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Ethnobotanical Knowledge and Crop Diversity in Swidden Fields: A Study in a Native Amazonian Society

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Abstract Crop diversity protects food consumption in poor households within developing nations. Here we estimate the association between crop diversity on swidden fields and ethnobotanical knowledge. We conducted research among 215 male household heads from a native Amazonian society. Using multivariate regressions, we found higher crop diversity among households that depend on agricultural production for household consumption. We also found a statistically significant and positive, but low, association between the ethnobotanical knowledge of the male household head and crop diversity. Doubling the stock of ethnobotanical knowledge of the male household head is associated with a 9% increase in the number of crops sown by a household. The association remained after we controlled for the household level of market exposure, but vanished after we controlled for the social capital of the male household head. Future research should compare the association between ethnobotanical knowledge and crop diversity across different agricultural systems (i.e., home gardens, fallow fields).

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Introduction

The traditional subsistence system in most parts of the Amazon is based on a combination of home gardens and swidden cultivation (also known as slash-and-burn or shifting cultivation) and the extraction of forest resources through hunting, fishing, and gathering (Dufour 1990; Salick 1989). Among those strategies, swidden cultivation ensures subsistence crops and provides most of the energy in Amazonian diets (Dufour 1994). Research shows that, to protect food production in agricultural fields, smallholders use several diversification strategies, including diversification of the crops grown during one season (i.e., crop diversity; Morduch 1995).

Research suggests that diversification in agricultural production makes households less vulnerable because diversification protects food production against adverse environmental (Bentley 1987; Zimmerer 1996) and economic shocks (Perreault 2005). In relatively remote rural settings, households diversify agricultural production in a variety of ways. Households plant several varieties of crops, scatter plots, stagger the planting season, and use intercropping (Altieri 1989; MacDonald 1998). In this article, we focus on the practice of planting several crops in the same season. We study crop diversity on swidden fields with respect to ethnobotanical knowledge, a potentially important covariate of the practice of crop diversity. First, we examine the association between crop diversity and household food consumption. Next, we examine the association between the ethnobotanical knowledge of the male household head and crop diversity in swidden fields. For the empirical analysis we use data from the Tsimane', a native Amazonian society of farmers and foragers in Bolivia.

Our article complements previous research on the determinants of crop diversity on swidden fields. Previous research has shown that knowledge of local crops is related to household crop diversity (Bellon and Brush 1994; Brush 2004), probably because people with more knowledge of cultivated plants are better able to plant more crops than people with less knowledge of cultivated plants. Rather than focusing on knowledge of crops, in this article we focus on a more exogenous variable—ethnobotanical knowledge of wild and semi-cultivated plants. We discuss potential pathways for the association in the discussion section.

The topic is important for at least two reasons. First, the conservation of crop diversity matters to the public, researchers, and policy-makers as concern grows over the loss of biological diversity (Vavilov 1994; Wood and Lenne 1997). For example, the Consultative Group on International Agricultural Research (CGIAR) has put considerable effort into creating a network of centers whose primary goal is to provide ex situ conservation for crop diversity (Fowler and Mooney 1990). In Latin America, previous research on the conservation of crop diversity has focused on commercial crops such as maize in Mexico (Bellon 2004; Bellon and Brush 1994; Brush 1995; Perales *et al.* 2005) and potatoes in the Andes (Brush 2000; Zimmerer 2003). The lowland Amazon region has been studied only lightly in this regard.

Second, researchers have lamented the loss of local ethnobotanical knowledge because it represents the irreversible loss of humanity's heritage and diversity (Cox 2000; Maffi 2002). Some researchers have also argued that local knowledge might contribute to farms' conservation of crop varieties (Altieri and Merrick 1987; Jarvis and Hodgkin 1999). If local ethnobotanical knowledge is being lost, and if there are benefits associated with such knowledge that the rest of the world enjoys (such as the conservation of crop varieties), then the world might suffer from the loss of this form of knowledge.

Crop Diversity

The Protective Role of Crop Diversity

Research suggests that there are two methods by which rural households protect changes in the level of food consumption to smooth consumption across time. First, households may take precautionary measures to protect their income before a negative shock strikes (Alderman and Paxson 1994; Dercon 2002; Morduch 1995). Second, rural households may rely on different safety nets after the shock. Some households use both methods (Morduch 1995, 2002). Among smallholders, one widely used precautionary strategy to protect income is diversification, which includes crop diversity.

Crop diversity protects household food production against localized risks related to environmental and economic variability (Zimmerer 1996; Brush 1992b). For example, in a study of the change from traditional shifting agriculture to intensive horticultural production among the Yucatec Maya, Humphries (1993) found that the high crop diversity in subsistence plots buffered the effects of environmental uncertainties. In a study of the Colombian Amazon, Hammond *et al.* (1995) found that crop diversity provided a buffer against environmental risks, such as rainfall fluctuations, attacks from pests, and plant diseases. In a series of studies in the Andean region of Paucartambo, Brush and colleagues documented that the peasants' choice of crops were shaped by the protective role of the crops (Brush 1991, 1992a, 2000; Brush *et al.* 1992). Those studies found that the selection of crops influenced household production, consumption, and social organization. They also found that crop diversity was higher among households that were more dependent on the crops for household consumption.

Covariates of Crop Diversity

Because crop diversity might smooth household food consumption, researchers have tried to identify its covariates. Macro-scale analyses suggest that the main culprits for the loss of crop diversity are modern farming technologies and new labor opportunities outside the rural sector (Fowler and Mooney 1990; Yapa 1993; Abbott 2005). However, local-scale analyses suggest that the relationship between crop diversity and modernization varies widely. Some studies on slash-and-burn agriculture in tropical Latin America have documented the erosive effect of modernization and market exposure on crop diversity (Henrich 1997; Humphries 1993; Putsche 2000; Peroni and Hanazaki 2002). However, other studies have shown that crop diversity in shifting agricultural systems is maintained as a strategy to ensure food security against variability in market conditions, such as fluctuations in the price of crops (Perreault 2005). As Bellon (2004) has highlighted, the maintenance of crop diversity by farming households might depend upon the interplay between the demand and supply for the diversity.

In trying to explain the apparently contradictory relations between market exposure and crop diversity, researchers have started to pay attention to the role of inter-village and inter-household variations in cultivated plant species diversity on swidden fields and home gardens. For example, in a study among a lowland Kichwa community in the Ecuadorian Amazon, Perreault (2005) found that crop diversity remained relatively high despite 30 years of market exposure. He attributed the maintenance of crop diversity not only to the material importance of crop production on household food security, but also to its symbolic importance as a marker of Kichwa identity. In a recent empirical study, Perales *et al.* (2005) investigate the link between ethnolinguistic diversity and maize crop diversity in the Maya highlands of central Chiapas in southern Mexico. Their findings suggest that maize populations are distinct according to ethnolinguistic group.

Studies on home gardens also suggest that village and household characteristics are important predictors of home gardens plant species diversity in traditional peasant communities. For example, in a study in three villages in northeast Peru, Lamont *et al.* (1999) found that ethnicity, distance to the market, and tourism affected home garden diversity. In another study in the same region (Coomes and Ban 2004) found that species diversity in home gardens from the same community was related to specific garden characteristics (e.g., age of the garden), household socio-economic features (e.g., wealth), and access to planting material.

Tsimane' Crop Diversity, Food Consumption, and Ethnobotanical Knowledge

The Tsimane' are a native Amazonian society of farmers and foragers who live in the lowlands of Bolivia, mostly along the Maniqui and Apere rivers in the department of Beni. Tsimane' hunt, practice slash-and-burn farming, and engage in wage labor. Detailed ethnographies of the Tsimane', including a description of Tsimane' agriculture, can be found in recent dissertations and books (Byron 2003; Daillant 2003; Huanca 2008, 1999), so here we focus on a description of Tsimane' crop diversity, food consumption, and ethnobotanical knowledge.

Tsimane' Agriculture and Crop Diversity

The Tsimane' grow crops in home gardens and in plots on cleared forest land. The Tsimane' obtain their main staples (upland rice, plantains, maize, and manioc) from plots cleared from old or fallow forest. Typically, the male household head clears all the plots in the household and women and children help him during sowing, weeding, and harvesting. Rice is the main cash crop and is typically grown in newly-cleared fields. After the rice harvest, fields may be partially replanted with maize, manioc, or plantains. Maize is used both for household consumption and for sale. Manioc, a hardy root crop that can last two or three years in the ground, is primarily sown for household consumption. Plantains are also mainly used for household consumption. Other crops planted in small patches include pineapples, peanuts, watermelons, squash, sweet potatoes, and sugar cane (Huanca 1999; Piland 1991; Vadez *et al.* 2003).

The Tsimane' rarely farm the same plot for more than two consecutive years. After 2years of continuous cultivation, the Tsimane' leave plots fallow so that the land can revert back to forest. However, before leaving plots fallow, the Tsimane' plant some useful species (e.g., fruit trees, pineapple). The Tsimane' also protect useful wild plant species, such as medicinal plants. The Tsimane' manage younger fallows more intensely than older fallows and they typically re-use fallows 5years after abandoning a plot (Huanca 1999).

The Tsimane' also plant home gardens. Home gardens include fruit trees, such as citrus, mango, avocado, papaya, and peach palm. In addition, Tsimane' plant—or protect the wild growth of—medicinal plants and other useful species, such as those that provide dyes, fibers (e.g. cotton), and fish poisons (Reyes-García *et al.* 2006).

In a study of Tsimane' agriculture, Piland (1991) found 91 different varieties of domesticated plants in active plots. He reported higher variability within species—30 varieties of manioc, seven of rice, and six of banana—than among crops. Most of the diversity of species was found in fallow plots and home gardens. Our previous research among the Tsimane' also suggests that crop diversity is relatively low in new fields, compared with the results from other studies in the Amazon (Eden and Andrade 1987; Johnson 1983; Wezel and Ohl 2005). In a previous study, we found that as many as 67% of newly-opened plots reportedly had only one crop (Vadez *et al.* 2004). Rice was the most important crop, present in 85% of new fields. Maize, plantain, and manioc were found in 57%, 33%, and 18% of new fields, respectively. Only 14% of new fields had crops other than the four primary crops mentioned above (Vadez *et al.* 2004).

Tsimane' Food Consumption

The Tsimane' are highly autarkic in consumption. In a previous publication (Godoy *et al.* 2002), we found that the mean annual personal income from cash earnings and from the imputed value of farm and forest consumption was low (or US $332/person), representing only one-third of the average income in Bolivia. We also found that market purchases accounted for less than 3% of the value of household consumption, which supports our finding that Tsimane' are highly autarkic. Most of the goods consumed by Tsimane' came from farm plots (comprising 42.5%), open courtyards and home gardens (comprising 29.7%), rivers, brooks, and ponds (comprising 18.1%), and forests (comprising 3.0%). Only 2.4% of the goods consumed by households came from outside the village and its surrounding lands, whether from another village or from towns.

The bulk of items in the Tsimane' diet consists of farm and forest foods that are traditionally processed into a variety of dishes. The Tsimane' diet is high in carbohydrates, which come primarily from farm plots (Byron 2003). Plantains, available year-round, are the most important staple in the Tsimane' diet and rice is the second most common food crop in the Tsimane' diet. Rice availability is determined by seasonal harvest cycles and it exhibits periods of scarcity in the pre-harvest months. Manioc and maize are also important crops in the Tsimane' diet and they are consumed primarily after they are brewed into a locally-made beer. In a nutritional study in two Tsimane' villages, Byron (2003) found that 47% of food items consumed by Tsimane' households came from farm production, making farm production the most common source of food. The other two sources of food items for the Tsimane' are the forest and the market.

Unlike other rural populations in developing countries, Tsimane' do not sell crops or assets, borrow, or rely on others to protect themselves from a drop in food consumption when shocks strike (Godoy *et al.* 2007). In a previous study with the same population, we found that 82.1% of the households that experienced shocks said they had to weather the spell on their own with no help from kin, friends, or outside institutions. The only mechanisms we found that would allow households to cope with shocks were income diversification (a precautionary strategy) and changes in the adult labor supply (an ex post strategy). We found that children's consumption levels were fully protected, despite the thin safety cushion, but evidence of full protection for adults was weaker (Godoy *et al.* 2007).

Tsimane' Ethnobotanical Knowledge

Like other native Amazonians, Tsimane' know much about forest plants and forest management (Reyes-García *et al.* 2003; Reyes-García *et al.* 2006). We have described Tsimane' ethnobotanical knowledge in previous articles (Reyes-García *et al.* 2006), so we restrict this section to an outline of three significant findings that relate to the work presented in this article. First, Tsimane' have extensive ethnobotanical knowledge and they share the knowledge of plants widely (Reyes-García *et al.* 2003). Second, among the Tsimane', ethnobotanical knowledge is positively associated to village-to-town distance (Reyes-García *et al.* 2005), but is not associated with other market proxies, such as monetary income or wealth. Third, occupations that take the Tsimane' out of their village and environment (e.g., wage labor) are negatively associated with ethnobotanical knowledge, whereas occupations that allow the Tsimane' to stay in their village and environment (farming and hunting) are positively associated with ethnobotanical knowledge (Reyes-García *et al.* 2007).

In sum, our previous research suggests four important points. First, farm plots production is important for the Tsimane' diet. Second, Tsimane' households have a thin safety cushion with which to cope with shocks. Third, Tsimane' children's consumption is fully protected and adult consumption is at least partially protected. Fourth, Tsimane' know a great deal about wild and semi-cultivated plants. Because Tsimane' food consumption is protected even though they do not rely on ex-post strategies to provide that protection, it is sensible to assume that Tsimane' likely hedge against adverse income shocks by using pre-emptive production strategies, such as diversifying sources of consumption. Because Tsimane' vary in their ethnobotanical knowledge, they represent an ideal population to test whether variations in ethnobotanical knowledge are associated to crop diversity.

The Estimation Strategy

Our estimation strategy has two steps. First, we estimate the association between crop diversity and household food consumption. If crop diversity is an effective pre-emptive strategy to protect household food consumption, then we should see a positive association between crop diversity and household food consumption. In the second step, we examine the relationship between crop diversity and ethnobotanical knowledge. We use the ethnobotanical knowledge of the male household head because, among Tsimane', male household heads are responsible for choosing and clearing the plot for farming. In the sensitivity analysis we do the same analysis for female. If variability in ethnobotanical knowledge is linked to household crop diversity, we should find a positive relationship between ethnobotanical knowledge and crop diversity.

Crop Diversity and Household Food Consumption

In the first step, we estimate the association between the level of household food consumption (the outcome variable) and crop diversity (the explanatory variable) using the following expression:

$$FC_{hv} = \alpha + \gamma \log D_{hv} + \zeta H_{hv} + \lambda P_{ihv} + \eta C_v + \varepsilon_{ihv} \quad (1)$$

In this equation, FC_{hv} stands for the level of household food consumption where *h* is the household and *v* the village. The expression $\log D_{hv}$ is the logarithm of the number of crops sown by the household. The term H_{hv} represents a vector of variables for the household that affect household food consumption (e.g., household cash income, household size) and crop diversity (e.g., the surface area of fallow or old-growth forest cleared). We use P_{ihv} to stand for a vector of observed variables for the male household head (e.g., age, schooling), where *i* is the male household head, and C_v stands for a set of village dummy variables to control for village factors that could directly affect household food consumption and crop diversity. Examples of such factors include soil quality or proximity to market towns. If crop diversity is associated with household food consumption, then γ should be positive.

We proxy short-run household food consumption with the monetary value of farm products consumed by the household because Tsimane' produce most of their subsistence crops in farm plots.

Ethnobotanical Knowledge and Crop Diversity

In the second step, we estimate the association between household crop diversity (the outcome variable) and the ethnobotanical knowledge of the male household head (the explanatory variable). We conduct the analysis at the household level rather than at the individual level because Tsimane' households are the units of agricultural production. We use the following expression to model crop diversity:

$$\log D_{hv} = \alpha + \beta L_{ihv} + \delta P_{ihv} + \theta H_{hv} + \nu C_v + \varepsilon_{ihv} \quad (2)$$

In this equation, $\log D_{hv}$ is the logarithm of the number of crops sown by the household, where *h* is the household and *v* the village. The term L_{ihv} captures the ethnobotanical knowledge of the male household head, where *i* is the individual. In this equation we defined the terms P_{ihv}, H_{hv} and C_v as in Eq. 1. If, as hypothesized, the ethnobotanical knowledge of the male household head is associated with household crop diversity, then β should be positive.

Potential Biases

There are three potential sources of bias in our estimations: measurement error in key variables, the possible existence of omitted variables, and possible reverse causality. First, measurement errors in our variables relate to the use of self-report data and to the proxy variables used. For example, we measured crop diversity through self-reports using a composite proxy that included one open-ended question (detailed on the next page). Respondents may vary in their willingness or ability to respond to the open question, thus producing measurement error. Measurement error in the variable crop diversity is likely to be systematic, and might be actually related to the actual crop diversity on fields (i.e., farmers who had high crop diversity might under-estimate the correct number of crops in their fields). Some of the key explanatory variables measured through self-reports may have random measurement error. For example, people may have given random answers to the ethnobotanical knowledge questions. Random measurement error in the explanatory variables would produce an attenuation bias and make our estimates more conservative. The measure of the value of farm products could also be flawed because we estimated the value of consumption using market prices, but markets for crops are poorly developed in the area.

We likely also introduced measurement error in the selection of the proxies. For example, agricultural knowledge is more likely to be associated to crop diversity than other domains of local ecological knowledge, such as ethnobotanical knowledge of wild and semi-cultivated plants. Since we used knowledge of wild and semi-domesticated plants rather than knowledge of domesticated crops, our results might underestimate the true dimension of the association between crop diversity and overall local ecological knowledge. Similarly, ethnobotanical knowledge may be more associated with home garden diversity since this is where crops needing greater care or special attention are likely to be planted. Excluding home garden crops in the assessment of crop diversity might produce an under-estimated measure of crop diversity.

Second, our estimations might be biased because of omitted variables. For example, previous research suggests that swidden fields in their second year might have more plant diversity than fields in their first year (Wezel and Ohl 2005). Failure to control for the age of the field could bias our estimations. Unfortunately, we do not have data on the age of the fields.

Finally, we can not document which variables are endogenous, therefore, we can talk about association but not about causality between the variables explored.

Methods

We collected survey information between May and October, 2005, in 13 villages along the Maniqui River in the department of Beni. The survey is part of the Tsimane' Amazonian Panel Study, a study in progress since 2002. We used formal interviews to obtain estimates of crop diversity, ethnobotanical knowledge, and the control variables.

Sample

To capture cross-sectional variation in participation in the market economy, we selected villages at different distances from the market town of San Borja (which has a population of approximately 19,000 people). We collected complete information from 215 male household heads.

Outcome Variables

Farm Food Consumption We asked the male and the female household heads to estimate the quantity of products consumed by the household during the 7days before the day of the interview. We limited the survey to 7days to reduce recall error, and we limited the foods consumed to a basket of goods that captures the main staples produced by the Tsimane'. Since less than 3% of the value of Tsimane' household consumption comes from market purchases (Godoy *et al.* 2002) and since we limited the list of items consumed to food staples, the measure is an adequate proxy for farm food consumption. To estimate the monetary value of farm food consumption, we multiplied the quantity of product consumed times the village price of the product. If the product did not have a village price, we used the price in San Borja, the closest market town.

Crop Diversity As a proxy for crop diversity, we asked the male household head to list all of the crops sown in each of the plots owned by the household during the previous planting season. The survey included questions about nine crops commonly sown by the Tsimane' (for example, "Did any person in the household sow rice during the last planting season?") and one open-ended question ("Which other crops did your household plant the last planting season?"). We asked only about crops planted in swidden fields, and we did not include crops growing in fallow fields or home gardens.

The Explanatory Variable

Ethnobotanical Knowledge To measure individual ethnobotanical knowledge, we asked participants 12 true–false questions about the uses of wild and semi-domesticated plants. Plants were selected at random from a list of 92 plants that we developed in an earlier study (Reyes-García *et al.* 2006). Subjects were asked whether they had ever used the plants for a specific purpose (e.g., "Have you ever used coyoj (*Zantedeschia* sp.) for medicine?"). None of the questions was purposefully false. We summed the number of positive responses to the 12 questions to arrive at a total score of ethnobotanical knowledge. The measure of ethnobotanical knowledge might contain random measurement error since we relied on the self-report of people rather than on objective measures.

Control Variables

Controls in the regression models include age, schooling, household cash, household size, area cleared of old forest and fallow forest, number of plots opened by the household, and a full set of village dummies. The age variable may contain measurement error because few Tsimane' adults know their age. Household cash was defined as the monetary value of sales, barter, and wage labor of adults in the household during the 2weeks before the interview. We measured household size as the number of male adult equivalents in the household during the week before the interview. Based on the age and sex of each participant, we computed a factor for each participant that captured their nutritional requirements expressed as a share of the nutritional requirements of an adult man (Byron 2003). We asked household heads to self-report the size and number of plots cleared by the household.

Results

Univariate Analysis

Table 1 contains definitions and summary statistics for the variables used in the regressions.

On average, male household heads in our sample were 42.1years old (standard deviation = 17.20) and had completed 2.3years of schooling (standard deviation = 2.80). We found a large variation in ethnobotanical knowledge. On a scale from 0 to 12, the average participant scored 5.40 points (standard deviation = 2.37). We found that the equivalent of 4.3 male adults lived in each household (standard deviation = 1.93). During a two-week period, each household obtained 342 Bs through sales, barter, and wage labor, or the equivalent of a total of 17days of salary for the household (at a daily wage of 20 Bs). The total amount represents the salary of 4.2days per male adult equivalent over a 2-week period. The monetary value of the household's own farm products consumed by the household was higher than the value of household cash income. The value of farm food consumption was 503 Bs during 7days (standard deviation = 267), or 1,006 over a 2-week period.

The average household opened 1.63 plots (standard deviation = 0.94), from which 0.48ha were from old growth forest (standard deviation = 0.61) and 0.55ha were from fallow forest (standard deviation = 5.1). Tsimane' households sow, on average, 6.02 different crops on their newly opened agricultural plots (standard deviation = 1.96). The

Table 1 Definition and summary statistics of variables used in regressions

Variable	Definition	Mean	Standard deviation	Min	Max
Male household head (*n* = 215)					
Age	Age of participant in years	42.1	17.20	17	85
Schooling	Maximum school grade achieved	2.3	2.80	0	13
Ethnobotanical knowledge	Score on a true-false questionnaire on the use of 12 wild plants	5.4	2.37	1	12
Household (*n* = 215)					
Household size	Male-adult equivalents during the three months before the interview	4.3	1.93	0.6	10.1
Household cash	Monetary value of sales, barter, and wage labor during the two weeks before the interview, in Bolivianos (US $1 = 8.03 Bolivianos).	342	431	0	3709
Farm food consumption	Monetary value of own farm products consumed during the 7 days before the interview, in Bolivianos	503	267	0	1686
Number of plots	Number of plots opened	1.6	0.94	0	6
Old-growth forest	Hectares of old-growth forest opened during the last planting season	0.48	0.61	0	3.5
Fallow forest	Hectares of fallow forest opened during the last planting season	0.55	0.51	0	2.5
Crop diversity	Number of crops sown	6.0	1.96	1	11

maximum number of different crops reportedly sown in agricultural plots was 11. Each of the households we interviewed reported having sown at least one crop during the planting season before the interview took place, although six households (or 2.5%) reported that they had not opened any new agricultural plots during that period. The average number of crops is low in comparison with other studies of crop diversity in swidden fallows in the Amazon. For example, in studies in the Colombian Amazon, Dufour (1990) reported an average of nine different crops per field among the Tukanoan, and Eden and Andrade (1987) reported an average of 12 crops per field among the Andoke.

Regression Analyses

Crop Diversity and Household Food Consumption The results shown in Table 2 (column a) suggest a large, positive, and statistically significant association between the number of crops sown on swidden fields by a household (the explanatory variable) and the value of household farm consumption (the outcome variable). A 100% increase in the number of crops sown by a household is associated with a 20.7% increase in the value of farm consumption (p = 0.04). Since the monetary value of farm food consumption was 503 Bs per week (see Table 1), doubling the number of crops sown by a household would be associated with an increase of approximately 100 Bs in the value of farm food consumption.

We ran the same regression model with one additional variable that controls for the total number of plots opened by the household (results not shown). We found essentially the same results as in the first regression. When we condition for the number of plots opened by the household, we find that doubling the number of crops sown by a household is associated with an increase of 23.6% in the value of farm consumption (p = 0.02).

To explore further the association between crop diversity and household farm consumption, we ran the same regression using three different proxies for agricultural production: the amount of rice and the amount of maize harvested by the household (Table 2, columns b and c), and the surface sown with manioc (Table 2, column d). We found that crop diversity was not associated with the amount of rice harvested (coefficient = 2.80, p=0.73), weakly associated with the amount of maize harvested (coefficient = 25.89, p = 0.16), and strongly associated with the surface sown with manioc (coefficient = 4.39, $p <$ 0.001). One more hectare sown with manioc would be associated with a 43.9% increase in household crop diversity.

In a robustness analysis, we used the body mass index (BMI: weight in kilograms/physical stature in square meters) of the adult male head of the household as proxy for individual consumption. Anthropometric indices of nutritional status, such as BMI, have been used extensively in studies of vulnerability among foraging-horticultural populations (Godoy *et al.* 2007; Hurtado and Hill 1990). We found that doubling the number of crops sown by a household was associated with a 3.8% increase in the BMI of the male household head (p = 0.08).

Ethnobotanical Knowledge and Crop Diversity In Table 3, we test the second step in our approach. The results of

Table 2 Association between crop diversity and household farm food consumption among Tsimane'

	Dependent variables			
	a Farm food consumption (Bs, log)	b Rice harvested (arroba = 11.5 kg)	c Maize harvested (24 ears)	d Surface manioc sown (0.1 ha)
Crop diversity (log)	0.207 (0.102)[a]	2.80 (8.18)	29.32 (20.83)	4.39 (0.574)[b]
Household cash	−0.0001 (0.0001)[c]	0.010 (0.017)	−0.0002 (0.021)	0.0003 (0.0003)
Household size	0.114 (0.018)[b]	1.57 (1.76)	2.81 (3.51)	−0.051 (0.084)
Fallow forest	0.002 (0.006)	6.81 (0.82)[b]	4.88 (1.42)[b]	0.041 (0.035)
Old-growth forest	−0.002 (0.005)	8.43 (0.703)[b]	4.79 (1.15)[b]	0.079 (0.028)[b]
Schooling	^	^	^	^
Age	^	^	^	^
Obs	231	227	127	236
R^2	0.44	0.69	0.03	0.13
F value[d]	8.61	15.09	49.73	104.08
P (*F*)[e]	<0.0001	<0.0001	<0.0001	<0.0001
Regression type	OLS	OLS	Tobit	Tobit

Regressions with robust standard errors (in parenthesis). Regressions results include dummy variables for villages (n=13−1=12) and a constant (not shown). For definition of variables see Table 1.
Caret variable not included because the regression was at the household level
[a] Significant at the 5% level
[b] Significant at the 1% level
[c] Significant at the 10% level
[d] LR chi square for the tobit models
[e] *P*(chi square) for the tobit models

Table 3 Association between male household head's ethnobotanical knowledge and household crop diversity

	Dependent variable: Crop diversity (log)			
	a OLS	b Lagged values	c Interaction effect	d
Ethnobotanical knowledge (log)	0.097 (0.049)[a]	0.191 (0.087)[a]	0.099 (0.052)[b]	0.025 (0.152)
Total debts	^	^	<0.0001 (<0.0001)	^
Own rice seed	^	^	^	−0.146 (0.260)
Interaction[c]	^	^	−0.010 (0.029)	0.088 (0.155)
Schooling	−0.015 (0.010)	−0.008 (0.031)	−0.016 (0.010)	−0.014 (0.011)
Age	0.004 (0.001)[d]	−0.00003 (0.003)	0.005 (0.001)[d]	0.004 (0.001)[d]
BMI	0.018 (0.009)[b]	0.036 (0.024)	0.018 (0.009)[b]	0.018 (0.010)[b]
Household size	0.028 (0.010)[d]	0.030 (0.019)	0.027 (0.010)[d]	0.027 (0.010)[a]
Household number of plots	0.070 (0.024)[d]	0.177 (0.092)[b]	0.071 (0.024)[d]	0.066 (0.025)[d]
Obs	215	136	215	211
R^2	0.34	0.44	0.34	0.32
F value	6.84	+	6.50	+
P (*F*)	<0.0001	+	<0.0001	+
Year of measurement of variables				
Dependent	2005	2004	2005	2005
Explanatory	2005	2003	2005	2005

Robust standard errors in parenthesis. See notes to Table 2.
Caret variable not included because the regression was at the household level
[a] Significant at the 5% level
[b] Significant at the 10% level
[c] Variable generated by multiplying the variable ethnobotanical knowledge by total debts (column c) or own rice seed (column d). +*F* statistics reported to be missing.
[e] Significant at the 1% level

Table 3, column a, suggest that the ethnobotanical knowledge of the male household head is positively related with crop diversity in swidden fields. Doubling the stock of ethnobotanical knowledge of the male household head is associated with a 9.7% increase (p=0.04) in the number of crops sown by the household.

Tsimane' households might vary in their dependence on agricultural versus extractive activities. To test whether the association remains the same after controlling for variability in dependence on agricultural activities versus extraction from forest products, we included a variable that captures the share of the value of agricultural versus forest products. To calculate the value of farm products, we used the monetary value of consumption of plantains, manioc, rice, maize, pigeon pea, ducks, pigs, chicken, and eggs during the 7 days before the interview. To calculate the value of forest products, we used the monetary value of game (mammals, birds, and fish) reportedly consumed by the household. We found essentially the same results (not shown). Doubling the stock of ethnobotanical knowledge of the male household head was associated with a 9.9% increase (p=0.04) in the number of crops sown by the household.

In Table 3, column b, we explore the temporality of the association between household crop diversity and the ethnobotanical knowledge of the male household head. To do so, we ran a regression of household crop diversity during time t_1 (the outcome variable) on explanatory variables lagged by 1 year (i.e., during t_0). We ran the regression with information from the same sample, but for a different time period. Information on the outcome variable was collected in the year 2004 and information on the explanatory variables was collected in the year 2003. We could not use information from the period 2004–2005 because we did not collect information on ethnobotanical knowledge during the year 2004. The sample size diminished because data were collected over a 2-year period and some people interviewed during the first year moved or were otherwise unavailable to be interviewed during the second year. We found a stronger relationship between household crop diversity and ethnobotanical knowledge using lagged variables than we found using contemporaneous variables. Doubling the ethnobotanical knowledge of the male head of the household was associated with a 19.1% increase in the number of crops sown by the household (p=0.04).

Extension

We did two additional analyses. First, we tested for a variety of interaction effects. We looked for interaction effects between our main explanatory variable (ethnobotanical knowledge) and two other variables: household-level market exposure (Table 3, column c) and individual social capital (Table 3, column d). If crop diversity protects the level of household food consumption and if integration into the market decreases crop diversity in fields (Henrich 1997; Humphries 1993; Putsche 2000; Peroni and Hanazaki 2002), then we should see that self-sufficient households will have more crop diversity and more ethnobotanical knowledge than households with greater exposure to the market. As a proxy for household market exposure, we used the total outstanding debts owed to the rest of the world by the male head of the household, because in the area, access to credit is a marker of integration into the market. We found no significant association between outstanding debts and crop diversity. The direct effect of ethnobotanical knowledge on crop diversity remained essentially unchanged in relation to the core model (coefficient=0.099; p=0.05).

We also tested for interaction effects between ethnobotanical knowledge and social capital. If crop diversity protects the level of household food consumption, then we should find that households with higher social capital would have less ethnobotanical knowledge and less crop diversity. This is because social capital could help households to self-insure against adverse income shocks. We used four different definitions of individual social capital: (1) receiving rice seeds during the last planting season, (2) number of times the person borrowed a set of assets (i.e., cooking pot, rifle), (3) amount of gifts received during the 7 days before the interview, and (4) amount of help received from outside the household during the 7 days before the interview. We found that the interaction effect between social capital the ethnobotanical knowledge of the male household head was not significant. Furthermore, when including the variables that proxy for social capital in the model, we found that the association between ethnobotanical knowledge and crop diversity was no longer significant.

The second extension of the model consisted of re-estimating Eq. 2 (Table 3, column a) for female household heads (results not shown). The results suggest that the ethnobotanical knowledge of the female head of the household was not associated with crop diversity in swidden fields (coefficient=0.048; p=0.25).

Discussion and Conclusion

We started this paper by asking whether crop diversity protects the level of household food consumption among the Tsimane'. We found that crop diversity was positively associated with the monetary value of household food consumption and with the production of crops devoted to consumption (but not the ones devoted to cash). We then moved on to examine the association between crop diversity and ethnobotanical knowledge. We found a positive association between the ethnobotanical knowledge of the male household head and household crop diversity. The association found is statistically significant, but small in terms of real magnitude. The association remained after we controlled for the level of market exposure of the household, but shrank considerably after we controlled for the social capital of the male household head.

The result presented in the first part of the paper—that crop diversity is positively associated with household production of food for consumption—resembles the result from previous research (Zimmerer 1996; Brush 1992b). Like previous researchers (Brush 1992b), we find that crop diversity is higher among households dependent on their own agricultural production for household consumption. We also find that crop diversity is positively associated with the production of consumption crops (i.e., manioc and maize), but not with the production of cash crops (i.e., rice). Our data suggest that the magnitude of the association between crop diversity and household farm consumption is important in real terms: doubling the number of crops sown in swidden fields by a household would be associated with one more hectare sown with manioc. Thus our findings mesh with previous research suggesting a positive role of agricultural crop diversity in household food consumption.

The second notable finding is the association between the ethnobotanical knowledge of the male household head and the number of crops sown by a household in swidden fields. The results presented here suggest that the magnitude of the association is low in real terms and probably unrealistic: Doubling the ethnobotanical knowledge of the male household head would be only associated with a 9% increase in crop diversity in swidden fields. Since households in our sample had an average of six crops in their fields, doubling the ethnobotanical knowledge of the male household head would be associated with only about 0.5 more crops. Furthermore, it is also not clear what the costs might be of doubling an adult's level of ethnobotanical knowledge since such competence probably reflects a stock accumulated over a lifetime. Last, because of omitted variable bias in our estimations, the true coefficients of the association are probably even lower than those presented in the main analysis. For example, in our robustness analysis we found that the magnitude of the association between ethnobotanical knowledge and crop diversity declined after we controlled for the social capital of the male household head. Social capital and own ethnobotanical knowledge might play different roles as safety nets in relation to income shocks. In the event of a shock, households with deep, extensive networks of kinship and reciprocity can rely on those networks when they need to borrow assets or food. Households with less social capital might have to rely on other mechanisms, such as ethnobotanical knowledge, to protect food consumption.

Other omitted variables might have to do with psychological attributes of the person. For example, people who have high ethnobotanical knowledge of wild and semi-cultivated plants might just be people with a general interest or predisposition to learn about useful plants (regardless of whether they are cultivated or wild). Results from a research on plant species diversity on home gardens show that informants explained the high diversity in some home gardens because of the owner's particular interest in plants and plant diversity (Coomes and Ban 2004). If psychological attributes are positively associated to both ethnobotanical knowledge and crop diversity, then the true coefficients of the associations explored are probably lower than those presented here.

The second finding, then, raises two related questions: Why might ethnobotanical knowledge of wild plants be associated with the number of crops in slash-and-burn agriculture? And why might the association be so modest? Researchers debate whether cultivation of tropical farms and home gardens imitates the diversity of the forest. Some researchers (Altieri 1999; Geertz 1970) have argued that people who observe plant relations in the forest might bring these relations into their fields. Other researchers (Beckerman 1983; Flowers *et al.* 1982; Vickers 1983) have argued that the structure of Amazonian swiddens does not necessarily compares in complexity with the surrounding forest. For example, Vickers (1983) examined the cultivation practices of the Siona-Secoya native Amazonians in Ecuador and found three types of cropping patterns: high-diversity intercropping, low-diversity intercropping, and monocropping. Plots with high-diversity intercropping showed some similarities to the tropical forest, but plots with low-diversity intercropping and monocropping showed few similarities to the forest. In our research we measured crop diversity in swidden plots, the area where low-diversity intercropping and monocropping occurs. It is possible that ethnobotanical knowledge of wild and semi-domesticated plants might be modestly related to agricultural crop diversity in swidden fields because swidden fields resemble the tropical forest less than other managed areas (i.e., home gardens). Future research should compare the association between ethnobotanical knowledge and crop diversity across agricultural systems with different structure (i.e., home gardens, fallow fields, swidden fields).

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