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REPORT

The Role of Ethnobotanical Skills and Agricultural Labor in Forest Clearance: Evidence from the Bolivian Amazon

Victoria Reyes-García, Unai Pascual, Vincent Vadez, Tomás Huanca, TAPS Bolivian Study Team

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Abstract Research on the benefits of local ecological knowledge for conservation lacks empirical data on the pathways through which local knowledge might affect natural resources management. We test whether ethnobotanical skills, a proxy for local ecological knowledge, are associated to the clearance of forest through their interaction with agricultural labor. We collected information from men in a society of gatherers–horticulturalist, the Tsimane' (Bolivia). Data included a baseline survey, a survey of ethnobotanical skills ($n = 190$ men), and two surveys on agricultural labor inputs ($n = 466$ plots). We find a direct effect of ethnobotanical skills in lowering the extent of forest cleared in fallow but not in old-growth forest. We also find that the interaction between ethnobotanical skills and labor invested in shifting cultivation has opposite effects depending on whether the clearing is done in old-growth or fallow forest. We explain the finding in the context of Tsimane' increasing integration to the market economy.

Keywords Ethnobotanical skills · Labor inputs · Market integration · Slash-and-burn agriculture · Tsimane' (Bolivia)

INTRODUCTION

Shifting cultivation (also known as slash-and-burn or swidden agriculture) is an agricultural system common throughout the tropics and subtropics in which small patches of forest vegetation are selected, cleared, and burned to provide nutrients for a temporary period (between 1 and 3 years) of crop production. Once the land becomes inadequate for crop production, it is left to be reclaimed by natural vegetation (Nair 1993). The shifting cultivation system results then in a mosaic of plots in different stages of recovery from agricultural production.

Although not the only or primary cause (Geist and Lambin 2002; Casse et al. 2004), shifting cultivation has been regarded as a major cause of deforestation (Angelsen and Kaimowitz 1999; Delang 2002; Palm et al. 2005). Since shifting cultivation has such a direct link to deforestation, researchers have tried to understand the micro and macro drivers of land use decisions by shifting cultivators. Overall, authors suggest that factors as diverse as land availability, often determined by land use rights (Deacon 1999; Alston 1999; Angelsen and Kaimowitz 1999), population density (Angelsen 1999; Pascual and Barbier 2006), household-specific preferences and initial conditions (Brown 2006), productivity-related factors (i.e., soil fertility and labor requirements) (Pascual and Barbier 2007), and market-related factors (i.e. role of prices or technology) (Bluffstone 1995; Omamo 1998; Angelsen 1999) affect land management in shifting cultivation systems.

Authors have proposed alternatives to reduce the area cleared through shifting agriculture, such as improvements in shifting agriculture management practices (Pascual 2005) or its substitution by other productive systems (Palm et al. 2005). Specifically, researchers have looked at the effect of improving labor efficiency, mostly through technological transfers (Lopez 1998; Gunatileke and Chakravorty 2003; Shively and Pagiola 2004; Pascual 2005). Findings from this body of research are context dependent. For example, Lopez (1998) found that increased labor efficiency (proxied by agricultural intensification) does not necessarily lead to a reduction in the degradation of communal forests in Cote d'Ivore. Other studies, however, suggest a positive association between labor efficiency and the reduction of forest pressures. For instance, Gunatileke and Chakravorty (2003) suggest that modernization of subsistence agriculture (through improved labor productivity) in the vicinity of protected forest may reduce deforestation. Shively and Pagiola (2004) analyzed the impact of agricultural intensification forest frontier region of the Philippines and found that higher levels of labor productivity on upland farms translated into less forest clearing. In research in Mexico, Pascual (2005) found that on- and off-farm labor diversification could help shifting cultivating households to improve their technical efficiency in farming and thus help to intensify land use at the expense of clearing additional forest land.

We shift the focus from technological transfer to local ecological knowledge as a factor that might affect labor efficiency in shifting cultivation systems and hence on forest pressure. Researchers have argued that locally developed knowledge and skills about the environment (hereafter local ecological knowledge) might help explaining the efficiency of traditional agricultural systems (Fox and Gershman 2000; Long and Zhou 2001; Hardwick et al. 2004) and might help curve the clearance of tropical forest for subsistence agriculture (Pascual 2005; Reyes-García et al. 2007b). Although suggestive, previous research has failed to identify the pathways through which local ecological knowledge might affect forest clearance for subsistence agriculture. Here, we take a step in that direction and test (1) the direct association of local ecological knowledge with the clearance of tropical forest and (2) its indirect association through its interaction with an important production input: agricultural labor efficiency. For the empirical analysis, we use a detailed data set from the Tsimane', a subsistence-oriented hunter–horticulturalist population in the Bolivian Amazon. Our research differs from previous research in that we analyze data from a society with tenuous links to the market society (Godoy et al. 2007).

We hypothesize that, as technological transfers, local ecological knowledge would have direct and indirect associations with forest clearance for shifting cultivation. Our model is based on the assumption that the objective of subsistence-oriented shifting cultivators' is to satisfy household nutritional requirements with the least amount of labor (Pendleton and Howe 2002). The model implies that the Tsimane' subsistence logic is less the maximization of profit by transacting agricultural products on the market, an approach that is associated to increase deforestation (Deacon 1995; Angelsen and Kaimowitz 1999; Foster and Rosenzweig 2003), than the diversification of their livelihoods to secure a nutritional standard (or the safety first approach). Our assumption is that subsistence-oriented shifting cultivators strive to maximize efficiency in farming to save time for other livelihood activities such as hunting and fishing (Sackett 1996). Hence, we assume that, in land abundant shifting cultivation systems, time is the household's main clearance constrain. For the study population, time is a key constraint because Tsimane' view agriculture outside shifting cultivation as inferior to hunting and fishing (Reyes-García et al. 2009b), so time invested in agriculture is time away from the preferred hunting and fishing productive activities.

Assuming that subsistence farmers practice shifting agriculture to satisfy household nutritional needs, and given their preference for allocating their time in hunting and fishing, we expect that the Tsimane' will use their local ecological knowledge to increase their efficiency in one or the most labor-intensive task in shifting agriculture, i.e., forest clearing. In settings with no access to modern agricultural technologies, farmers rely on their local ecological knowledge to make decisions regarding agricultural production. For example, research suggests that indigenous peoples have a detailed knowledge that allows them to classify soils depending on temporal, social, and environmental factors (Barrera-Bassols and Toledo 2005; Saito et al. 2006). Given that understanding of soil dynamics is fundamental for farmers' land use decision-making, one would expect that people with greater knowledge of soils might be better at selecting soils suitable for farming. Similarly, research also suggests that indigenous peoples have detailed entomological knowledge, particularly with regard to how insects can affect agricultural outputs (Bentley and Rodriquez 2001). Therefore, one would expect that people with greater entomological knowledge would be more protected against the attacks from pests. In the same way, one would also expect that people with greater local ecological knowledge would also have a higher likelihood of getting right the best timing for the critical chores in clearing forest under shifting cultivation, e.g., felling trees and burning of the felled biomass, as well as have better knowledge of what seeds to select, how to store and when to plant them.

Taken together, if shifting cultivators operate under the logic of diversification of livelihood activities and if labor investments are a major constraint on shifting agriculture (de Janvry et al. 1991), one can model forest clearance decisions as if farmers with greater ecological knowledge would then, *ceteris paribus,* prefer to clear less forest to obtain the same agricultural output by applying their local ecological knowledge (and hence save time to other livelihood activities). Therefore, a plausible hypothesis is that local ecological knowledge might reduce the marginal costs of clearing a unit of forest, hence improving labor efficiency in shifting cultivation, which—under the need to diversify a livelihood portfolio in a subsistence oriented economy—would effectively imply that shifting cultivators with greater ecological knowledge either (i) clear less forest given a fixed amount of labor invested in shifting cultivation, or alternatively (ii) use less labor to clear a given amount of forest land than those with lower ecological knowledge.

THE TSIMANE' CASE STUDY

To test the above hypothesis, we conducted research among the Tsimane', one of the largest Amerindian groups in the Bolivian Amazon. The Tsimane' are an ideal case to test our hypothesis because (1) their livelihood is largely based on a diversity of subsistence activities, including—the less preferred and labor intensive—shifting agriculture (Vadez et al. 2008) and (2) they share large amounts of local ecological knowledge (Reyes-García et al. 2003).

The Tsimane' number ~8000 and live in less than 100 villages (~20 households) concentrated along rivers and logging roads in the department of Beni (Huanca 2008). Tsimane' hunt, practice shifting agriculture, and to a lesser extent engage in wage labor with loggers and colonist farmers. Tsimane' hold land communal titles since 1996, although the land demarcation process is yet to conclude. Tsimane' lands are frequently visited by loggers and traders who commercialize products with Tsimane', but rarely from colonist farmers who encroach their lands (Reyes-García et al. 2010).

On average, Tsimane' households in our sample cleared 1.5 plots/year; 0.72 hectares (ha) of old-growth forest and 0.55 ha of fallow forest. The bulk of the Tsimane' crop harvest goes to household consumption, followed by barter, then sale, and, last, storage of seeds for the next cropping season. This attests for their strong subsistence orientation and weak market integration. Tsimane' living in villages far from towns barter agricultural surplus for commercial goods brought by traveling traders, but a growing share of Tsimane' living close to towns earn income by clearing more forest to enlarge their agricultural plots to grow cash crops (Vadez et al. 2008; Fig. 1).

Tsimane' farming is extensive; households usually farm around villages in a radius of ~2 km. Every year, during July–August, Tsimane' draw on their knowledge of soil types, topography, weather, and the like to decide where and how much forest to clear. Men clear plots, but thereafter plots belong to the person who sows the plot. Accuracy in timing matters; if too late, brambles and brush will get too wet to burn well and leave too much debris when burning fields (typically in August–September). The potential weed burden also matters; fallow forests are easier to cut, but contain more weeds. Old-growth forests are harder to clear as they contain larger trees to fell, but contain fewer weeds. To minimize peaks of work around weeding and harvesting time some Tsimane' opt to use old-growth forests. To reduce the risk of crop loss and to smooth the work load, they stagger planting. After one or two cultivation cycles, the Tsimane' abandon their plots and clear another patch.

Our previous research suggest that Tsimane' allocate about 22% of their daily productive time to agriculture, with a larger use of agricultural labor in the rainy (27.21%) than in the dry season (9.99%) (Reyes-García et al. 2009b). The share of time allocated to agriculture is similar to the share of time allocated to foraging (21%) and larger than the share of time allocated to market activities (14.25%) and production of tools and crafts for household use (14.25%). Most of the time devoted to agriculture is spent in actual crop production, i.e., from sowing to harvesting (12.21%). Post-harvest activities (i.e., transporting, processing, and storing crops) take about 5.25% of Tsimane' productive time, whereas activities related to plot preparation (i.e., slashing, felling, and burning) represent only 2.72% of Tsimane' productive time through the year.

Our previous research also provides two important insights on the local ecological knowledge hold by the Tsimane'. First, as it has also been argued by other authors (Berkes et al. 2000; Toledo et al. 2003), Tsimane' local ecological knowledge system, rather than a compilation of information about plants and animals, is a way to understand the world. Our previous research suggests that people who share large amounts of local ecological knowledge display better indicators of health than people who do not share as much local ecological knowledge (McDade et al. 2007; Reyes-García et al. 2008a). This is so, even when we use a broad measure of local ecological knowledge, highlighting the idea that local ecological knowledge constitutes a complex body of knowledge linked to a larger coherent ensemble. We expect that the same broad measure of local ecological knowledge would be associated to tangible environmental outcomes.

The second insight from our research on local ecological knowledge among the Tsimane' relates to its distribution. The Tsimane' show a high level of concordance about the potential use of plant, especially with people of the same village (Reyes-García et al. 2003). Despite high levels of knowledge sharing, local ecological knowledge is distributed according to socio-demographic characteristics of informants: elders know more than youngsters and men display larger levels of overall knowledge than women, although women are more knowledgeable in specific domains such as medicinal plants (Reyes-García et al. 2005). We have also found that people who engage in occupations that take place out of their environment (e.g., wage labor) display lower levels of knowledge than people who engage in occupations that take place in their environment (farming and hunting) (Reyes-García et al. 2007a). For example, the ethnobotanical skills of the male household head are associated with an increase in the number of crops sown by a household (Reyes-García et al. 2008b) and with a reduction in the amount of forest cleared per household (Reyes-García et al. 2007b). What remains to be discerned is the pathway by which such knowledge affects the area of forest land cleared for shifting agriculture.

METHODS

The Model

We proxied local ecological knowledge with ethnobotanical skills. To test the association of ethnobotanical skills with the clearance of tropical forest through its interaction with agricultural labor efficiency, we use a reduced Eq. 1

$$Y_{\mathrm{pihct}} = \alpha + \beta L_{\mathrm{pihct}} - \gamma ES_{\mathrm{ihct}} + \beta' L_{\mathrm{pihct}} * dES_{\mathrm{ihct}} + \gamma P_{\mathrm{ihv}} + \varsigma H_{\mathrm{hv}} + \eta C_{\mathrm{v}} + \varepsilon_{\mathrm{pihct}} \quad (1)$$

where the dependent variable (Y) is the logarithm of the area of a forest plot p cleared by person i of household h, in community c, at time t. We predict that labor (L) inputs used in the clearance of the plot will have a positive association with the size of the plot as land clearing is a labor-intensive activity; and that ethnobotanical skills (ES) will have a direct negative association with land clearing. We also predict that there is a negative effect of the interaction between ethnobotanical skills and labor ($L*dES$) on forest clearing captured by the coefficient (β'), i.e., the marginal effect of ethnobotanical skills (dES) on labor productivity in terms of the amount of forest clearance. The interaction term ($L*dES$) helps capture the hypothesis that having ethnobotanical skills above the average would affect the marginal product of labor inputs in terms of forest clearance. That is, the interaction can shed light on whether the effect of labor on area cleared would differ depending on the level of ethnobotanical skills farmers have. P_{ihv} stands for a vector of control variables for the male household head (e.g., age, schooling, etc.) that may have an effect on forest clearance, but which cannot be readily assumed in a direct way. The term H_{hv} represents a vector of control variables for the household that is assumed to affect the area cleared (e.g., household size). C_{v} stands for a set of village dummy variables that control for village factors that could affect area cleared given unobservable characteristics, e.g., soil quality or proximity to markets.

Given that we focus on already cleared plots as the unit of observation, the dependent variable is not bound from below or above. Thus, we use OLS with robust standard errors when the Breusch–Pagan test for heteroskedasticity Prob $> \chi^2$ was lower than 0.10. Unless indicated otherwise, we only discuss those factors that affect the cleared plot area with a 95% confidence level or above.

The Sample

We selected villages at different distances from the market town of San Borja (about 19000 people). Between May 2002 and October 2003, we visited all the households in the 13 selected villages twice and interviewed all adult (>15 years) men willing to participate in the study. We interviewed men of 15+ years of age as at this age Tsimane' men start clearing their own plots. We focused on men because men keep the responsibility for clearing the land. We collected complete information from 190 males in 163 households. Since many men have more than one agricultural plot and since we collected data for 2 years, our final sample consists of 466 plots (Figs. 1, 2).

Data

Data were collected through a baseline survey, a survey of ethnobotanical skills, and two annual surveys on forest clearance.

Outcome Variable

To estimate the amount of area cleared for agricultural purposes, we asked informants to estimate the surface of each plot opened during the most recent planting season and the type of forest cleared (Vadez et al. 2003). Interviews were conducted during August–September in 2002 and 2003 and referred to the area cleared during May–August of the same year. We differentiate between fallow forest and old-growth forest. To facilitate the interpretation of coefficients in the model, we transformed the variable of forest area cleared into logarithms.

Explanatory Variables

The explanatory variables fall under the following categories:

Labor inputs used to clear plots. The amount of persons/day inputted in preparing the plot for agriculture was estimated with survey data collected between 1 and 3 months after plots were cleared. We asked plot owners to recall the number of days and the number and age of people who participated in slashing, felling trees, and cleaning debris in a plot. We computed adults as one full working day and children as half-day. For owners of more than one plot, information was collected separately for each plot. We generated a variable that captures the total number of person/days devoted to prepare a plot, including the time dedicated to slash, fell, and clean each plot. For regression analyses, we transform the data into logarithms.

Fig. 1 Tsimane' agricultural plot: Rice and plantain (photograph by Ana C. Luz)

Ethnobotanical Skills

We use a standard measure to proxy ethnobotanical skills (Reyes-García et al. 2007b). Specifically, we measured participant's self-reported ability to make objects from wild and semi-domesticated plants. We conducted free-listing with 50 participants to construct a list of items made from plants. We randomly selected 18 objects from 15 different plant species and asked participants whether they had ever made the items. The ethnobotanical skills score was the sum of all positive answers from the list of 18 objects. Since some respondents score 0 in our ethnobotanical skills measure, we did not transform this index to logarithms.

Interaction Between Labor Inputs and Ethnobotanical Skills

To capture whether ethnobotanical skills change labor productivity in terms of land clearance, labor input and ethnobotanical knowledge are interacted. For ease of interpretation of the coefficient associated with the interaction variable, we first generated a new variable that captured whether the person had ethnobotanical skills above or below the mean. Specifically, we used the average ethnobotanical skills score (mean = 7.9; SD = 3.70; $n = 235$) as a reference to create a dummy variable that divided the sample between those with bellow-average ethnobotanical skills (i.e. ≤ 7; $n = 105$) and those with above-average ethnobotanical skills (i.e. ≥ 9; $n = 85$). The 44 informants who had a score between 7 and 9 points where excluded from the analysis. We then multiplied the dummy variable measuring the level of ethnobotanical skills and the logarithm of the number of person/days invested in clearing a plot.

Control Variables

Variables used as control included the age of the participant, schooling (maximum formal education level

Fig. 2 Tsimane' woman sowing maize with a stick in a recently cleared fallow plot (photograph by Vincent Vadez)

attained), disposable cash income (from wage labor and sales), number of plots own by the person on the same planting season, household size, a binary variable to control for the year of data collection (2002 or 2003), and a full set of village dummy variables to control for unobserved local variables.

Potential Biases

Potential biases in our estimations relate to (i) measurement errors of dependent and explanatory variables, (ii) omitted variables, and (iii) possible reverse causality. First, we might have measurement error in ethnobotanical skills, our proxy measure of local ecological knowledge, because the ability of a person to craft items from a plant might only have a tenuous association with agricultural labor efficiency than other more direct measures of local agricultural knowledge. Additionally, the test for skills is based on self-reports, so the measure might suffer from random measurement error if—for example—some informants have better memory than others. We expect that this effect is randomly captured by the white noise. This is also why a dichotomous approach to define the variable in terms of above or below the average of ethnobotanical knowledge is used as this might reduce the bias that otherwise would have arisen through the use of a continuous variable.

Second, our estimations might be biased by the role of omitted variables. For example, in research on a traditional shifting cultivation system in Mexico, Pascual (2005) finds that soil fertility affects technical efficiency in farming. Although the use of village level variables tries to minimize some of such potential biases, failure to control for characteristics that vary within the community, such as soil fertility, may bias our estimations in unknown magnitude and direction.

The third potential bias of our results relates to endogeneity. Associations might be potentially endogenous, if—for example—clearing larges pieces of old-growth forest results in an increase of individual ethnobotanical skills. However, since the accumulation of ethnobotanical skills occurs through a person lifetime (Reyes-García et al. 2009a), we do not expect reverse causality to be strong.

RESULTS

Descriptive Statistics

Table 1 contains definitions and summary statistics for the variables used in the analysis. On average and independently of the plot size, it took about 19 person/days to clear a plot, of which 8.5 persons/days were allocated to slash, 8.8 persons/days to fell trees, and 1.7 persons/days to clean debris before burning. We found a large variation in labor inputs across plots: some plots received less than one person/day of labor, whereas others took as much as 84 person/days (SD = 14.4). Variation in labor inputs correlated to the size of the plot ($r = 0.562$, $P < 0.0001$). Plots in old-growth forest required higher labor investment that plots in fallow forest, probably because of their larger size and the larger size of trees to be felled. On average, a plot in old-growth forest required 24.0 person/days of work (10.2 days to slash, 11.8 days to fell trees, and 2.0 days to clean debris), whereas a plot in fallow forest required an average of 16.2 persons/day (7.6 days to slash, 7.0 days to fell trees, and 1.6 days to clean debris; Fig. 2).

Multivariate Analysis

Results in Table 2 (column [a]) suggest (1) the expected positive effect of labor on total area deforested, be it land cleared from old-growth or fallowed forest, (2) a negative effect of ethnobotanical skills, and (3) no statistical significant interaction effect between labor and ethnobotanical skills on cleared forest area. Specifically, a 1% increase in labor time increases the total area deforested by 0.5% ($P < 0.001$) and an additional point in the score of ethnobotanical skills by households is associated with a 3% reduction in the forest area cleared through sifting cultivation ($P = 0.01$).

Since clearing old-growth or fallow forest implies different skills and time requirements, it is plausible to assume that the effect of ethnobotanical skills on labor productivity in forest clearing might vary depending on

Table 1 Definition and summary statistics of variables used in regressions

Variable	Definition	*N*	Mean	Standard deviation
Outcome variables				
Area	Tareas of old-growth and fallow forest opened during the last planting season (10 Tareas = 1 hectare)	466	6.13	3.61
Area of old-growth forest	Tareas of old-growth forest opened during the last planting season	172	7.22	3.85
Area of fallow forest	Tareas of old fallow forest opened during the last planting season	294	5.50	3.31
Explanatory variables				
Labor	Total person-days that took preparation (slash, fell, and cleaning) of the plot for agriculture.	466	19.09	14.36
Ethnobotanical skills	Self-reported ability to make 18 objects from wild and semi-domesticated plants	190	7.93	3.95
Control variables				
Individual level				
Age	Age of participant (years)	190	35.63	14.95
Schooling	Maximum school grade achieved by participant	190	2.57	2.84
Cash income	Monetary value of sales, barters, and wage labor during the 2 weeks before the interview, in Bolivianos (US $1= 8.03 Bolivianos)	190	123.16	139.91
Number of plots	Number of plots own by the individual during the agricultural season	190	1.31	0.52
Household level				
Adults in household	Number of people over 15 years of age living in the household at the time of clearing	163	2.85	1.34

Table 2 Regression results: Association between plot area (outcome) and ethnobotanical skills and labor inputs

	Outcome variable		
	Area (log)	Area of old-growth forest (log)	Area of fallow forest (log)
Explanatory variables	[a]	[b]	[c]
Labor (log)	0.525**	0.431**	0.531**
	(0.041)	(0.070)	(0.050)
Ethnobotanical skills	−0.030*	0.036	−0.066**
	(0.012)	(0.021)	(0.015)
Interaction labor (log)*	0.049	−0.078*	0.155**
Skills (dummy)	(0.027)	(0.038)	(0.044)
Control variables			
Age	0.003	0.003	0.003
	(0.001)	(0.003)	(0.002)
Schooling	0.011	0.009	0.007
	(0.009)	(0.016)	(0.013)
Cash income	−0.00002	−0.0001	0.0001
	(0.0001)	(0.0001)	(0.0002)
Number of plots	−0.044	−0.038	−0.047
	(0.037)	(0.054)	(0.051)
Adults in household	0.032*	0.077**	0.024
	(0.015)	(0.027)	(0.020)
Year	0.056*	−0.024	0.092**
	(0.022)	(0.037)	(0.029)
Dummy for type of forest cleared	0.089	^	^
(Old-growth forest = 1)	(0.052)		
Constant	0.528**	0.035	0.140
	(0.194)	(0.340)	(0.234)
N	466	172	294
R^2	0.53	0.44	0.57

Note: Ordinary least squares (OLS) regressions with robust standard errors when the Breusch–Pagan test for heteroskedasticity Prob > χ^2 lower than 0.10. For definition of variables see Table 1. Robust standard errors in parenthesis. * and ** significant at the 5 and 1% level. Regressions contain a set of dummy variables for village of residency of plot owner

^ Variable intentionally excluded from the analysis

whether the plot is opened on one type of habitat or the other. In columns b and c (Table 2), we conduct the analysis by type of forest where the plot was opened. The data suggest that labor investment has a positive effect both on the area of old-growth and fallow forest opened. A 1% increase in labor time increases the area of old-growth forest and fallow forest cleared by 0.43 and 0.53%, respectively ($P < 0.001$), confirming that, in our case study, it is a harder to clear old-growth forest than fallow forest land.

Ethnobotanical skills seem to have different direct and indirect effects on area cleared depending on the type of forest. For plots opened in old-growth forest, we find that the ethnobotanical skills of shifting cultivators seem not to bear a direct effect on the amount of cleared land (column b), whereas for plots in fallow forest (column c), ethnobotanical skills bear a statistically significant negative association with the area cleared. An additional point in the score of ethnobotanical skills is associated with a 6.6% smaller surface cleared in fallow forests ($P < 0.001$)

More interesting is the different effects that the interaction of ethnobotanical skills with labor play regarding the extent of forest area cleared on both types of forests. In the case of old-growth forest, having above-average ecological knowledge reduces the amount of land cleared per unit of labor ($P = 0.04$). Specifically, a 1% increase in labor inputs on old-growth forest for the plot of a person with above-average ethnobotanical skills results in an area of fallow forest cleared 7.8% smaller than the same increase invested in the old-growth forest plot of a person with below-average ethnobotanical skills. Contrary, for fallow forest the interaction term bears a positive and statistically significant association with the area cleared. That is, those households with above-average ethnobotanical knowledge clear more fallow forests per unit of labor. More specifically, a 1% increase in labor inputs on fallow forest for the plot of a person with above-average ethnobotanical skills results in an area of fallow forest cleared 15.5% larger than the same increase invested in the fallow forest plot of a person with below-average ethnobotanical skills. The difference in the sign and magnitude of the indirect effects in both the types of forests masks the non-statistically significant effect when the type of forest is not distinguished.

Robustness Analysis

To test the robustness of our findings, we conducted additional analysis of the models that account for the differences in old-growth and fallow forest plots. When reporting results (Table 3), we do not include the variable labor since its association with area cleared remains positive and statistically significant across all the models. In our first model, we use a more inclusive definition of ethnobotanical skills (row 2), using the average skill level (7.9 points) as a reference to create a dummy variable for the interaction term. Therefore, results in row 2 include the full sample. Changes in the definition produce weaker results than the core model, but do not change results radically.

Since Tsimane' allocate different amounts of time to slashing, felling trees, and clearing debris, in our next robustness text, we differentiate between the number of persons/day dedicated to each of those activities. Results of the model using time to slash (row 3) resemble results of the core models, except that the interaction variable losses statistical significance in the old-growth forest model. The magnitude of the effect of using time for felling trees (row 4) is marginally smaller than the magnitude of the effect of total labor for clearing in the core model for plots in old-growth forest land. Last, results for the two models with time for cleaning debris (row 5) are not statistically significant, except for the interaction term in fallow forest. These results suggest that labor inputs allocated into felling trees seem to mediate most of the association between labor inputs and ethnobotanical skills in plots in old-growth forest, whereas labor inputs in slashing and in felling trees mediate the association in plots cleared in fallow forests.

DISCUSSION

In shifting cultivation, households rely almost entirely on their own labor to eke out their livelihood. Since labor investments are a major constraint on those agricultural systems (de Janvry et al. 1991), authors have examined the effect of improving labor efficiency on area cleared for agriculture (Lopez 1998; Gunatileke and Chakravorty 2003; Shively and Pagiola 2004; Pascual 2005). Here, we examined the direct and indirect (through its effect on the productivity of labor) effect of local ecological knowledge on area cleared in shifting cultivation by distinguishing the type of habitat, i.e., fallow and old-growth forest. Our work provides two related findings. First, based on the case study of the subsistence-oriented Tsimane', we find that there is a direct effect of ethnobotanical skills in lowering the extent of forest cleared in fallowed land, though this effect cannot be proven for old-growth forest habitats. Second, the interaction between ethnobotanical skills and labor invested in shifting cultivation has opposite effects depending on whether the clearing is done in old-growth or fallow forest land. Those two findings need to be interpreted in association.

Contrary to our previous findings (Reyes-García et al. 2007b), we do not find a direct effect of ethnobotanical skills in lowering the extent of forest cleared in old-growth forest, once we control for its interaction with labor productivity. However, we find that those with above-average knowledge clear less old-growth forest land per unit of

Table 3 Robustness analysis

Dependent variable:		Area of old-growth forest (log)		Area of fallow forest (log)	
Explanatory variables:		Ethnobotanical skills	Interaction (Labor* skills)	Ethnobotanical skills	Interaction (Labor* skills)
Changes					
[1]	Core model (as in Table 2)	0.036	−0.078*	−0.066**	0.155**
		(0.021)	(0.038)	(0.015)	(0.044)
[2]	Outcome: inclusive definition for skills	0.020	−0.054	−0.050**	0.110**
		(0.017)	(0.031)	(0.014)	(0.033)
[3]	Explanatory: slash	0.035	−0.091	−0.048**	0.169**
		(0.020)	(0.035)	(0.017)	(0.062)
[4]	Explanatory: fell	0.044*	−0.111**	−0.047**	0.129**
		(0.019)	(0.044)	(0.016)	(0.061)
[5]	Explanatory: cleaning debris	0.021	0.011	−0.015	0.069**
		(0.018)	(0.025)	(0.016)	(0.018)

Note: Regressions resemble columns [b] and [c] in Table 2, except for the changes noticed in the column "Changes". See notes in Table 2 labor than those with lower knowledge. Based on our ethnographic understanding, a potential explanation for this finding is that people with larger local ecological knowledge might engage in more selective and less intensive clearing by practicing joint production while clearing. For instance, there might be patches of old-growth forest that are selected because of their potential to be used for other purposes, e.g., collection of wood, wild edibles, or non-timber forest products, even if using the same amount of time for clearing. Therefore, it is not that clearing is less efficient, but that the same amount of labor is used for joint production: obtaining food from clearing land and obtaining wild foods or firewood. Therefore, having more knowledge discourages from typical slash-and-burn extensive clearing and it helps more selective clearing.

On the other hand, we find that greater ethnobotanical skills decrease the clearing of fallow forest and that those with high skills are more efficient in clearing fallow forest, as they clear more land per unit of labor invested. In the local context, with Tsimane' not aiming at maximizing land cleared, but at spearing time for other activities, the two findings together might imply that the highly skilled farmers can spare time from clearing fallow land for shifting agriculture and allocate the saved labor to other tasks such as hunting or fishing. The low-skilled farmers, on the contrary, clear more fallow land and, therefore, put more time in clearing, which leaves them with less time for other tasks.

It should be noted that one we assumed that Tsimane' agricultural production is oriented to household consumption. However, Tsimane' nowadays are gradually entering the market economy (Godoy et al. 2009) including the adoption of cash crops (Vadez et al. 2008). It is possible that the desire to increase agricultural production to obtain surplus for the market pushes the Tsimane' to use their ethnobotanical skills to clear more fallow forest, presumably to increase their agricultural production for the market. In other words, in a subsistence economy not oriented to maximize production, Tsimane' might have used their ethnobotanical skills to maximize the amount of time freed from agricultural production, but in a market economy, oriented to maximize production for the market, Tsimane' might be using their ethnobotanical skills to maximize the area of fallow forest cleared (and thus increase production for the market) through the effective use of agricultural labor inputs. Since the shift to cash cropping is more acute in villages close to the market town (Vadez et al. 2008), where old-growth forest is scarce, the change in the use of ethnobotanical skills is reflected in the increasing pressure on fallow forest.

We conclude discussing some implications of our findings. Much attention has being paid to find alternative options for shifting cultivation, including the total abandonment of forest plots, the adoption of productivity increasing green revolution-type technologies, the application of modern "evergreen" agroforestry knowledge (Palm et al. 2005), and the intensification of land use by improving technical efficiency in farming (Pascual 2005). Research suggests that the adoption of such technologies by farmers is costly in terms of the labor investment (Ramirez and Shultz 2001), and largely depends on factors as diverse as land resources, and the wider institutional, economic, and techno-political context (Bellon and Taylor 1993). Findings from this article suggest that the strengthening of local ecological knowledge could be another option to reduce the area cleared under shifting agriculture through its interaction with agricultural labor. Results from our work suggest that strengthening local ecological knowledge may contribute to the reduction of land clearing for shifting agriculture while maintaining crop output levels and the local (and traditional) low-input technology. The results, however, should be taken with caution as it only applies to individuals who operate under a subsistence-based, not under a market-based, economic rationality.

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AUTHOR BIOGRAPHIES

Victoria Reyes-García (✉) is a ICREA Professor at the Institut de Ciència i Tecnologia Ambientals, Universitat Autònoma de Barcelona. Her research interests include ethnoecology, traditional knowledge systems, and community based conservation.
Address: ICREA and Institut de Ciència i Tecnologia Ambientals, Universitat Autònoma de Barcelona, 08193, Bellatera, Barcelona, Spain.
Address: Heller School for Social Policy and Management, Brandeis University, Waltham, MA 02454-9110, USA.
e-mail: victoria.reyes@uab.cat

Unai Pascual is a University Lecturer at the department of Land Economy, University of Cambridge, UK (since 2003), and Ikerbasque Visiting Research Fellow (2010–2011) at the Basque Centre for Climate Change (BC3). His research interests include ecological and development economics, natural resource modeling and environmental policy.
Address: Department of Land Economy, University of Cambridge, Cambridge CB39EP, UK.
Address: Basque Centre for Climate Change (BC3), Alameda Urquijo 4, Bilbao, Basque Country, Spain.
e-mail: up211@cam.ac.uk

Vincent Vadez is a principal scientist with the International Crops Research Institute for the Semi Arid Tropics (ICRISAT), India. His research interests include the role of rooting traits and of canopy development and conductance on the adaptation of crops to drought.
Address: ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), Patancheru 502324, Andhra Pradesh, India.
e-mail: v.vadez@cgiar.org

Tomás Huanca is the Director of the Centro Boliviano de Desarrollo Socio-Integral (CBIDSI), Bolivia. His research interests include topics related to indigenous culture like ethnoecology, traditional knowledge, indigenous territories and their conservation.
Address: CBIDSI-Centro Boliviano de Investigación y de Desarrollo Socio Integral, Correo Central, San Borja, Beni, Bolivia.
e-mail: thlaura@hotmail.com