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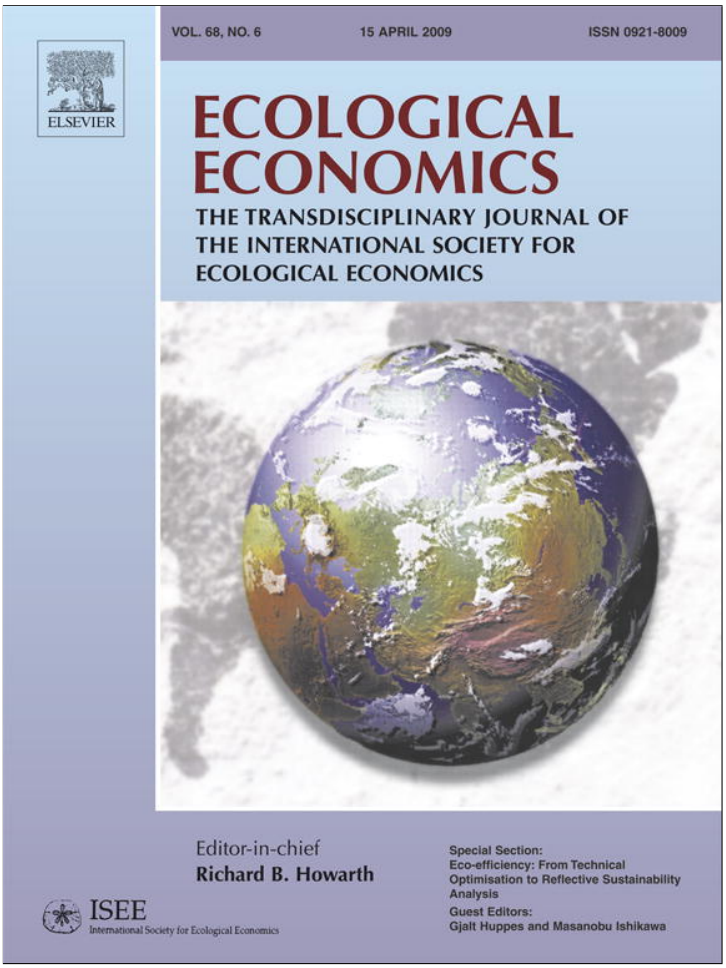

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ANALYSIS

The relation between forest clearance and household income among native Amazonians: Results from the Tsimane' Amazonian panel study, Bolivia

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ABSTRACT

The Amazon rain forest harbors some of the world's richest biological diversity. During the twentieth century, two types of actors cleared that forest: native Amazonians and outside encroachers. Of the two actors, we know more about what drives outside encroachers to clear forest than about what drives native Amazonians to clear forest. The past research focus has served well because during the twentieth century outside encroachers cleared most of the Amazonian forest. But the past research focus needs to be expanded because native Amazonians are claiming *de jure* stewardship of the forests they inhabit, and with tighter jurisdiction over those forests will likely come changes in the amount of forest native Amazonians clear. Prior research in rural areas of low-income nations suggests that household income affects household forest clearance. To estimate the effects of household real income on the total forest area (old-growth + fallow) cleared by households we use a panel composed of five annual household surveys (2002–2006, inclusive) from 324 households of a native Amazonian society in Bolivia (Tsimane'). We control for household and village fixed effects and use an instrumental variable for household income. We find positive and significant household real income elasticities of forest clearance of 0.35 and 0.47 and an increase in forest clearance of 5.3%/year. The main finding stood up well to sensitivity analysis. These estimates suggest that in the near future, the forest in the Tsimane' territory will likely face increasing pressure from the Tsimane' themselves, not just from outside encroachers.

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1. Introduction

The Amazon rain forest harbors some of the world's richest biological diversity (Malhi et al., 2008; Whinnett et al., 2005). During the twentieth century two types of actors cleared the Amazon rain forest (hereafter forest): native Amazonians and outside encroachers (London and Kelly, 2007). Traditionally, households of native Amazonians practiced slash-and-burn farming to plant chiefly subsistence crops. They cleared the forest to sow crops for 1–3 consecutive years, and then abandoned the plot. During the past two decades, households of native Amazonians have continued to clear the forest to plant subsistence crops, but they have also started to clear the forest to put in cash crops (Vadez et al., 2004) and large domesticated animals, such as cattle and pigs (Bremmer and Lu, 2006; Lu, 2007; Rudel et al., 2002a,b). Unlike forest clearing for slash-and-burn farming, forest clearing for pastureland and for commercial farming generally entails the permanent removal of forest. In recent years, native Amazonians have also started to clear forest permanently to stake private claims to land before outside encroachers step in. Outside encroachers include cattle ranchers, logging firms, road builders, oil firms, coca cultivators, and colonist farmers (Godoy et al., 1998). Outside encroachers have cleared forests in the Amazon to plant pasture for cattle, to cultivate commercial crops (e.g., soybeans), to build physical infrastructure, and to claim land (Hecht et al., 1988; Painter and Durham, 1995; Repetto and Gillis, 1988; Schmink and Wood, 1992; Wood and Porro, 2002; Wunder, 2000). Unlike most of the forest cleared by native Amazonians, forest clearing

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by outside encroachers typically entails the permanent conversion of forest to pastureland or to farmland.

Of the two actors, we know more about what drove outside encroachers to clear forest than about what drives native Amazonians to clear forest. The past research focus has served well because during the twentieth century outside encroachers cleared most of the Amazonian forest (Barbier, 2004; Killeen et al., 2007). But the past research focus needs to be expanded because native Amazonians are claiming *de jure* stewardship of the forests they inhabit (Nepstad et al., 2006; Redford and Stearman, 1993; Rudel et al., 2002b), and with tighter jurisdiction over those forests will likely come changes in the amount of forest native Amazonians clear.

Several studies have examined the relation between household income (hereafter income) and household forest clearance (hereafter forest clearance) among native Amazonians. Vadez et al. (2008) pooled three consecutive annual household surveys (2000, 2001, and 2002) from a panel study of the Tsimane' (a native Amazonian group in Bolivia) and regressed the area of forest cleared by the household (outcome variable) against household income, the natural logarithm (hereafter log) of area under rice cultivation, an index of market dependence, and dummy variables for villages. They found positive but insignificant associations between household income and the clearance of (a) old-growth forest or (b) total forest, defined as old-growth forest plus fallow forest. Drawing on a cross-sectional survey done during 1996 among 209 Tsimane' households in 18 villages, Pendleton and Howe (2001) regressed separately the area of old-growth forest, fallow forest, and total forest cleared (outcome variables) against the prices of maize, rice, and bananas, while controlling for individual and community attributes. They found that the price of bananas and rice bore a positive association with the area of old-growth forest cleared, but they also found that the price of maize bore a negative association with the area of old-growth forest cleared; the price of bananas, rice, or maize did not affect the area of fallow forest cleared. Godoy (2001) drew on one cross-sectional household survey among four lowland groups of native Amazonians in Bolivia (Tsimane', Mojeño, Yuracaré, and Chiquitano) and found that only farm income bore a positive association with the area of old-growth forest cleared; wage income did not affect the area of old-growth forest cleared. Total income, or earnings from the sale of farm goods and from wage labor, bore no significant association with the area of old-growth forest cleared, except among the Yuracaré ($n = 62$). Among the Yuracaré, the relation between the area of old-growth forest cleared and total household income resembled an inverted U.

These studies suggest that the relation between household income and household forest clearance among native Amazonians varies across time and space, a point underscored by other researchers writing more broadly about forest clearance in rural areas of low-income nations (Angelsen and Kaimowitz, 1998, 1999; Barbier and Burgess, 2001). Prior studies about forest clearance and income among native Amazonians have produced suggestive but fragile results in part because they have not corrected for the endogeneity of income.[1] First, because the studies relied on cross-sectional data from households — or on pooled panel data analyzed as a cross section (e.g., Vadez et al., 2008) — they could not control for fixed attributes of households that affected both forest clearance and income. Examples of such attributes include role models, local ecological knowledge of household heads (Reyes-García et al., 2007), and a household's stock of health. Second, income might affect forest clearance, but forest clearance might affect income. None of the studies just reviewed control for possible two-way causality between forest clearance and income. Third, these studies have failed to take into account that forest clearance among native Amazonians is a multidimensional activity that is part consumption, part income, part savings, and part investment. Because native Amazonian societies are highly autarkic, and because prices are non-existent or spotty, one cannot mechanically apply a demand and supply framework or other conventional modeling approaches that work well in more developed economies.

Given the hurdles in empirical estimations of how household income might affect household forest clearance, here we draw on a panel data set composed of five consecutive annual household surveys (2002–2006, inclusive) from 324 households in one native Amazonian society in Bolivia, the Tsimane', to achieve the following aims:

(1) Provide a descriptive model of how total household income affects the clearance of local forest by households without making assumptions about the existence or quality of markets for capital or labor, and
(2) Improve the precision of prior estimates by doing the following: (a) using an instrumental-variable approach to control for the endogeneity of household income, (b) controlling for fixed attributes of villages each year, (c) controlling for fixed attributes of households across all five years of the study, (d) controlling for year effects, and (e) using multiple observations of forest clearance for each household across the five years of the study.

We stress total household income rather than different types of household income (e.g., earnings from wage labor or earning from the sale of farm and forest goods) because income from wage labor and from the sale of farm or forest goods were heavily censored at zero (see below), so combining different sources of income into one variable produces more variation in household income, our chief explanatory variable. In adding different sources of income we give up the possibility of identifying how different types of income might affect forest clearance, but our approach has merit because much of the earlier research (e.g., Angelsen and Kaimowitz, 1998, 1999) has already highlighted the role of different types of income on forest clearance. We stress the clearance of local forest or forest surrounding a village because a rise in the level of household income could induce native Amazonians to clear forests beyond their villages.[2] If so, then estimates of the relation between the clearance of local forests and income would yield an incomplete portrait of how income levels affect the total amount of forest cleared. We believe that the stress on the clearance of local forest captures most of the forest cleared by native Amazonians because — to our knowledge — native Amazonians have not started to displace forest clearance beyond their villages, though this is a theoretical possibility we cannot dismiss.

2. Data

For this article we draw on data from an annual panel study in progress among the Tsimane' that started in 2002 (Leonard and Godoy, 2008). Information was collected annually during June–September from all Tsimane' in 13 Tsimane' villages along the Maniqui River, department of Beni. The panel includes about 250 households and 1500 people. Villages differ in their proximity to the market town of San Borja (mean = 25.96 km; standard deviation [SD] = 16.70), the only town along the Maniqui River. Four Bolivian university graduates conducted the survey and four Tsimane' who worked in the study from its inception served as translators. The complete data set and its documentation, along with publications from the project, are available for public use at the following web address: http://people.brandeis.edu/~rgodoy/.

[1] Other possible reasons for the weak results include: (a) random errors in the measure of income, (b) low levels of income, typical of indigenous populations in Latin America (Hall and Patrinos, 2006; Lunde et al., 2007), (c) small variation in income levels, (d) small sample size, and (e) small variation in the area of old-growth or fallow forest cleared, with heavy left-hand censoring for each type of forest (Pendleton and Howe, 2001).

[2] See Suri and Chapman (1998) for a review of the literature of how industrial nations displace environmental costs to low-income nations.

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3. Context: forest clearance and income among the Tsimane'

The Tsimane' number about 8000 people and live in about 100 villages in the Bolivian Amazon, mostly along the Maniqui and the Apere rivers in the department of Beni. The Tsimane' economy centers on hunting, fishing, plant foraging, and on slash-and-burn farming.

Prior studies among the Tsimane' contain ethnographic descriptions and discussions of forest clearance (Godoy, 2001; Reyes-García et al., 2007; Vadez et al., 2004; Pendleton and Howe, 2001) and income sources (Godoy et al., 2007). These studies point to four findings that bear on this article. First, self-reported answers about forest clearance provided by plot owners bore a positive and statistically significant association with measures of forest clearance taken by researchers (Vadez et al., 2003). Therefore, the measure of the outcome variable used in this article — self-reported answers about the clearance of old-growth forest or fallow forest — provides a reasonably accurate estimate of actual forest clearance. Second, the price of rice (Pendleton and Howe 2001) and the cultivation of rice as a cash crop accounts for an increasingly important share of the area of forest cleared by households (Vadez et al., 2008). Third, the ethnobotanical knowledge of the male head of a household is associated with less forest clearance (Reyes-García et al., 2007). Fourth, the Tsimane' remain highly autarkic (Godoy et al., 2007). For example, among people over 16 years of age, 74.88% of the sample reported no earnings from wage labor and 56.40% of the sample reported no earnings from the sale of farm or forest goods for the two weeks before the day of the interview.

We next provide a description of the institutions regulating usufruct rights to forest, of why Tsimane' clear forest, of how they clear the forest, and of their sources of income.

3.1. Institutional arrangement

Tsimane' practice farming in their ancestral lands (Huanca, 2008). Tsimane' land legally belongs to the entire ethnic group; Tsimane' cannot buy or sell land to each other or to outsiders. In a typical village, houses lie scattered around the school, and households usually farm around the village in a radius of about 2 km. The forest available to each household for farming depends on the number of households in the village and on the abundance of forest surrounding the village. During the study period the mean and the median number of households in a village were 25 and 17 (SD = 17), and the average household had 6.35 people (SD = 2.83).

Tsimane' households typically clear some old-growth forest and some fallow forest. Cleared plots have informal owners; those who cleared a plot of old-growth forest have usufruct rights to continue using the cleared plot for farming, or to use forest products from the cleared plot as it reverts back to forest. Years after last using a plot for farming, Tsimane' will remember who initially cleared the plot and who has first rights to the fallow forest on that plot. Tsimane' plant a variety of useful plants on cleared plots as the cleared plot reverts back to fallow forest; they put in plants as property markers, or as a way to claim usufruct rights to the land as it reverts back to fallow forest. These plants also serve for food, construction material, medicines, and other ends (Huanca, 1999). In practice, the right to use a fallow forest is lax. People who did not initially clear a plot of old-growth forest are able to clear the plot for farming after it has become a fallow forest, or simply extract some of the planted tree crops or fruit trees in the fallow forest.

Cleared plots or fallow forests generally remain unfenced. When cattle or domesticated pigs threaten planted crops, Tsimane' either build a fence on a cleared plot to enclose their own domesticated animals (see below), or else put a fence around part of the village to halt the advance of cattle from outsiders and, in so doing, protect the property of all villagers.

Tsimane' believe that all plants and animals were human in mythical times, and that the gods converted some of those early humans into today's animals and plants. Because Tsimane' believe that humans, animals, and plants share a common ancestry, they view plants and animals as their kin, and, consequently, have a reverential attitude toward the plants and animals of their forest (Huanca, 2008). For instance, as they prepare to clear a patch of old-growth forest for farming, Tsimane' will ask the spirit of large trees for permission before cutting them down.

3.2. Reasons for forest clearance by Tsimane'

Tsimane' households clear the forest for multiple ends. First, and most importantly, they clear the forest to plant some of their main subsistence (typically annual) farm crops, such as manioc, maize, rice, and plantains. Less important subsistence farm crops include peanuts, sugar cane, sweet potatoes, and citrus (Vadez et al., 2008; Piland, 1991). Second, more and more households — particularly those near market towns (Vadez et al., 2004) — clear forest to plant rice for sale (Vadez et al., 2008). Farm crops (particularly rice) account for more than half of the income of households (Vadez et al., 2008). The global increase in the price of food during 2008 has induced some Tsimane' to explore the possibility of seeking bank credit to hire Tsimane' workers and clear more forest to plant additional rice. Third, some Tsimane' have started to clear small parcels of forest to put in cattle and pigs. The animals represent a form of investment or saving, useful when unexpected needs for cash arise. Typically fed by allowing them to roam freely in the village common and eat scraps, natural vegetation, and planted crops, large domesticated animals impose a cost on other villagers; they eat crops and clothing, and even kill some of the smaller domesticated animals. As a result, households that own large domesticated animals clear forest to build corrals for their animals to reduce conflicts with other villagers. Fourth, as noted, households clear forest as a form of investment. Abandoned forests which Tsimane' once farmed have owners. Villagers recognize that those who first cleared a plot of old-growth forest have the right to the fallow forest that grows back after abandoning the cleared plot (Huanca, 1999).

3.3. Method of forest clearance

Tsimane' clear forest during the dry season, between May and August, and let the tree trunks and bramble dry from exposure to the hot sun of the dry season. They use cutlasses and metal axes to clear the forest and the underbrush. Planting of annual crops takes during August–December, and harvest takes place during the rainy season (January–April). Men tend to cut the large trees, but women and men jointly carry out most subsequent farm tasks (e.g., weeding, harvesting). Tsimane' rely on household laborers to clear the forest, but Tsimane' who work for wages, such as school teachers or wage laborers in logging camps or cattle ranches, will hire other villagers to clear the forest or rent chainsaws from loggers or cattle ranchers; 8.23% of households reported using chainsaws to clear the forest. Tsimane' use plots for 1–2 year consecutive years before abandoning the plot, but in villages with higher population pressure and in villages closer to market towns, Tsimane' tend to shorten the fallow.

3.4. Sources of income

Among the Tsimane', the sources of income include: (a) sale of farm crops, principally rice, but also plantains, maize, manioc, and fruits, (b) sale of forest products, principally thatch palm and timber, but also honey, firewood, and fish, (c) wage labor in logging camps, cattle ranches, and in the homestead of colonist farmers, (d) salaried work as school teachers or for local institutions, and (e) (often distress) sale of domesticated animals (Godoy et al., 2007).

4. Modeling forest clearance among native Amazonians

How one models forest clearance by households among native Amazonians depends on the question posed. The central motivation

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behind this article is to estimate the effect of total household levels of income — irrespective of the income source — on the area of forest cleared by a household. In highly autarkic economies, the choice of model is far from straightforward because households clear forest for multiple ends: to produce food and other goods (e.g., construction material) for their own consumption, to produce forest and farm goods for sale or for monetary income, or to invest (e.g., land clearing to put in cattle and stake claims to land). Because in highly autarkic rural settings consumption, production, and income overlap so much, and because the supply and demand framework operates poorly owing to the absence of fully functioning markets for inputs and outputs, standard approaches are questionable.

If one views forest clearance chiefly as a form of investment or saving, then one would need village interest rates, which are missing in autarky. If one views forest clearance as a form of income, then one would need prices for farm crops, forest crops, and for wages, also missing in autarky. Equating forest clearance with income would also require a convincing measure of human capital to estimate a standard earnings function, but the measure of human capital in a highly autarkic setting is problematic. Should one use a proxy for modern human capital (e.g., schooling) or a proxy for local or traditional knowledge of the environment (e.g., ethnobotanical knowledge)? And, if the latter, how would one measure traditional knowledge? Last, if one views forest clearance as a form of consumption, then one would need to define temporary income in such a way that it excludes own consumption (a hard task in autarky since much of people's income is their consumption).

When faced with a complex, messy reality in which consumption, production, income, and investments overlap, one requires a gentler, less orthodox approach than one might use in a more formal economy. Because it remains unclear what theory might be most appropriate to the task at hand, here we provide a descriptive econometric model of forest clearance. By this we simply mean that we regress the total area of forest cleared by a household against household income while controlling for a wide range of standard covariates used in studies of household deforestation (Angelsen and Kaimowitz, 1998, 1999), but take seriously the task of removing the endogeneity biases of household income.

5. Hypothesis

We hypothesize that total forest clearance should bear a non-linear relation with respect to household income, and this is because household income will simultaneous increase and decrease forest clearance. We next explain the rationale behind the hypothesis.

Income should increase forest clearance through three paths. First, if income comes from the sale of farm goods, then higher prices for farm goods will increase household income and household forest clearance (Pascual and Barbier, 2007; Pendleton and Howe, 2001). Second, if households clear forest mainly to produce food for their own consumption, then one should also expect that higher levels of household income will increase the area of forest cleared by households because most of the foods from forest clearance are likely to be normal goods, at least among the Tsimane'.[3] Third, if forest clearance is a form of savings or investment, then one should expect higher levels of income to correlate with more deforestation; with higher income, people are more likely to increase investments in their land by staking claims to land, and with higher income people are also more likely to save in domesticated animals owing to the absence of rural banks.

But counterbalancing these forces toward more forest clearance from greater household income, one should also find pressure to lower forest clearance as household income increases. Higher income implies a higher opportunity cost for rural workers, particularly if they can find employment outside of the village economy (e.g., logging camps, cattle ranches), and with a higher opportunity cost, one should expect less forest clearance, as suggested by several studies reviewed by Angelsen and Kaimowitz (1998). Furthermore, as one reviewer pointed out, another reason for a negative relation between forest clearance and income could be that some subsistence crops planted in cleared forest may not be normal goods. As income increases households may substitute away from these subsistence crops to market goods. Unfortunately, our data on potentially inferior goods (e.g., manioc) is too spotty to test this idea.

[3] For example, Alarcón and Immink (1999) find positive income elasticities of consumption for maize, rice, beans, wheat, roots, and most other foods among low-income urban slum dwellers in Guatemala City.

6. Estimation strategy

We use the following linear approximation to estimate the effect of total household income on the clearance of forest by a household:

$$\ln Y_{hvt} = \alpha + \gamma \ln I_{hvt} + \delta(\ln I)^2_{hvt} + \eta C_{hvt} + \beta V_t + \varepsilon_{hvt} \quad (1)$$

In Eq. (1), ln$Y$ stands for the log of the total area of forest cleared by household h in village v at time (or year) t, where total area of forest cleared captures the sum of the area of old-growth forest and fallow forest cleared by a household. Explanatory variables include: (a) ln$I$ stands for the log of inflation-adjusted (hereafter real) income earned by all people over 16 years of age in the household from the sale of goods, wage labor, and barter transactions, divided by the number of people in the household, (b) $(\ln I)^2$ is the quadratic term for the log of real income of the household (ln$I$), (c) C includes control variables (e.g., access to credit, household size, schooling, health), which tend to affect both forest clearance and household income (Angelsen and Kaimowitz, 1998, 1999), and (d) V includes a full set of dummy variables for villages to control for attributes of villages that remained fixed during the study period and that affect forest clearance and income (e.g., propinquity to town, prices, institutions, forest stocks). Table 1 contains more details on how we measured the variables in Eq. (1). We express all monetary values in real terms; the notes to Table 1 contain a description of the deflators used. Table 2 contains summary statistics of the main variables used in the regression analysis. We estimate the parameters of Eq. (1) using a household fixed-effect panel linear regression and a two-stage least-squares instrumental variable panel regression.

The strategy outlined so far allows us to redress many of the biases that plague naïve estimates of the effect of household income on household deforestation, but it does not allow us to remove all the biases from the potential endogeneity of household income. For this reason, in the next section we discuss the use of an instrumental variable for household income.

7. Instrumental variable for household income

In this section we describe the four steps followed to identify the instrumental variable for household income, and justify the use of the instrumental variable.

7.1. Step 1: why might income be endogenous?

An estimate of the effect of household income on forest clearance might be biased by the role of omitted variables that were not swept away by the other explanatory variables of Eq. (1). This could happen if household-level variables changed over time and: (a) affected forest clearance and income or (b) were not included in expression (1). For instance, the use of a household fixed-effect model would remove the role of the stock of household ecological knowledge, or that part of ecological knowledge that remained fixed during the five years of the panel study, but if ecological knowledge (or other variables measured at the household level) changed over the study period, then this might bias the estimated parameter of income.

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Table 1
Definition of variables measured annually, 2002–2006 (inclusive), used in the regressions (number of households = 324)

Name of variable in Tables 2–3	Definition
Dependent variable	
Log total forest area cleared*	Natural logarithm of sum of old-growth and fallow forest cleared during the year before the interview. Raw variable measured in *tareas* (10 *tareas* = 1 ha). 4.36% of observations left censored.
Explanatory variables	
Log household real income/person*, **	Log of mean, real (i.e., inflation-adjusted) income/person in household earned during the two weeks before the day of the interview. Income sources include sales, barter, and wage labor and were collected only for people ≥ 16 years of age (or younger if they headed a household). Total household income divided by head count in household. In the regression we also include the quadratic of the log of real income/person.
Log household real monetary wealth/person*	Log of real monetary value of household's wealth measured with five traditional physical assets (e.g., canoes, bows), 13 modern physical assets (e.g., radios, cutlasses), and four domesticated animals (e.g., cattle, chickens, ducks) owned by the household. Value divided by household head count to arrive at an estimate of the mean value of wealth/person in the household.*
Schooling years	Sum of the maximum school grade achieved by all members of the household
Bed-ridden days	Total number of bed-ridden days by all members of the household during the 14 days before the day of the interview.
Household size	Number of people in the household
Credit	Number of people in household with self-reported access to credit in a future emergency
Number plots cleared	Number of forest plots cleared.
Survey year	Year of survey

* +1 added before taking natural logarithms.
** To obtain real values, we used the deflators from the Unidad de Análisis de Políticas Sociales y Económicas (UDAPE), a policy analysis bureau of the Bolivian government. The information was downloaded on March 3, 2008 from the following web address of UDAPE: http://www.udape.gov.bo/ (Table 1.1.5, Deflactores implícitos del PIB por rama de actividad económica). The deflators (base = 1990) were: 2002 = 222.23, 2003 = 231.50, 2004 = 257.70, 2005 = 235.14, and 2006 = 247.85.

7.2. Step 2: the rationale for using a household's rank in income each year in the village as an instrumental variable for the level of household income

We equate household rank with the place of the household in the income hierarchy of all households in a village each year. We assigned a rank of one (or 100%) to the household with the highest income in a village during the first year. We express the rank of all other households in the village during the first year as a share of the income earned by the richest household in the village during the first year. For example, if during the first year a village had three households — one household each earning (i) 100 *bolivianos* (richest household), (ii) 80 *bolivianos* (second richest household), and (iii) 60 *bolivianos* (third richest household, or the poorest household) — then the three households would have the following ranks: (i) 1 (100/100), (ii) 0.80 (80/100), and (iii) 0.60 (60/100). We repeated the steps to obtain a measure of household rank for each household for each of the next four years. Household rank in income correlates highly with the level of household income because we used the level of household income to create a measure of household rank in income, but household rank in income probably does not correlate directly with the amount of forest cleared by the household because households clear forest for a variety of ends, but not to change their rank. Forest clearance could only influence household rank in income through the level of household income. It is possible that households with higher rank might feel the need to clear forests to put in cattle to show off their rank; if so, then household rank in income and household forest clearance would be correlated directly via cattle, without being mediated by household income. We control for this possibility by including household wealth as a control variable. As indicated in Table 1, the measure of household wealth captures the monetary value of domesticated animals (including cattle and pigs) owned by the household each year, and so allows us to control for that part of the instrumental variable that might be directly correlated with household forest clearance. One additional argument for using household rank in income as an instrumental variable for the level of household income deserves mention. Rank is not a variable over which a household has complete control; a household might decide to change its rank, but the final rank in income of a household in a village each year will depend on the decisions (and income) of other households over which it has less or no control.

Table 2
Summary statistics of main variables used in the regressions

Name of variable	Observations	Mean	SD
Dependent variable			
Log total forest area cleared	819	2.24	0.65
Explanatory variables			
Log household real income/person	824	0.56	0.37
Log household real monetary wealth/person	813	0.66	0.39
Schooling years	824	7.67	5.71
Bed-ridden days	824	5.00	3.39
Household size	824	1.72	0.50
Credit	824	0.80	1.16
Number plots cleared	820	1.67	0.97

7.3. Step 3: testing whether household income is exogenous

To test whether household income is exogenous, we ran a regression with the measure of household income as a dependent variable; as explanatory variables we included the potential instrumental variable for household income — household rank in income — and all the other explanatory variables shown in column [1] of Table 3. From this regression we obtained a predicted residual, $\hat{s}$. We then used the regression of column [1], Table 3, but added the residual, $\hat{s}$, as a regressor. We found a p value for the residual of 0.69, so we accept the null hypothesis that household income is exogenous.[4]

7.4. Step 4: statistical test for the validity of the instrumental variable

We estimated the regression in column [1], Table 3, but added the variable for household rank in income. If household rank in income is a valid instrumental variable for household income, then it should bear a tenuous link with forest clearance after conditioning for household income, and that is what we found. We found that the coefficient of household rank in income was −0.08 ($p = 0.69$) but the coefficient of household income was 0.43 ($p = 0.11$), slightly higher than the coefficient of column [1] (coefficient = 0.35; $p = 0.04$). A reliable instrumental variable should also be highly correlated with the endogenous regressor (Angrist and Krueger, 2001). To test this we regressed household income (outcome variable) against all the explanatory variables of column [1](Table 3) plus household rank in

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Table 3
Effects of household real income per person and household forest clearance among Tsimane', Bolivia: regression results using annual panel data (2002–2006)

Explanatory variables	Dependent variables — natural logarithm of total forest area cleared by household (total = old-growth forest + fallow forest)	
	[1]	[2]
Log household real income	0.35**	0.47**
Square of log household real income	−0.188*	−0.28*
Log household real monetary wealth/person	−0.08	0.39**
Schooling years	0.008	−0.006
Bed-ridden days	0.004	−0.003
Household size	0.10	0.44
Credit	−0.004	0.01
Number plots cleared	0.29***	0.34***
Survey year	0.05***	0.05***
Log income and square of log income:		
Joint test: F or χ^2 and ($p>F$ or $p>\chi^2$)	$F=2.08$ (0.12)	$\chi^2=4.58$ (0.10)
Inflection point (*bolivianos*)	0.95	0.82
Observations	808	
R^2 overall	0.32	0.40
Regression type	Household fixed effect	2-stage least squares instrumental variable

Note: Regressions are panel linear models and include clustering by household, full set of dummy variables for communities, constant (not shown), and robust standard errors. For column [1] joint test is F and, in parenthesis, $p>F$; for column [2], joint test is χ^2 and, in parenthesis, $p>\chi^2$. IV = instrumental variable. IV for household real income = household's income rank in the village each year (e.g., richest household = 1, next richest household = % of income of richest household). Inflection point = household real income beyond which forest clearance begins to fall (+) or rise (−); baseline mean real income per person = 0.56 real *bolivianos*; inflection point estimated through first derivative. See notes to Table 1 for deflators used. ***, **, and ** significant at the 1%, 5%, and 10% level.

income, and found that household rank in income had a coefficient of 1.14 and a t statistics of 28.33. From this we conclude that the use of household rank in income is a conceptually and statistically sensible instrumental variable for household income.

In sum, we find strong statistical evidence that household income might be exogenous and we also find good evidence for the use of household rank in income as a valid instrumental variable for household income. Column [2], Table 3, contains the result of the two-stage least squares instrumental-variable panel linear estimation with two instrumental variables for household income: (a) household rank in income and (b) the square of household rank in income. We use (a) as an instrumental variable for ln$I$ and (b) as an instrumental variable for $(\ln I)^2$ in Eq. (1).

8. Regression results

Table 3 contains the regression results. The results in column [1] suggest that a 1%-increase in household income is associated with an increase of 0.35% in the area of forest cleared by a household. The quadratic term for the log of household income has a coefficient of −0.18 and is statistically insignificant at the 95% confidence interval ($p=0.09$). We find weak evidence that the relation between the log of total forest clearance by a household and the log of household income resembles an inverted U. An F test for the joint statistical significance of the log of household income and the quadratic term for the log of household income suggests that they are marginally significant ($F=2.08$, $p>F=0.12$). The two coefficients imply that forest clearance will fall once mean personal real income for a two-week period reaches 0.95 *bolivianos*, 68.49% higher than the mean current personal real income for a two-week period of only 0.56 *bolivianos*.[5]

In column [2] we use household rank in real income as an instrumental variable for the level of household income. Using instrumental variables produces slightly stronger results than those in column [1]. When we use instrumental variables for the log of household real income and for the square of the log of household real income, we find that a 1%-increase in income is associated with an increase in the total amount of forest clearance of 0.47% ($p=0.04$); the quadratic term for the log of household real income is −0.28, but not statistically significant at the 95% confidence level ($p=0.10$), nor were the two terms — log of household real income and the square of the log of household real income — statistically significant at the 95% confidence level ($\chi^2=4.58$, $p>\chi^2=0.10$).

One other result deserves brief mention even though it does not bear directly on the main thrust of the article. The results of Table 3 suggest that the annual rate of total forest clearance was 5.32% (column [1]) and 5.82% (column [2]), with confidence levels above 99% in both cases.

We did additional analysis (results not shown) to test the robustness of the main results. We next discuss the results of the additional analysis.

First, we used a household random-effect model rather than a household fixed-effect model for the regression in column [1] and found slightly stronger results and better evidence that the link between the log of household forest clearance and the log of household real income resembles an inverted U.[6] For example, the coefficient for the log household real income was +0.39 ($p=0.008$) and the coefficient for the square term of the log of household real income was −0.22 ($p=0.02$). The test of joint statistical significance produced a χ^2 statistic of 7.13 and a $p>\chi^2$ of 0.02.

Second, we re-estimated the regression of column [1] using the change in the log of forest clearance between year $t+1$ and year t; as explanatory variables we used the ones shown in Table 3 (Stern, 2004). Those results show that the log of household real income and the square of the log of household real income had virtually no effect on the rate of change of forest clearance.

Third, we re-estimated the regression of column [1], but using, separately, as outcome variables the two types of forests: the log of the area of old-growth forest cleared, and the log of the area of fallow forest cleared. Those results suggest that household real income had a greater effect on the area of old-growth forest cleared than on the area of fallow forest cleared, but with neither old-growth forest or with fallow forest were results statistically significant at the 95% confidence level or higher.

Fourth, we took out the variable for the log of household real income and for the quadratic term of the log of household real income and replaced them in the same regression of column [1], Table 3, with two new variables that captured different source of real income: (a) the log of household real monetary earnings from wage labor and (b) the log of household real monetary earnings from the sale of farm and forest goods. We found that each of the two sources of monetary income bore a positive association with forest clearance but in neither case were results statistically significant. The coefficient for the log of household real monetary earnings from wage labor was +0.05 ($p=0.54$) and the coefficient for the log of household real monetary earnings from the sale of farm and forest goods was +0.06 ($p=0.40$). These result supports our approach of combining the different sources of income rather than treating them separately since each source of income treated separately produces weak results owing to the high share of zero values in each source of monetary income. At least among

[4] For details on the methods used to test the exogeneity of income, see Wooldridge (2003).

[5] During 2002–2006, the average nominal exchange rate was 7.4 *bolivianos* to one US dollar. International studies suggest that the turning point of forest clearance at present is about 2–3 times higher than mean current income (Barbier and Burgess, 2001).

[6] Bhattarai and Hammig (2001) note that fixed-effect models might be more appropriate in estimating the effect of income on forest clearance. Although we ran the main regressions with household fixed effects, in the robustness analysis we decided to check and see whether results stood up to the use of a model with household random effects.

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the Tsimane' the effect of household income on household forest clearance seems to come from the role of total household income.

Fifth, the measure of income we used included the monetary value of goods earned in barter transactions. We redefined income to exclude these goods and only include monetary earnings from wage labor and monetary earnings from the sale of goods. We found that changing the definition of income produced only slightly weaker results than those of column [1], Table 3. The coefficient of the log of monetary income was +0.22 ($p=0.068$) (instead of +0.35) and the coefficient of the square of the log of monetary income was −0.10 ($p=0.08$) (instead of −0.18). The test of joint significance of the two terms produced an F statistics of 1.70 and a probability of exceeding the F critical value of 0.18. This suggests that the main results we obtained are fairly robust to the definition of income used.

Last, we used the approach of Pendleton and Howe (2001) to see whether we could replicate their results. We used the area of total forest clearance measured in *tareas* (10 tareas = 1 ha) as an outcome variable, and we used a lowered-censored tobit regression for the estimation. As explanatory variables we included the village prices of maize and rice, the distance to the nearest town (measured in hours walking), household size, and mean schooling level in the household. We could not include some of the variables used by Pendleton and Howe because they are not part of the annual panel surveys used here; the variables used by Pendleton and Howe, but excluded here, include a measure of private time preference, the price of bananas and soap, hunting success, and proximity of the village to a road. The results are not strictly comparable because we use a panel with repeated measures of the same household and we did not have data on some of the variables used by Pendleton and Howe. This caveat aside, we found essentially the same result as they did: maize prices bore no significant association with total forest clearance, but rice prices bore a positive association with the total area of forest cleared. They found that an increase of one *boliviano* in the village price of rice was associated with an increase of 1.93 *tareas* of total forest cleared ($t=2.66$). We found that an increase of one *boliviano* in the village price of rice was associated with an increase of 0.47 *tareas* of total forest cleared ($t=3.44$). The coefficients for rice prices in the two studies differ significantly, but they both suggest that higher village rice prices are associated with a greater amount of forest clearance by households.

In sum, we find: (a) positive household real income elasticities for total forest clearance (%Δtotal forest clearance/1%Δ household real income) of 0.35 (inflection point 0.95 *bolivianos*) and 0.47 (inflection point 0.82 *bolivianos*), with the range depending on the type of regression used, (b) suggestive but not strong evidence for an inverted U-shaped relation between the log of household forest clearance and log of household real income, (c) results that are robust to changes in the definition of income, and (d) results that support and build on results from earlier work of other researchers suggesting that rice prices are associated with greater forest clearance.

9. Discussion and conclusions

As native Amazonian societies become empowered and gain legal title to their land (Stocks, 2005), they will likely be more effective in curbing encroachment into their land and gaining a stronger role in deciding how much forest to clear and how much forest to leave standing. Owing to the shortage of primary data on forest clearance among native Amazonians, owing to the absence of appropriate modeling approaches, and owing to the fact that native Amazonian societies are highly autarkic, it is hard to fathom what will happen to forest clearance as native Amazonian societies gain a stronger legal say in how to manage natural resources within their territories.

In the short run, many variables within native Amazonian societies, such as population growth, health, credit, and household income, will likely drive forest clearance by native Amazonians. Here we have focused on the role of one such variable — household real income — in shaping household forest clearance. The focus on household income has merit because income tends to shape many indicators of well being across societies and because monetary income will grow in importance as highly autarkic people gain a stronger foothold in the market economy.

We found positive and significant real income elasticities of forest clearance even after correcting for the endogeneity of household real income, and even after controlling for fixed effects of households and villages. The elasticities we found, 0.35–0.47, imply that doubling real income will induce 35–47% more forest clearance. Recall that previous research found virtually no effect of income on forest clearance, so our results contrast with past findings. The use of panel data allows us to overcome many of the data limitations of previous studies, and the use of a sensible instrumental variable for household income, allows us to overcome the possible endogeneity biases of household income.

We found weak evidence for the hypothesis that the relation between the log of household forest clearance and log of household real income was non-linear. The strength of the evidence hinged on the econometric model used, with stronger evidence for an inverted U-shaped relation when using instrumental variables or a random effect model.

Income elasticities of forest clearance of 0.35–0.47 plus a secular trend in forest clearance of 5.32–5.82%/year (after controlling for real income and other covariates) suggest that in the short run the forest in the Tsimane' territory will face increasing pressure from the Tsimane' themselves, not just from outside encroachers. How much forest will remain standing after taking into account internal pressures will depend on the size of the territory and on the role of other variables. For example, one study suggests that owing to the large amount of forest available to the Matsigenka native Amazonian society in the Manu National Park of Peru, forest clearing among Matsigenka might not threaten conservation, at least not in the short run (Ohl-Schacherer et al., 2007). But among societies with a smaller territory, income growth will likely undermine forest conservation.

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