	-1.62	-1.89	2.83	-13.14	4.18	178
$\Delta FPAR$ p90_{t-1}^{t+1}	-2.41	-2.53	3.2	-13.13	7.12	178
ΔLAI p90_{t-2}^{t+1}	-.9	-1.34	3.03	-11.57	5.75	178
$\Delta FPAR$ p90_{t-2}^{t+1}	-1.32	-1.46	3.17	-10.89	7.92	178
$\Delta NDVI_{t-1}^{t+1}$	66.24	63.21	229.36	-615.46	765.33	178
$\Delta NDVI_{t-2}^{t+1}$	128.61	155.16	203.72	-488.65	769.82	178
LAI $90^{th} percentile_{t-1}$	26.34	26.05	7.34	4.71	50.43	178
LAI $90^{th} percentile_{t-2}$	25.35	25.5	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	66.5	9.43	12.9	83.86	178
NDVI winter max $_{t-1}$	7115.3	6987.95	832.17	1976.44	8491.89	178
NDVI winter max $_{t-2}$	6986.38	6895.99	819.33	1857.98	8148.56	178
Med. collection time	3.5	3.83	1.43	1	8	178
% of Vil. area in FUG	.15	.2	.19	0	1	178
Med. time to road	2.5	5.65	7.61	0	40	178
# killings 20km ar.	126.5	151.35	97.69	0	698	178
Vil. elevation: mean	1329	1474.46	784.55	119	5278	178
Vil. elevation: std. dev.	300.78	333.52	208.38	12.74	1520.83	178
Vil. snow cover * 1000	.3	2.62	7.37	0	60.21	178
Rainfall z-score	-.9	-.93	.65	-2.32	.96	178
Monsoon GDD	1271.08	1181.45	409.92	0	1815.29	178
Cooling Degree Days	4.74	149.11	470.31	0	4042.55	178
VDC area in km^2	25.95	44.31	83.33	2.36	815.01	178
Village # HH.	945.5	1148.89	784.75	240	4692	178

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

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. This product, distributed by the NASA using 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.