

# Forest Degradation and Economic Growth in Nepal, 2003–2010

Jean-Marie Baland, François Libois, Dilip Mookherjee

**Abstract:** We investigate the relation between economic growth, household firewood collection, and forest conditions in Nepal between 2003 and 2010. Comovements in these are examined at the household and village levels, combining satellite imagery and household (Nepal Living Standard Measurement Survey) data. 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, as effects of demographic growth were offset by substantial reductions in per household collections. Households substituted firewood by alternative energy sources, particularly when livestock and farm-based occupations declined in importance. Engel curve specifications which include household productive assets (a proxy for occupational patterns) provide more accurate predictions. Hence structural changes accompanying economic growth play an important role in offsetting adverse environmental consequences of growth.

**JEL Codes:** D12, O1, Q2

**Keywords:** Deforestation, Environmental Kuznets curve, Growth, Nepal

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

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(see, e.g., 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 (Kumar and Hotchkiss 1988; Dasgupta 1995). 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.<sup>1</sup> Deforestation contributes to climate change as natural forests absorb a substantial fraction of greenhouse gases in the earth's atmosphere.<sup>2</sup> Accordingly, arresting deforestation is an important goal adopted by the 2015 Paris Agreement on Climate Change.<sup>3</sup>

The extent to which deforestation may be caused by economic growth in developing countries is central to evaluating the sustainability of currently ongoing develop-

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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, Bardhan, Das, Mookherjee, and Sarkar (2010)

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.

ment patterns and the need for corrective policies. To investigate this issue, we focus on the Himalayan forests located in the Hills and Mountain regions of Nepal,<sup>4</sup> 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 Mountain regions 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 factors behind the large-scale floods observed in the Ganga and Brahmaputra river basins. Moreover, over the period examined, income grew at an annual rate of 5.5% in Nepal (GDP per capita, PPP, World Bank) and poverty fell dramatically, with a head count ratio dropping from 46% in 2003 to 15% in 2010 (computed at \$1.90 a day, World Bank), much faster than in neighboring areas of India and China. Finally, in the Hills and Mountain of Nepal, firewood is by far the main source of energy for households (93% of households report wood as their main cooking fuel in our sample), both for cooking and heating.<sup>5</sup>

We find that forest conditions (measured by forest cover and biomass) remained 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 neighboring forest cover, providing support for the hypothesis that firewood collection is an important determinant of deforestation (see, e.g., Baland et al. 2014, 209–10). Total village-level collections remained essentially stable between 2003 and 2010 and accounted for at most 2% of the forest biomass, which 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 an 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

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4. The Hills and Mountain are two of the three agro-ecological zones of Nepal. They are defined based on altitude, crop, and livestock production systems. For a more comprehensive description, see, for instance, <http://www.fao.org/ag/agp/agpc/doc/counprof/nepal/nepal.htm>.

5. 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.

household level. We start by estimating Engel curves using cross-sectional and temporal variations across households in our sample.<sup>6</sup> 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 and 2010 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, nonfarm business assets, household size and composition, and 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 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, Bardhan, Das, Mookherjee, and Sarkar (2010) 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 nonfarm business assets rose. The former set of household characteristics are positively related to firewood collection, while the latter have a significant negative association.<sup>7</sup> This reflected a shift in occupational patterns away from farm- and livestock-based occupations that are complementary to firewood collection and toward nonfarm occupations that are substitutes. Nonfarm occupations necessitate going away from the village and neighboring 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.<sup>8</sup> Household fuel expenditures (i.e., on firewood alternatives) rose substantially between 2003 and 2010. In the cross-section, they exhibit similar correlations with various house-

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

7. 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.

8. Bluffstone (1995), Amacher et al. (1996), Baland and Platteau (1996), Baland, Bardhan, Das, Mookherjee, and Sarkar (2010).

hold 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 explore the connections between collections, collection times, and forest conditions. We are the first in the economic 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.<sup>9</sup>

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.<sup>10</sup> 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.<sup>11</sup> 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 heat-

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

10. Lele (1991), Jalal (1993), Barbier et al. (1997), Barbier (1998, 2010), Duraiappah (1998), Lopez (1998), Maler (1998).

11. Grossman and Krueger (1995), Barbier (1997), Yandle et al. (2002), Stern (2004).

ing, a large fraction of which is met by collecting firewood from forests.<sup>12</sup> 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 ecosystem 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 EKC, which are typically estimated at 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 socioeconomic status subject to less measurement error.

The paper is organized as follows. In section 1, we describe the major trends in forest conditions and collection of firewood in Nepal between 2003 and 2010. In section 2, 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 3. In section 4, we examine more closely the relations between forest biomass, collections, and collection time. Section 5 discusses the existing literature and concludes the paper.

## 1. MAJOR ECONOMIC TRENDS AND DEFORESTATION IN NEPAL: CONTEXT AND DESCRIPTIVE STATISTICS

The World Bank Living Standards Measurement Survey (LSMS) for Nepal interviewed 3,912 households in 2003–4 and 5,998 households in 2011–12 concerning their production and consumption activities in the preceding one year.<sup>13</sup> We focus

12. World Economic Forum 2006 Summit Report, World Bank (2000).

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, Bardhan, Das, Mookherjee, and Sarkar (2010). Unfortunately, the satellite imagery data available in the 1990s do not provide the relevant information necessary for our research. We have therefore decided to drop this additional data set in our main presentation and provide some robustness checks on our main estimates using the larger sample including the 1995 data in table A2.

on the villages located in the Hills and Mountain regions of Nepal, which share a similar agro-ecological system and a comparable reliance on forest resources. Table A3 (tables A1–A10, B1, B2 are available online in the appendix) compares the Terai with the Hills and Mountain, 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 3,590 households (1,474 in 2003 and 2,116 in 2010), located in 301 villages. Tables A5–A7 provide a description of the main household-level variables used in our analysis.

In these regions, 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 purchases.<sup>14</sup> 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, etc.) amount to NPR 2,086 (Nepalese rupee; from NPR 1,379 in 2003 to NPR 2,578 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 NPR 101,000 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.<sup>15</sup> 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 nonfarm 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

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14. 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.

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

Forest User Groups (CFUGs). These groups are empowered to control access to the forests, taxing forest products, hiring forest guards, and launching plantation programs.<sup>16</sup> 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 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) data set, 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.<sup>17</sup> 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 and 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 nontrivial measurement errors observed at the micro-level,

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16. 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.

17. 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; 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.



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.<sup>18</sup> We first define the leaf area index, LAI, which corresponds to the share of an area that 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 broad-leaved trees. Given the seasonality in the density of leaves in those areas, we use the 90th 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.<sup>19</sup>

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 90th 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 reports for every 16 days the maximum of the ratio

$$\frac{\text{Near Infra Red} - \text{Visible Red}}{\text{Near Infra Red} + \text{Visible Red}}$$

It proxies the amount of radiation captured by chloroplasts, which are green because they absorb all visible colors 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.<sup>20</sup>

These three measures of forest condition vary a lot across villages but remain remarkably stable between 2003 and 2010. In figure 1, 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 appears to follow a completely different process. While there is some fluctuation between years, there are no discernible trends in the Hills and the Mountain along any of those measures, except perhaps a slight increase in

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18. LAI and FPAR pixels have a 1 km × 1 km resolution while NDVI is more precise with a 250 m × 250 m resolution.

19. 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.

20. 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).

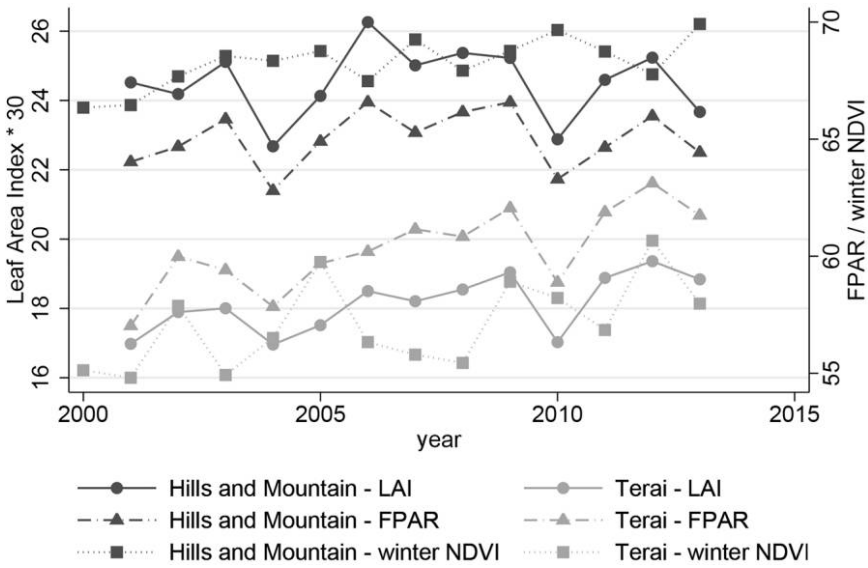


Figure 1. Evolution of biomass in surveyed villages in the 2000s

NDVI over the decade. In the Terai, by contrast, forest conditions seem to be improving, starting from a much lower initial level.

## 2. 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 (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  $t + 1$ .<sup>21</sup> We first define the total amount of fuelwood removed per unit area, using the administrative boundaries of the village.<sup>22</sup>

21. 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 behavior over the last 12 months, and this period spans over a leaf cover peak.

22. The various biomass indexes 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.

In a village  $j$  at time  $t$ ,  $C_{jt} = (\overline{C}_{jt} \times N_{jt})/A_j$ , where  $\overline{C}_{jt}$  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:

$$\Delta B_{jt} = B_{jt+1} - B_{jt-1} = \alpha + \varphi C_{jt} + \sigma B_{jt-1} + \sum_{z=1}^Z \rho_z V_{zjt} + \epsilon_{jt}, \tag{1}$$

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

Table 1 reports the estimation of this regression for each of our three forest measures, controlling for a number of relevant village variables.<sup>23</sup> As argued above, village collections are measured as densities, that is, annual total collection per unit area, since biomass is also measured as an average per unit area. The first columns (cols. 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 columns (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 in a village correspond to a 1.7% reduction in LAI ( $0.000129 \times 3276.17/25.5$ ). The estimated coefficients 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 come 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, Bardhan, Das, and Mookherjee 2010). Hence our regression results confirm the prior expectation that LAI would be more sensitive to collections than the other two biomass measures.<sup>24</sup>

23. 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.”

24. 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 kg per bharis  $\times$  3,276 bharis per square kilometers  $\times$  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.

Table 1. Degradation of Forest and Annual Firewood Collection

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Δ LAI 90th Percentile			Δ FPAR 90th Percentile			Δ NDVI Winter Max		
Collection densities	-.000129 (-1.59)	-.000150* (-1.94)	-.000205** (-2.26)	-.000170* (-1.94)	-.000176** (-2.19)	-.000207** (-2.27)	-.000113* (-1.78)	-.0000955 (-1.61)	-.000102 (-1.52)
LAI 90th percentile <sub>t-1</sub>	.0378 (.26)	-.312 (-1.31)							
LAI 90th percentile <sup>2</sup> <sub>t-1</sub>	-.00384 (-1.37)	-.00223 (-.51)							
LAI 90th percentile <sub>t-2</sub>		.387 (1.63)	-.0928 (-.62)						
LAI 90th percentile <sup>2</sup> <sub>t-2</sub>		-.00130 (-.28)	-.00132 (-.46)						
FPAR 90th percentile <sub>t-1</sub>				.0743 (.49)	.825 (1.56)				
FPAR 90th percentile <sup>2</sup> <sub>t-1</sub>				-.00173 (-1.50)	-.0106*** (-2.64)				
FPAR 90th percentile <sub>t-2</sub>						-.760 (-1.47)		-.0692 (-.36)	
FPAR 90th percentile <sup>2</sup> <sub>t-2</sub>						.00967** (2.42)		-.000602 (-.41)	



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 neighboring 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 nonlinearity 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.

### 3. 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, Bardhan, Das, Mookherjee, and Sarkar (2010) 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 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, Bardhan, Das, Mookherjee, and Sarkar (2010) 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 intravillage variations in a cross-sectional analysis helps control for the bias resulting from unobserved village heterogeneity. But it does not allow us to estimate the effects of collection times, which do not vary 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-zone 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 Mountain correspond to three different ecological belts). We distinguish between 22 belt zones in the Hills and Mountain, 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 varying sets of controls using a quadratic or a logarithmic specification.<sup>25</sup> 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 col. 1).<sup>26</sup> 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 conflict-related deaths within 20 km of the village, the presence of biogas installations, and 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 NPR 300,000, 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%.

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 semiparametric panel regression.<sup>27</sup> The estimation controls for belt-zone fixed effects and the

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25. 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.

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

27. Baltagi and Li (2002) suggest eliminating the fixed effects by first differencing the model over time, assuming that the nonparametric 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 nonparametric part of the

Table 2. Engel Curves

	Wood (1)	Wood (2)	Wood (3)	lnWood (4)	Wood (5)
Consumption expenditure	.372*** (8.03)	.246*** (5.23)	.271*** (6.02)		.170*** (4.03)
Consumption expenditure <sup>2</sup>	-.000539*** (-4.37)	-.000429*** (-4.46)	-.000450*** (-4.50)		-.000291*** (-3.57)
Log. consumption expenditure				.283*** (12.09)	
Household size					5.950*** (10.62)
Median collection time		-3.123* (-1.96)	-4.382*** (-2.68)	-.0404** (-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	3,590	3,590	3,590	3,343	3,590
Estimated turning point	344.93	286.38	301.15	NA	292.32

Note. Standard errors robust to heteroskedasticity; *t*-statistics in parentheses. 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 20 km around the village in the previous year, as well as previous year snow cover, rainfall deviation, cooling degree days, and monsoon growing degree days.

\*  $p < .1$ .

\*\*  $p < .05$ .

\*\*\*  $p < .01$ .

village controls. The first panel presents the semiparametric 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; see also table 3).

model from its parametric components. The partialled-out residuals will then be used to draw the nonparametric part of the regression. For more details, see Libois and Verardi (2013).



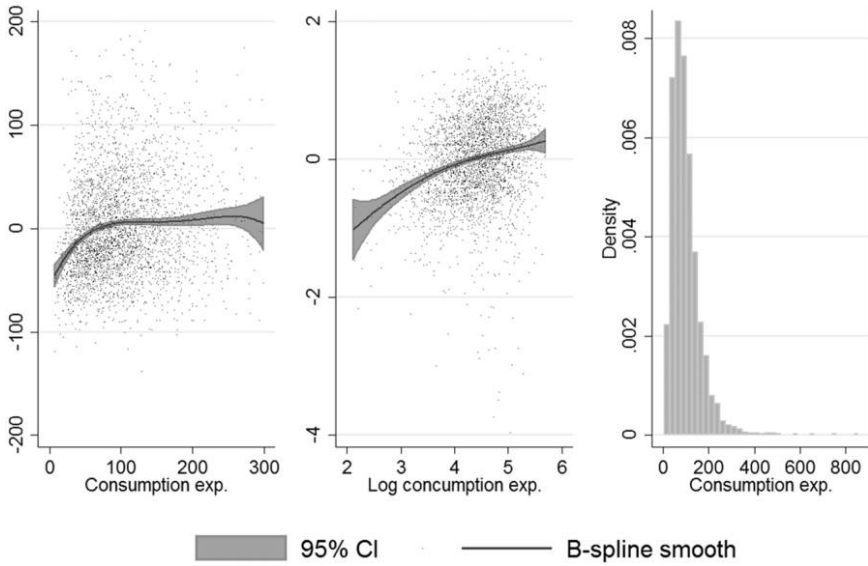


Figure 2. Annual firewood demand in bharis as a function of annual consumption. The semiparametric estimation of the Engel curve includes controls for the share of the village area managed by community forest user groups, the number of biogas installations per household in the village, the median access time to road, the village median altitude and altitude standard deviation, number of people killed in the 20 km 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 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.

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 a rise of about 8 bharis (or 10%) in firewood collections per household and per year as a result of the NPR 44,000 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, Bardhan, Das, Mookherjee, and Sarkar (2010), who argue for incorporation of house-

Table 3. Changes in Annual Firewood Collections

Year	Wood Collected in Bharis per Year	Frequent Consumption Expenditure in 1000NPR <sub>2010</sub> per Year
2003	85.84 (55.20)	74.92 (47.43)
2010	78.91 (61.68)	119.19 (67.11)
Observed change	-6.93	+44.28
Predicted change in wood collection based on $\Delta$ consumption:		
<b>+8.51</b>	Semiparametric estimation based on figure 2, specification (1)	
<b>+7.44</b>	Parametric estimation based on table 2, specification (3)	
<b>+4.38</b>	Parametric estimation based on table 2, specification (5)	
Predicted change in wood collection based on $\Delta$ consumption and $\Delta$ household size:		
<b>+2.97</b>	Parametric estimation based on table 2, specification (5)	

Note. Numbers in bold are predicted change in wood collection based on estimations. They can be compared to observed quantities and changes in the upper part of the table.

hold 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 labor allocation decisions, which depend in turn on productive assets owned by the household. Stocks and composition of household assets represent occupational patterns that 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 downward 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; for example, recall errors may lead to downward biases, whence the estimated coefficient would be biased upward. 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 a 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, 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%. Nonfarm occupations require household members to work set hours, usually in a semi-urban location outside the village, which creates 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 nonfirewood 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.

In table 5, we reestimate the Engel curve by incorporating into the set of regressors household occupation or household assets and demographics, which include household

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
Proportion female	.35	.37
Proportion children	.39	.37
Average education (years)	2.41	3.16
Proportion with nonfarm business	.22	.28
Number of migrants	.40	.80
Proportion agricultural working time	.82	.72
Consumption expenditure (1,000 NPR/year)	74.9	119.2
Firewood (bharis/year)	86	79
Collection time (hours/bhari)	3.5	3.9
Fuel expenditures (NPR/year)	1,979	2,578

Note. 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<sub>2010</sub>.

Table 5. Annual Firewood Collection

	Wood (1)	Wood (2)	Wood (3)	Wood (4)	Wood (5)	Wood (6)	Wood (7)
Consumption expenditure	.0957** (2.15)	.189*** (4.48)	.0996** (2.03)	.174*** (3.79)	.0815 (.88)	.101 (1.57)	
Consumption expenditure <sup>2</sup>	-.000214*** (-2.86)	-.000312*** (-3.81)	-.000214*** (-2.65)	-.000286*** (-3.37)	-.000148 (-.48)	-.000206** (-2.16)	
Proportion agricultural work time	26.19*** (6.99)	16.65*** (4.82)					
Big livestock			2.529*** (4.73)	2.171*** (4.11)	2.213*** (3.08)	2.887*** (3.97)	2.640*** (4.94)
Land owned, ha			3.701* (1.96)	.479 (.26)	6.013** (2.29)	1.325 (.58)	4.129** (2.20)
Household size	7.296*** (12.03)	5.991*** (10.76)	6.175*** (8.35)	5.440*** (7.74)	7.312*** (8.74)	5.176*** (4.89)	6.550*** (10.96)
Proportion female			1.384 (.26)	-5.726 (-1.01)	-11.78* (-1.75)	.516 (.07)	1.362 (.25)
Proportion children			-3.119 (-.63)	-7.548 (-1.47)	-5.314 (-.80)	-3.491 (-.49)	-3.008 (-.62)
Average education			-2.360*** (-5.84)	-1.299*** (-3.01)	-1.886*** (-3.80)	-2.412*** (-4.65)	-2.126*** (-5.66)

= 1 if nonfarm business				-6.911*	-5.433**	-6.416***														-5.746**	-6.018***
				(-1.95)	(-2.58)	(-2.81)														(-2.15)	(-2.71)
No. of migrants				3.825**	1.744*	-1.276														-1.480	-1.207
				(2.08)	(1.75)	(-1.22)														(-1.26)	(-1.15)
Median collection time				-1.878		-4.055***														-6.625***	-4.083***
				(-1.09)		(-2.79)														(-3.07)	(-2.83)
% of village area in FUG				-41.43**		-8.210														6.506	-7.630
				(-2.47)		(-7.4)														(.52)	(-.69)
Biogas per household				-107.4		-58.75*														-34.21	-54.81
				(-1.45)		(-1.70)														(-.95)	(-1.61)
Year fixed effects	Yes	Yes	Yes	2003	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	2010	Yes
Spatial fixed effects				Belt zone	Village	Belt zone	Village	Belt zone	Village	Belt zone	Village	Belt zone	Village	Belt zone	Village	Belt zone	Village	Belt zone	Belt zone	Yes	Belt zone
Village controls				Yes	NA	Yes	NA	Yes	NA	Yes	NA	Yes	NA	Yes	NA	Yes	NA	Yes	Yes	Yes	Yes
Observations				1,474	3,590	3,590	3,590	3,590	3,590	3,590	3,590	3,590	3,590	3,590	3,590	3,590	3,590	3,590	2,116	2,116	3,590
Turning point				275.28	304.19	232.2	303.48	303.48	303.48	304.19	232.2	303.48	303.48	304.19	304.19	232.2	303.48	303.48	245.33	245.33	NA

Note. Standard errors clustered at the village level,  $t$ -statistics in parentheses. Village-level controls include median access time to road, village median altitude and altitude standard deviation, number of people killed in the 20 km around the village in the previous year, as well as previous year snow cover, rainfall deviation, cooling degree days, and monsoon growing degree days.

\*  $p < .1$ .

\*\*  $p < .05$ .

\*\*\*  $p < .01$ .

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 reestimated 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 nonfarm assets is particularly striking and suggests the importance of occupational effects operating through the shadow cost of collection. Rising farm-based assets raise collections as expected, while rising nonfarm assets lower collections possibly owing to rising collection costs outweighing the direct income effects. The coefficient on household size is positive and significant, 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.

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 that 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.

Since rising nonfarm 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.

Table 6. Consumption and Occupational Patterns: Determinants

	Annual Consumption Expenditure		Proportion Agricultural Work Time	
	(1)	(2)	(3)	(4)
Big livestock	1.658*** (3.61)	.646 (1.41)	.0187*** (7.80)	.0223*** (9.09)
Land owned, ha	14.71*** (8.39)	12.83*** (7.74)	.0101 (1.48)	.0263*** (3.61)
Household size	9.882*** (13.93)	9.964*** (13.88)	-.0110*** (-4.40)	-.0111*** (-4.51)
Proportion children	-13.69*** (-2.75)	-16.16*** (-3.33)	.128*** (4.46)	.150*** (5.52)
Proportion female	-.628 (-.11)	4.451 (.78)	.206*** (5.92)	.194*** (5.85)
Average education	4.987*** (12.49)	6.500*** (13.04)	-.0170*** (-7.79)	-.0227*** (-10.11)
= 1 if nonfarm business	9.914*** (4.41)	10.60*** (4.55)	-.252*** (-17.40)	-.265*** (-19.90)
No. of migrants	.0148 (.01)	-.0631 (-.06)	.0425*** (7.43)	.0385*** (7.14)
Median collection time		-.470 (-.42)		.00405 (.72)
% of village area in FUG		11.49 (1.46)		-.0453 (-1.08)
Biogas per household		64.18** (2.00)		-.322** (-2.06)
Year fixed effects	Yes	Yes	Yes	Yes
Spatial fixed effects	Village	Belt zone	Village	Belt zone
Village controls	No	Yes	No	Yes
Observations	3,590	3,590	3,590	3,590

Note. Standard errors clustered at the village level, *t*-statistics in parentheses. Village-level controls include median access time to road, village median altitude and altitude standard deviation, number of people killed in the 20 km around the village in the previous year, as well as previous year snow cover, rainfall deviation, cooling degree days, and monsoon growing degree days.

\* *p* < .1.

\*\* *p* < .05.

\*\*\* *p* < .01.

Using the estimated coefficients of columns 3 and 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

Table 7. Fuel Expenditures in NPR<sub>2010</sub> per Year

	Fuel Expenditure (1)	Fuel Expenditure (2)	Fuel Expenditure (3)	Fuel Expenditure (4)	Fuel Expenditure (5)	Fuel Expenditure (6)	Fuel Expenditure (7)
Consumption expenditure	16.25** (2.21)	12.94* (1.83)	18.40** (2.31)	13.99* (1.86)	28.20*** (3.86)	20.20** (2.11)	
Consumption expenditure <sup>2</sup>	.00556 (.24)	.00860 (.40)	.00266 (.11)	.00712 (.32)	-.0412 (-1.61)	.00174 (.07)	
Proportion agricultural work time	-1695.2*** (-5.24)	-1135.1*** (-4.44)					
Big livestock			-158.7*** (-3.70)	-86.94*** (-2.61)	-105.6*** (-3.09)	-213.6*** (-3.16)	-140.2*** (-3.20)
Land owned, ha			-355.5*** (-3.27)	-138.6 (-1.53)	-309.3** (-2.28)	-381.4** (-2.19)	-114.1 (-1.13)
Household size	-137.9*** (-3.20)	-80.46** (-2.04)	-57.44 (-1.04)	-49.23 (-.98)	-28.26 (-.71)	-92.53 (-1.08)	133.8*** (2.79)
Proportion female			22.11 (.06)	665.2* (1.89)	749.2** (2.56)	-369.3 (-.69)	87.91 (.24)
Proportion children			-162.2 (-.42)	488.3 (1.32)	11.37 (.03)	-198.9 (-.36)	-470.3 (-1.19)
Average education			102.5*** (3.28)	80.24*** (3.15)	101.4** (2.45)	74.39* (1.91)	224.0*** (6.48)



= 1 if nonfarm business	229.8 (1.37)	269.8* (1.82)	768.6*** (3.21)	-69.58 (-.35)	419.0** (2.50)
No. of migrants	-167.5** (-2.16)	-60.45 (-1.02)	-95.28 (-1.55)	-170.0 (-1.60)	-166.9** (-2.14)
Median collection time	344.9** (2.57)		-86.83 (-1.23)	501.5*** (2.65)	342.4** (2.54)
% of village area in FUG	895.7 (1.33)		291.3 (.40)	671.0 (.88)	1,036.4 (1.45)
Biogas per household	-5,471.9** (-2.29)		-4,211.2 (-1.55)	-6,403.6** (-2.46)	-4,244.9 (-1.59)
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	3,590	3,590	1,474	2,116	3,590
Turning point	-1,462.05	-752.51	342.17	-5,796.01	NA

Note. Standard errors clustered at the village level, *t*-statistics in parentheses. Village-level controls include median access time to road, village median altitude and altitude standard deviation, number of people killed in the 20 km around the village in the previous year, as well as previous year snow cover, rainfall deviation, cooling degree days, and monsoon growing degree days.

\*  $p < .1$ .

\*\*  $p < .05$ .

\*\*\*  $p < .01$ .

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 expenditure	+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
Proportion female	+.02	+.02	+.02	+0	+2
Proportion children	-.02	+.05	+.05	+3	+8
Average education	+.74	-1.75	-1.58	+76	+166
= 1 if nonfarm business	+.06	-.39	-.36	+14	+25
No. of migrants	+.40	-.51	-.48	-67	-67
Median collection time	+.41	-1.66	-1.67	+137	+140
% of village 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		+1,199

in table 8. 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 corresponds to a fall in collections by 1.7 bharis. For annual fuel expenditures, the observed change is equal to NPR 1,199, and our predicted changes vary between NPR 298 and NPR 1,066.

#### 4. 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 neighboring 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:

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

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 biomass.

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 appendix table 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), 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%)

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 90th percentile <sub>t-1</sub>		-0.0400*** (-3.17)	-0.0292** (-2.01)	-0.0351** (-2.29)					
FPAR 90th percentile <sub>t-1</sub>				-0.0344*** (-4.17)	-0.0361*** (-2.73)	-0.0378*** (-2.79)			
NDVI winter max <sub>t-1</sub>							-0.00271** (-2.37)	-0.000305* (-1.90)	-0.000372** (-2.36)
% of village area in FUG		1.402*** (2.64)	1.235** (2.40)		1.388*** (2.62)	1.255** (2.41)		1.507*** (2.84)	1.340** (2.59)
Biogas density		-1.684 (-.85)	-2.776 (-1.52)		-1.755 (-.90)	-2.730 (-1.51)		-1.390 (-.70)	-2.392 (-1.30)
Livestock density			-0.00215 (-1.03)			-0.00183 (-.90)			-0.00172 (-.82)
Farm land density			-0.00143 (-.28)			-0.00113 (-.22)			-0.00254 (-.49)
Population density			.00277** (2.19)			.00271** (2.16)			.00264** (2.10)

Proportion female density	-0.0132 (-1.02)	-0.116 (-0.91)	-0.0116 (-0.84)	
Proportion child. density	-0.00375 (-0.38)	-0.00506 (-0.50)	-0.00809 (-0.80)	
Education density	-0.00147** (-2.08)	-0.00140** (-1.97)	-0.00138** (-1.99)	
Nonfarm business density	.00420 (.75)	.00313 (.55)	.00477 (.83)	
Out-migrant density	.00897*** (2.86)	.00839*** (2.69)	.00807*** (2.63)	
Year fixed effect	Yes	Yes	Yes	Yes
Belt-zone fixed effects	Yes	Yes	Yes	Yes
Village controls	No	No	No	Yes
Observations	301	301	301	301

Note. Standard errors robust to heteroskedasticity; *t*-statistics in parentheses. Village-level controls include median access time to road, village median altitude and altitude standard deviation, number of people killed in the 20 km around the village in the previous year, as well as previous year snow cover, rainfall deviation, cooling degree days, and monsoon growing degree days.

\*  $p < .1$ .

\*\*  $p < .05$ .

\*\*\*  $p < .01$ .

results in a fall of only 0.22 hours (6%) in collection times (using col. 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.

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.<sup>28</sup> 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.

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 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 bharis per year ( $887 * .0087$ , from col. 8).<sup>29</sup> 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 influences positively the collection of firewood, and these effects are not fully captured by collection times.

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28. 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, Bardhan, Das, and Mookherjee (2010).

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

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 loses 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 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 nonfarm 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 feedback effects on collections are large enough for a stable equilibrium in collections, biomass, and collection times to appear.<sup>30</sup> For the sake of the argument, consider that collections caused a 20% reduction in biomass, that is, 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 directly or indirectly through increasing collection times. This may also be due to the various measurement errors in these estimates, which tend to bias downward our estimates.

## 5. 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 and 2010. This occurred despite substantial growth in consumption expenditures of households in neighboring 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

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

Table 10. Annual Firewood Collection

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Firewood Collections in Number of Bharis per Year								
LAI 90th percentile <sub>t-1</sub>	.522*** (3.67)	.615*** (3.70)	.501** (3.07)						
FPAR 90th percentile <sub>t-1</sub>				.235* (2.36)	.501** (3.07)	.364* (2.26)			
NDVI winter max <sub>t-1</sub>							.00529*** (4.45)	.00873*** (4.22)	.00756*** (3.62)
% of village area in FUG		-12.98* (-2.16)	-7.588 (-1.22)		-13.00* (-2.16)	-7.566 (-1.22)		-15.60* (-2.57)	-9.835 (-1.56)
Biogas per household		-38.33 (-1.61)	-45.55 (-1.92)		-41.76 (-1.75)	-49.08* (-2.07)		-41.91 (-1.75)	-48.10* (-2.02)
Median collection time			-3.731*** (-4.70)			-3.793*** (-4.76)			-3.721*** (-4.64)
Big livestock	2.952*** (6.93)	2.687*** (6.23)	2.646*** (6.14)	2.954*** (6.92)	2.652*** (6.15)	2.620*** (6.09)	2.870*** (6.70)	2.655*** (6.16)	2.619*** (6.09)
Land owned, ha	4.613** (2.94)	4.193** (2.63)	3.960* (2.48)	4.661** (2.95)	4.154** (2.60)	3.948* (2.46)	4.639** (2.94)	4.010* (2.52)	3.791* (2.38)
Household size	6.341*** (11.86)	6.534*** (12.23)	6.561*** (12.33)	6.339*** (11.82)	6.531*** (12.20)	6.558*** (12.31)	6.345*** (11.88)	6.519*** (12.22)	6.548*** (12.33)



Proportion female	.501 (.09)	2.696 (.50)	2.455 (.46)	-302 (-.06)	2.036 (.38)	1.857 (.35)	.0935 (.02)	2.692 (.50)	2.519 (.47)
Proportion children	-2.334 (-.50)	-2.560 (-.55)	-2.817 (-.61)	-2.460 (-.52)	-2.754 (-.59)	-2.980 (-.64)	-2.407 (-.51)	-2.247 (-.48)	-2.535 (-.55)
Average education	-2.211***	-1.956***	-2.038***	-2.263***	-1.981***	-2.066***	-2.217***	-1.902***	-1.986***
= 1 if nonfarm business	(-6.83)	(-5.92)	(-6.20)	(-6.95)	(-5.98)	(-6.26)	(-6.84)	(-5.74)	(-6.02)
	-6.337**	-6.288**	-6.103**	-6.194**	-6.088**	-5.948**	-5.966**	-6.097**	-5.942**
No. of migrants	(-3.00)	(-2.95)	(-2.87)	(-2.92)	(-2.85)	(-2.80)	(-2.81)	(-2.86)	(-2.80)
	-1.379	-1.346	-1.221	-1.309	-1.232	-1.136	-1.365	-1.168	-1.067
Year fixed effect	(-1.38)	(-1.36)	(-1.24)	(-1.31)	(-1.25)	(-1.16)	(-1.38)	(-1.18)	(-1.08)
Belt-zone fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Village controls	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Observations	3,590	3,590	3,590	3,590	3,590	3,590	3,590	3,590	3,590

Note. Standard errors robust to heteroskedasticity; *t*-statistics in parentheses. Village-level controls include median access time to road, village median altitude and altitude standard deviation, number of people killed in the 20 km around the village in the previous year, as well as previous year snow cover, rainfall deviation, cooling degree days, and monsoon growing degree days.

\*  $p < .1$ .

\*\*  $p < .05$ .

\*\*\*  $p < .01$ .

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 a nontrivial 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 that 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 twentieth 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.<sup>31</sup> 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.

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31. 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.

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, Heltberg et al. 2000; Adhikari et al. 2004; Arnold et al. 2006; Baland et al. 2006; Gundimeda and Kohlin 2008). 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 that 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 to our analysis is Baland, Bardhan, Das, Mookherjee, and Sarkar (2010), 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.<sup>32</sup> 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, Bardhan, Das, and Mookherjee (2010), 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, it does 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 ad-

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

dress 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 that 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 show 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.

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