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ANALYSIS

Fire use and prevention by traditional households in the Brazilian Amazon☆

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ABSTRACT

Fire is an important land management tool for smallholders in the Brazilian Amazon. However, when fires are not properly controlled they can give rise to large-scale wildfires that threaten forests, agricultural plantations, and settlement areas. We use data from a survey of 220 households to examine fire prevention and the scale of fire prevention and burning activities among traditional subsistence households in the Tapajós National Forest in Pará, Brazil. We find that in traditional households, economic variables such as the opportunity cost of household time, market conditions, and the hiring wage are important predictors of these decisions, as is household reliance on standing forest resources for non-timber products. Our results confirm that traditional households actively engage in fire prevention, and suggest that fire prevention is motivated by a desire to protect agricultural plantations as well as standing forest reserves. The results suggest that increased income, improved infrastructure, and improved access to markets for labor and agricultural goods will encourage fire prevention among smallholders in communities with education and planning programs.

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1. Introduction

As human populations have increased over the last century, and as lines between human settlement areas and forested landscapes have been relentlessly extended, the threat posed by fire use to human welfare, environmental integrity, and global climate change looms large. Fire in the Brazilian Amazon remains an important tool for clearing of forested land and maintenance of cleared areas used for agricultural production, however, recent extreme drought conditions in Brazil experienced during El Niño years of the 1997–1998 and the 2005–2006 dry seasons have contributed to escaped fires burning up to 1000 km^2, endangering human health, private property, forested landscapes, and national and state infrastructure (Holdsworth and Uhl, 1997; Cochrane and Schulze, 1998; Nepstad et al., 1999; de Mendonça et al., 2004).

The ecological effects of these fires on the flammability of tropical forests have been studied extensively. Increasing fire use is resulting in reduced evapotranspiration on regional scales, which in turn further contributes to the severity of droughts, changing climate patterns (Carvalho et al., 2004), and additional threat of large-scale uncontrolled fires. When

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combined with high rates of land clearing deforestation and destructive logging practices, the resilience of the forest ecosystem is severely compromised by these positive feedback cycles (Nepstad et al., 2001), leaving it more flammable and less able to store carbon (Zarin et al., 2005). It has been estimated that the area of forest burned as a result of wildfire may be up to threefold that of areas intentionally converted by landowners (Alencar et al., 1997), and that burning in the Brazilian Amazon region is responsible annually for 4–5% of global anthropogenic carbon emissions (Fearnside, 1997). Economic losses to landowners follow large-scale wildfires and include crop losses, degradation of pasture, and loss of timber resources and non-timber forest products in their legal reserves (Holdsworth and Uhl, 1997; Nepstad et al., 1999; de Mendonça et al., 2004).

Other work has focused on how to predict and control widespread fire events, and models have been created that predict forest flammability. Nepstad et al. (1998) in particular suggest targeting areas for enforcement of bans on burning and for fire suppression (see also Costa, 2004). An important shift towards fire management and landowner education at the community level is also being pushed heavily by NGOs and by the Brazilian government alike.

Other related studies have suggested the importance of property rights enforcement and implementation of community programs designed to educate landowners about burning (Nepstad et al., 1999; Nepstad et al., 2001; Moran et al., 2006).

Our purpose is to examine the fire prevention behavior of smallholder households in the Brazilian Amazon, with a goal of relating these results to the formulation of policies that will promote well-managed frontier forests. While fire prevention can include many activities, such as monitoring burning, fire breaks, or burning during certain times of the year, we choose to focus on the most important one for smallholders in our sample; this is the (labor-intensive) clearing of fire breaks prior to burning forested areas. We base the analysis on a recently completed survey of 220 households in fifteen communities of the Floresta Nacional do Tapajós (hereafter referred to as 'FLONA') in the state of Pará, Brazil. Traditional communities within the FLONA present a unique opportunity to study the drivers of fire prevention behavior.

These households tend to engage actively in various types of prevention behavior (Sorrensen, 2000; Toniolo, 2004; Moran et al., 2006), in part because of implementation of community fire prevention agreements in the study area and other work in community-based fire prevention over the last decade by the Brazilian environmental regulatory agency IBAMA (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis) and by IPAM (Instituto de Pesquisa Ambiental da Amazônia) in communities of the FLONA. The location of our study site within a national forest may distinguish our sample households from Brazilian smallholders in general, but it allows us to specifically examine fire prevention decisions that have escaped attention in the smallholder economics modeling literature. Two important contributions of our work are, first, to develop a framework for understanding fire prevention choices and accidental fire risk within the traditional economic household model applied to smallholders, and, second, to empirically examine for the first time the various economic and household drivers of fire *prevention* behavior and the interaction of this behavior with other decisions that are well-addressed in the literature, such as burning and land clearing.

Our focus on the fire prevention decision-making of small landowners in the Brazilian Amazon who use fire identifies the drivers of burning and fire prevention behavior at the household level. Such information is necessary in the future design of policies aimed at reducing wildfire risk in the region. Because fire is an important substitute for clearing labor and chemical inputs in the production process, the household must often weigh the dangers associated with burning during the dry season against the benefits of increased burn efficiency during this period (Sorrensen, 2000; Varma, 2003; Moran et al., 2006). For the rural subsistence household, there is then an important opportunity cost of household time associated with either engaging in fire prevention or with mechanical land-clearing and preparation required if fire is not used. It follows that, from a household welfare perspective, it is important to consider these opportunity costs and their effect on the household time allocation to other subsistence activities such as non-timber forest product collection or agricultural production (Costa, 2004).

Our approach builds upon the theory of economic household modeling. We first construct a subsistence household model of expected utility maximization by introducing an assumed exogenous probability of accidental fire, where on-farm labor is allocated between various productive activities (including fire prevention and land clearing by burning) and time allocated to leisure (e.g. see Singh et al., 1986; Jacoby, 1993). Several other studies have used economic household models to address the role of risk and income in household decision-making in the region (Caviglia-Harris, 2004; Perz, 2004), but none have focused on fire risk or fire prevention decisions. Further, while a vast body of evidence shows that the degree of economic risk posed by accidental fire to households in the Brazilian Amazon region is high (Nepstad et al., 1999; Sorrensen, 2000; Simmons et al., 2004; Toniolo, 2004; Ioris, 2005; Moran et al., 2006), this work either characterizes losses incurred as a result of accidental fire, addresses the role of household characteristics in land-use/land-cover changes, or seeks to explain the role of social variables in community fire prevention activity. We build on these analyses to identify the important drivers of the fire prevention decision and we introduce a new framework for evaluating the risk of accidental fire as a factor in household decisions.

2. Household model

To define the link between household decisions and fire prevention, we use an expected utility maximization model specifying household allocation of on-farm (own) labor between various productive activities and time allocated to leisure, following the seminal work by Jacoby (1993). This will be done under an assumption that labor markets are not fully complete, in which case a 'shadow wage' must be defined that expresses the opportunity cost of time of adult labor to household production. Labor markets are incomplete in our sample, because households routinely have difficulty

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obtaining off-farm work given that settlements are spread over large areas and located near completely impassable roads during the wet season, and transportation costs and infrastructure are such that off-farm wage employment opportunities are extremely limited with very low wages in the FLONA (Pattanayak and Sills, 2001; Caviglia-Harris and Sills, 2005) As others have shown, the estimation of a shadow wage for cases like this with incomplete labor markets becomes necessary (Jacoby, 1993; Amacher et al., 2004).

Many studies have addressed household decisions such as level of forest clearing (Angelsen, 1999; Shively, 2001a; Pendleton and Howe, 2002; Shively and Fisher, 2004). These provide a starting point for our study in modeling the ways that accidental fire, fire prevention, and slash-and-burn agriculture enter the household decision-making process. When risk is incorporated in models without fire, subsistence households are often assumed to be risk-averse (Amacher et al., 1992; Rosenzweig and Binswanger, 1993; Morduch, 1995; Barrett 1999; Shively, 2001b).[1] Households have also been found to hedge against risk by seeking non-production income (Howe, 2003), participating in off-farm labor markets, clearing land, and collecting non-timber forest products when available (Bluffstone, 1995; Angelsen, 1999; Kochar, 1999; Pattanayak and Sills, 2001; Rose, 2001; Pendleton and Howe, 2002; McSweeney, 2004).

We begin with a model of the traditional household. Assume that household decisions are made ex-ante to the realization of accidental fire in a given year. Let the probability of occurrence of an accidental fire be denoted P, so that $(1-P)$ is the probability that a household does not experience accidental fire in the next year. The expected level of household utility is defined by this probability and the utilities the household receives in the case of fire (U^F) and in the case of no fire (U^O),

$$U = P \cdot U^F(\cdot) + (1-P) \cdot U^O(\cdot). \quad (1)$$

The concave utility function of a representative household in our sample is assumed to be an increasing function of all goods consumed and leisure time in each case:

$$U^j \equiv U[X, N, Q_c, l; \Omega] \text{ for } j = F, O, \quad (2)$$

where consumption of agricultural goods (the sum of purchased agricultural goods and own production that is consumed) is denoted by Q_c, consumption of non-timber forest products by N, consumption of other purchased non-food goods by X, and leisure time by l, which is equivalent to the total time allocation to the household minus time spent in household labor activities (exclusive of hired labor that comes from outside the household) ($l = T - L$). T is total time and L is a vector of labor time spent in agriculture, non-timber forest product collection, and fire prevention. Finally, utility also depends on a vector of household-specific characteristics, Ω.

Production of non-timber forest goods is a function of household labor time allocated to collection of these goods (L_N), of forested area available to the household (A_F), and household characteristics, Ω.

In the case of an accidental fire we introduce an additional term to represent protection of household resources afforded by fire prevention exercised by the household. Fire prevention is defined by clearing of fire breaks and will be denoted by α. Prevention increases household production possibilities should a fire occur. We assume that prevention reduces fire damage and thus increases the percent of the crop that can be harvested should fire strike; in the absence of fire, the smallholder simply obtains 100% of production, but will have spent the cost for fire prevention in terms of labor time.[2] Given that fire breaks are a labor-intensive activity, the protective effect of it in the case of accidental fire is an increasing function of labor dedicated to the task of fire prevention. Thus, we write $\alpha \equiv \alpha(L_p)$, where $\alpha(L_p)$, $\alpha'(L_p) > 0$, and $\alpha''(L_p) < 0$. Using this, non-timber forest production by the household in non-fire and fire cases is written:

$$N^O \equiv N(L_N, A_F; \Omega), \quad (3a)$$

and

$$N^F \equiv \alpha(L_p) N(L_N, A_F; \Omega). \quad (3b)$$

Agricultural production in the case of accidental fire (Q_p^F) and no fire (Q_p^O) depend positively on family agricultural labor (L_A) and hired labor (L_H), on agricultural capital, K, and on the area of land burned for agriculture, A_B, as well as on household characteristics, Ω. For notational simplicity in the model, we treat land area burned for agriculture as equivalent to area planted.[3] As in the case of non-timber forest production, we include level of fire prevention, $\alpha(L_p)$, as a protection effect to agricultural production in the case of accidental fire, so that:

$$Q_p^O \equiv Q_p[A_B, K, L_A, L_H; \Omega], \quad (4a)$$

and

$$Q_p^F \equiv \alpha(L_p) Q_p[A_B, K, L_A, L_H; \Omega]. \quad (4b)$$

Fire prevention represents an opportunity cost to both household production and to leisure. This opportunity cost of time spent in fire prevention enters directly through the household time constraint ($l \equiv T - L_A - L_p - L_N$), and indirectly through household land available for production, ($A_B \equiv A - A_F - A_E$), where A is the total endowment of land in hectares, is the area burned for agriculture, A_F is land area in forest, and A_E is area cleared as 20 an aceiro, or firebreak. Land in the firebreak is not planted, and therefore A_E is simply a direct function of labor allocated to fire prevention ($A_E \equiv A_E(L_p)$) given that this activity is labor dependent.

[1] Subsistence households have been assumed to face diverse risks, including illness (Amacher et al., 2004), crop loss (Fafchamps, 1993; Kochar, 1999), price stochasticity (Saha, 1994; Barrett, 1999), land confiscation (Alston et al., 1999) and environmental disasters (Rosenzweig and Binswanger, 1993; Takasaki et al., 2004).

[2] An alternative would simply be to assume that production is lost should fire occur and prevention not have been done, while production is completely saved if accidental fire arrived and fire prevention were undertaken. This would be of no consequence to the analysis.

[3] This assumption is relaxed later in our econometric analysis.

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Under the above assumptions the household cash budget constraint is:

$$P_c\left[P\left(Q_p^F(\cdot)-Q_c^F\right)+(1-P)\left(Q_p^O(\cdot)-Q_c^O\right)\right]+I=w_H L_H+p_x X, \quad (5)$$

where P_c is the price of agricultural goods, I is exogenous income to the household, w_H is the wage at which the household hires labor, if any, and p_x is the price of other goods. The first two terms of Eq. (5) show that the household can consume its own production of crops, purchase crops in the market, or sell what it does not consume out of its own production in the market, both in the case of accidental fire and no accidental fire.

The household expected utility problem is one of maximizing Eq. (1) subject to Eqs. (3a)–(3b), (4a)–(4b), and (5), the probability of accidental fire (P), and a non-negativity constraint for fire prevention labor ($L_p>0$). The Lagrangian function for this problem is,

$$\begin{aligned} Max_{\{A_B,L_p,L_N,\ldots\}}\xi = {} & P\cdot U^F\left[X,N^F(\alpha,L_N,A_F;\Omega),Q_c^F,l;\Omega\right] \\ & +(1-P)U^O\left[X,N^O(L_N,A_F,\Omega),Q_c^O,l;\Omega\right] \\ & +\lambda\{P_c[P(Q_p^F[\alpha,A_B,K,L_A,L_H;\Omega]-Q_c^F) \\ & +(1-P)(Q_p^O[\alpha,A_B,K,L_A,L_H;\Omega]-Q_c^O)]+I-W_H L_H+P_X X\} \\ & +\gamma L_p+\mu(T-L_A-L_P-L_N) \end{aligned} \quad (6)$$

where λ is the multiplier for (5), γ is the multiplier for the non-negativity constraint on L_p, and μ is the multiplier for the household time constraint. First order conditions for interior solutions of Eq. (6) with respect to area burned for agriculture (A_B) and labor allocated to fire prevention (L_p) can be obtained by substituting the land constraint ($A_B \equiv A - A_F - A_E(L_p)$) and production functions (4a)–(4b) into Eq. (5) and differentiating,[4]

$$\begin{aligned} \frac{\partial\xi}{\partial A_B} = {} & -P\left(\frac{\partial U^F(\cdot)}{\partial N^F}\frac{\partial N^F(\cdot)}{\partial A_F}\right)-(1-P)\left(\frac{\partial U^O(\cdot)}{\partial N^O}\frac{\partial N^O(\cdot)}{\partial A_F}\right) \\ & +\lambda P_c\left[P\left(\frac{\partial Q_p^F(\cdot)}{\partial A_B}\right)+(1-P)\left(\frac{\partial Q_p^O(\cdot)}{\partial A_B}\right)\right]=0 \quad \text{, and} \end{aligned} \quad (7)$$

$$\begin{aligned} \frac{\partial\xi}{\partial L_p} = {} & A_E'(L_p)\left[-P\left(\frac{\partial U^F(\cdot)}{\partial N^F}\frac{\partial N^F(\cdot)}{\partial A_F}\right)-(1-P)\left(\frac{\partial U^O(\cdot)}{\partial N^O}\frac{\partial N^O(\cdot)}{\partial A_F}\right)\right] \\ & +P\alpha'(L_p)\left(\frac{\partial U^F(\cdot)}{\partial N^F}\right)+\lambda A_E'(L_p)P_c \\ & \times\left[-P\left(\frac{\partial Q_p^F(\cdot)}{\partial A_B}\right)-(1-P)\left(\frac{\partial Q_p^O(\cdot)}{\partial A_B}\right)\right]+\lambda P_c P\alpha'(L_p)Q_p^F \\ & +\gamma-\mu=0. \end{aligned} \quad (8)$$

The interpretation of Eq. (7) is straightforward. The household will burn land so as to equate the expected marginal benefit to production from burning land for agriculture (second term in brackets) to the indirect expected marginal cost to household utility from decreased non-timber forest product collection over a smaller forested area resulting from an increase in burned land area. Condition (8) shows that the household will supply labor to fire prevention so as to equate the expected marginal benefits of protection to production and to non-timber forest collection in the case of a fire (the two terms that include $\alpha'(L_p)$), with the sum of the expected marginal cost to production and utility (through a decrease in non-timber forest product collection) of removing land through clearing of firebreaks (the two terms that include $A_E'(L_p)$) and the opportunity cost of time.

The first order condition for labor allocated to fire prevention Eq. (8) can be rearranged at the corner solution of zero fire prevention, where $L_p=0$ and $\gamma>0$, to obtain:

$$\begin{aligned} & P\alpha'(L_p)\left(\frac{\partial U^F(\cdot)}{\partial N^F}\right)+\lambda P_c P\alpha'(L_p)Q_p^F \\ & < \left\{ \begin{array}{l} A_E'(L_p)\left[P\left(\frac{\partial U^F(\cdot)}{\partial N^F}\frac{\partial N^F(\cdot)}{\partial A_F}\right)+(1-P)\left(\frac{\partial U^O(\cdot)}{\partial N^O}\frac{\partial N^O(\cdot)}{\partial A_F}\right)\right] \\ +\lambda A_E'(L_p)P_c\left[P\left(\frac{\partial Q_p^F(\cdot)}{\partial A_B}\right)+(1-P)\left(\frac{\partial Q_p^O(\cdot)}{\partial A_B}\right)\right]+\mu \end{array} \right\} \Leftrightarrow L_p=0. \end{aligned} \quad (9)$$

Eq. (9) suggests that the household will not engage in fire prevention if the sum of the indirect expected marginal benefit to utility from the effect of fire prevention and the direct expected marginal benefit to income from the effect of fire prevention on agricultural production is less than the sum of the indirect expected marginal costs to utility through a decrease in forested area for non-timber forest product collection and available agricultural land from land cleared for fire prevention, plus the opportunity cost of household time, μ.

Our task now is to estimate equations explaining the decision to engage in fire prevention and labor time spent in fire prevention, as well as hectares of land burned for agricultural plantations, and the decision to collect non-timber forest products using household survey data. The decision to engage in fire prevention follows Eq. (9) and can be estimated with a Probit regression, where the dependent variable is defined as one if the household engages in (i.e., supplies labor to) fire prevention and zero otherwise. Explanatory variables are those identified in Eq. (10), such as components important to utility, prices, production and fire related variables, and opportunity cost of time. If the household decides to participate in fire prevention, the level of participation in fire prevention is then described by Eq. (8). Thus, we expect the level of participation to increase as the household's perception of the expected protective effect of prevention to non-timber production and crop production increases, or as the opportunity cost of removing land from production (a function of prices and market variables) decreases. The corresponding econometric model for fire prevention labor use and the level of fire prevention labor employed consists, respectively, of the following two equations to estimate:

$$\Pr(L_p=1)\frac{e^{\beta Z_p}}{1+e^{\beta Z_p}}, \quad (10)$$

and

$$L_p=G(Z_p,\alpha_p;\varepsilon_p) \text{ if } L_p>0, \quad (11)$$

[4] The first order condition with respect to non-timber forest product collection is as follows:

$$\frac{\partial\xi}{\partial L_N}=P\left(\frac{\partial U^F(\cdot)}{\partial N^F}\frac{\partial N^F(\cdot)}{\partial L_N}\right)+(1-P)\left(\frac{\partial U^O(\cdot)}{\partial N^O}\frac{\partial N^O(\cdot)}{\partial L_N}\right)-\mu=0.$$

Thus, the utility maximizing household will equate the expected marginal benefit to utility of labor allocated to non-timber forest product collection to the opportunity cost of household time, μ, and will not engage in non-timber forest product collection if the sum of the first two terms is less than μ. See Pattanayak and Sills (2001) for an alternate but similar discussion of the household non-timber forest product collection decision.

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where ε_p is an error with a censored Normal distribution. Eq (10) is a 'participation' Probit regression explained by Eq. (9), while Eq. (11) is a regression for the level of participation explained by Eq. (8), estimated as a Tobit model to account for censoring of the dependent variable. Eq. (11) is conditional on fire prevention being observed (i.e., participation) for the household in the sample. The parameter β is a vector of coefficients to estimate in the participation decision, α_p is a vector of coefficients to estimate for the level of participation, Z_p is the vector of explanatory independent variables present following both Eqs. (8) and (9), and G(.) is a reduced form equation.

The area of the smallholder lot burned for crop production can be examined in a similar manner as fire prevention, with explanatory variables following Eq. (7). Here, however, we will not examine the decision to burn or not to burn, as all households burn on a definite cycle.[5] The only relevant choice is the scale of burning, which we estimate with a Tobit model given by: $A_B = A(Z_B, \alpha_B; \varepsilon_B)$, where ε_B is an error for the burning decision, Z_B is a vector of explanatory variables, i.e., those contained in Eq. (7), and α_B is a vector of parameters to estimate.

There are several econometric issues to address when estimating the fire prevention and burning decisions above. First, some of the explanatory variables in Z_P and Z_B are potentially endogenous and correlated with the errors implicit in each decision. These include household income, the household opportunity cost of time, and whether the household collects non-timber forest products or hunts (these choices are important to fire prevention and burning land use decisions through the utility terms in Eqs. (7)–(9)). We follow an instrumental variable procedure to accommodate this endogeneity. For the opportunity cost of time, Jacoby (1993) shows that the value marginal product is a suitable instrument; this equals the shadow wage in the case where the household is optimizing own labor decisions. As in the other economic studies discussed earlier, exogenous income will be used as an instrument for household income. For non-timber forest product collection and for hunting, we will use a first stage prediction of this variable in place of actual observed collection in our regressions. In the first stage, non-timber collection and hunting participation will be regressed on all exogenous variables in the model, and a predicted probability will be constructed for all households in the sample. Identification will be checked for all equations estimated using the sufficient order condition (Greene, 1997).

Selection bias is another potential concern in the fire prevention estimation of Eqs. (10) and (11), since not all households in the sample engaged in these activities. Selection bias arises if the errors in the participation decision and level of activity are correlated, rendering separate Probit and Tobit models inappropriate. If this correlation is significant, then a Tobit type II model would be appropriate for Eqs. (10) and (11), as well as for the land burned decision (e.g., see Greene, 1997). We will test for selection bias by first estimating a Tobit type II model and then examining the significance of the selection parameter. As we will show later, it turns out that the selection parameters were insignificant for all decisions where non-participation was observed, confirming the approach set forth in Eqs. (10) and (11). Finally, heteroskedasticity may be present in the cross sectional data, and we will correct for this using White's consistent covariance method.

3. Data and results

In order to estimate the above equations, a recall-based questionnaire was applied to households by a team of six enumerators in March and April of 2006. The sample consisted of 220 households in 15 communities within the FLONA in the state of Pará, Brazil (Fig. 1). The questionnaire included questions about household, market, and lot characteristics, and had sections focusing on household labor allocation, agricultural production, consumption, burning, and fire prevention. Interviews were conducted during the wet season, such that the year's worth of information collected pertained to the last dry season and preceding wet season of 2005. Sampling followed approaches used in other studies performed in the region (See e.g. Godoy et al, 1998; McSweeney, 2004; Perz, 2004; Perz, 2005). The sample data are representative of the

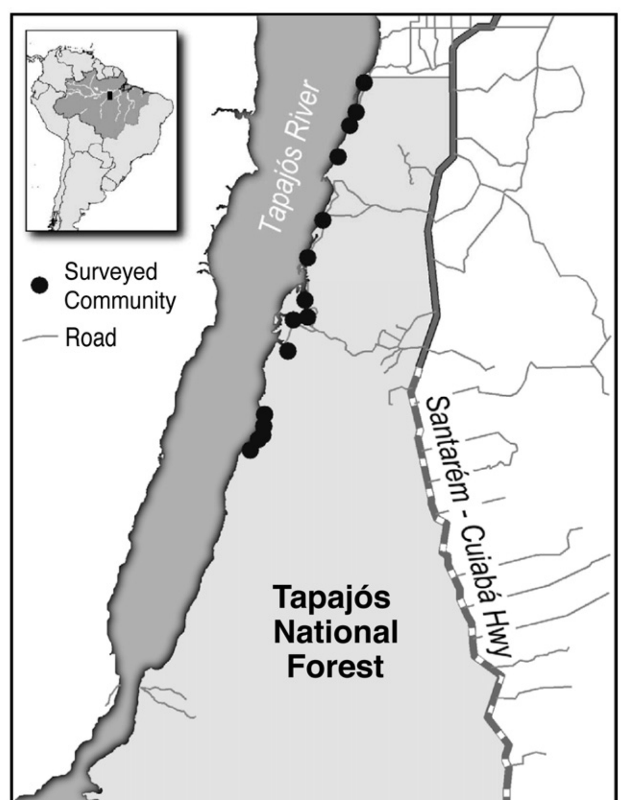

Fig. 1 – Geographical representation of the Floresta Nacional do Tapajós.

[5] In our data, discussed in the next section, this does not mean that every household burned during the recall period of our survey. Different households were on different production schedules or burn intervals, and as a result the data was in fact censored at zero for both of these decisions. This means that the second stage requires a Tobit model for the burning and crop production equations.

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Table 1 – Descriptive statistics for sample households

	Full sample		Households that did not clear firebreaks		Households that cleared firebreaks	
	$n=220$		$n=59$		$n=161$	
	Mean	SD	Mean	SD	Mean	SD
Household characteristics						
Number of household members	4.81	2.23	4.37	2.55	4.97	2.11
Number of children (<15 years)	2.00	1.77	1.66	1.75	2.13	1.77
Sum of years of education of all household members	17.52	11.10	17.44	12.20	17.55	10.71
Expenditure on household structure in Reais[a]	1498.12	2489.30	1696.62	2107.07	1439.97	2597.45
Years on lot	30.56	18.12	27.67	18.41	31.63	17.95
Time since accidental fire (years)	5.95	4.64	7.86	4.60	5.56	4.62
Economic parameters						
Size of agricultural plantation	0.42	0.45	0.30	0.37	0.46	0.47
Value of annual crop production ($*R*)	1000.53	1607.85	591.55	1119.81	1150.41	1731.94
Number of head of cattle	4.11	34.03	2.64	8.61	4.65	39.46
Household hired labor last year (0,1)	0.39	0.49	0.32	0.47	0.41	0.49
Wage paid by household ($*R*/day)	11.87	2.51	11.6	1.68	11.94	2.70
Days of labor hired by the household	4.11	11.22	3.14	8.61	4.47	12.04
Household took out a loan last year (0,1)	0.16	0.37	0.19	0.39	0.16	0.36
Exogenous income to the household last year ($*R*)	1066.48	8154.12	794.25	1922.76	1166.24	9467.32
Shadow wage of planting labor ($*R*/day)	27.42	57.96	5.60	26.81	34.23	63.22
Household decisions						
Household hunts (0,1)	0.24	0.43	0.08	0.28	0.30	0.46
Household collects non-timber forest products (0,1)	0.19	0.39	0.10	0.30	0.22	0.42
Household fishes (0,1)	0.82	0.38	0.64	0.48	0.89	0.32
Household burns land for agricultural production (0,1)	0.5	0.50	0.41	0.50	0.53	0.50
Household burned land for agricultural production in the last year (0,1)	0.35	0.48	0.20	0.41	0.41	0.49
Area burned by the household last year (ha)	0.36	0.97	0.09	0.28	0.45	1.10
Household has experienced an accidental fire (0,1)	0.21	0.41	0.15	0.36	0.23	0.42
Time since accidental fire (years)	5.95	4.64	7.86	4.60	5.56	4.62
Household spent time in firebreak clearing this year (0,1)	0.73	0.44	0	0	1	0
Household burned land and cleared firebreaks (0,1)	0.43	0.50	0	0	0.59	0.49
Household didn't burn land or clear firebreaks (0,1)	0.21	0.41	0.80	0.41	0	0
Household didn't burn land, but cleared firebreaks (0,1)	0.30	0.46	0	0	0.41	0.49
Household burned land, but did not clear firebreaks (0,1)	0.05	0.23	0.20	0.41	0	0

[a] $2.37 Brazilian Reais=$1.00 U.S. Dollar (as of July, 2005).

population within the FLONA for several reasons. First, every household approached agreed to be interviewed. Second, with a total of 220 households interviewed, we sampled a large percentage of the total population of approximately 500 households in the FLONA.[6]

Indeed, when we compare our data on household characteristics such as household size, number of dependents, and land tenure, we find them to be similar to other studies conducted recently within the FLONA, such as Pattanayak and Sills (2001) and Caviglia-Harris and Sills (2005). Finally, there is little variation in the types of labor-intensive agricultural systems and types of inputs used by households in the FLONA and in our sample.

Detailed information was collected about time spent in a range of labor activities for each member of the household. A major portion of the questionnaire focused on the amount of land burned by the household during the just-ended dry season for various purposes, fire prevention activities adopted by the household, and the degree to which the household allocates labor resources to the clearing of firebreaks.[7] In addition, we collected information about household experience with accidental fire.

[6] Pattanayak and Sills (2001) assume a population size of approximately 3000 and an average household size of approximately 5; this means that by their definition and our descriptive statistics concerning family size, there are approximately 600 households in our sample area. Our sample size is relatively large also by these estimates.

[7] Firebreaks are a widely-used, labor-intensive form of fire prevention that help to protect cropping areas against own fires or fires set by neighbors, and to ensure that intentional fires do not escape intended limits. In practice, households in the FLONA clear a strip of 0.5–5 m around agricultural plantations or around the area to be burned (Toniolo, 2004).

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In 1974, The Floresta Nacional Tapajós became the first state environmental reserve created in the legal Amazon region of Brazil (Ioris, 2005). Settlements were established within the FLONA by the pro-expansion government during this period, persisting today in the form of many of the communities interviewed. Referring to Table 1, descriptive statistics from the sample have been provided for the full sample, and for those households that did and did not engage in fire prevention. The average sample household contains 4.81 members.[8] Most households practice subsistence agriculture, and manioc is the most important staple crop. Some households hunt (24%) or collect non-timber forest products (19%), and virtually all households engage in crop production. Many households also engage in fishing for household consumption.[9] Ranching is not a predominant land use in the area (our survey results show that the average household herd is only 4 head).

All sample households are located within the boundaries of the FLONA, which is located south of the city of Santarém in the Brazilian state of Pará (see Fig. 1).[10] Communities in the northernmost part of the forest (closest to Santarém) are closer to improved (graveled or dirt) roads with more frequent bus schedules, affording them lower travel times to markets when compared to households located further south along the river bank or close to the road entering at km 83. Despite their remote location, communities in the FLONA are subject to a high level of involvement of the Brazilian environmental regulatory agency IBAMA, the Brazilian Institute of the Environment and Renewable Natural Resources (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis), and other NGOs such as IPAM, the Institute for Environmental Research of the Amazon (Instituto de Pesquisa Ambiental da Amazônia). The active presence of these organizations is particularly relevant when studying fire prevention in the region; programs targeting burning behavior have been implemented in recent years by IBAMA, and IPAM has established a system of community agreements adopted in 1994 stipulating precautions to be taken when burning. All communities in the region participate in these programs.

It appears that communities in the FLONA experience a reduced risk of accidental fire when compared to other frontier communities along the Transamazon and along the BR-163 highway, as 21% of sample households in our study reported having experienced an accidental fire in the past (Table 1).[11] Households also reported, on average, that they had not experienced an accidental fire in nearly six years. Reduced risk of accidental fire does not seem to diminish the importance of fire prevention (or of adhering to rules stipulated by the community accords); 73% of sample households reported clearing firebreaks during the past year. This is higher than in Sorrensen (2000), who finds that in the region to the north of the FLONA, only 25% of households engage in any type of fire prevention behavior (most of our sample used fire breaks, however). Interestingly, we find some apparent complementarity between use of forests on the smallholder lot and the propensity to install firebreaks. When we compare across households that do and do not install firebreaks in Table 1, we find that households who engage in fire prevention are more likely to hunt, fish, and collect non-timber forest products on their lot, but they are also more likely to have experienced accidental fire. Households that install firebreaks also tended to have lived on their lots longer, had larger plantations, and had higher income.

With these points in mind, we begin our econometric analysis by estimating a Tobit model of the crop production function explained by Eqs. (4a)–(4b) (Table 2). The dependent variable is the annual value of crops ($R) produced in the past year by the household.[12] Significant variables at the 10% level or better are the number of years household has lived on the current lot (+), the size of last year's agricultural plantation in hectares (+), mandays spent planting by the household (+), mandays spent harvesting by the household (+), mandays hired by the household (+), and the dummy variable for whether the household allocates labor to clearing firebreaks for the purposes of fire prevention (+) (i.e., the fire protection term in Eqs. (4a) and (4b)).

Signs of significant coefficients in our production function estimation are as anticipated. Positive and significant coefficients on planting, harvesting, and hired labor are expected within the framework of household utility maximization. Household expertise in the cultivation of particular crops and long-term investment in perennials

[8] Average household size and number of dependents are consistent with or slightly lower than averages obtained from other studies conducted in the region, while number of years on lot is longer for our sample (Perz and Walker, 2002; Vosti et al., 2003; Walker et al., 2002).

[9] Products commonly collected by sample households include açaí, bacaba, palha, breu, cipó, honey, leite de sucuba, piquiá, and uxí. A small number of households sell curaua (a type of fiber) and extract rubber.

[10] The area is bordered on the west by the Tapajós river and on the east by the Santarém-Cuiabá highway (BR-163) which crosses the Transamazon highway to the south of the FLONA. The reserve itself is approximately 150 km in length, and can be accessed by road from the north, by a road entering from the BR-163 at km 83, or by boat from the Tapajós river.

[11] Perz and Walker (2002) in their 1996 survey of Uruará households find that the same percentage of households in their sample (21%) have experienced fire prior to the 1996–1997 El Niño year, and Toniolo (2004) finds incidence of accidental fire to be significantly lower in communities with an element of common property structure, such as those within the FLONA. Additionally, because widespread burning occurred in the dry season of 2005, we would expect that the probability that a household would have experienced an accidental fire at some point to have been significantly increased in our sample since the 1996 and 2004 studies by Perz and Walker and Toniolo. Our incidence of accidental fire at 21% is also lower than the average obtained from more recent studies conducted in communities outside the FLONA — Perz (2004) finds that 28% of households in his Uruará survey have experienced damage to vegetation due to fire.

[12] This variable was constructed by applying the average of reported prices for each volumetric measure reported for each crop to the amount produced by the individual household in the past year. It has been calculated this way for production function estimation in other studies where several crops are produced by the household, as it accounts for differences in weights and units.

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Table 2 – Tobit estimation of the value of crop production

Independent variable	Coefficient
Number of years household has lived on lot	0.720*** (0.245)[a]
Sum of years of education of all household members	0.105 (0.267)
Household reported experiencing accidental fire in the past (0,1)	0.736 (0.520)
Size of agricultural plantation (last year) in hectares	2.154*** (0.694)
Days spent planting by all household members in the last year	0.641*** (0.199)
Days spent harvesting by all household members in the last year	0.226* (0.117)
Days hired by household in the last year	0.378** (0.187)
Hectares of land burned for planting of crops in the last year	0.009 (0.597)
Household clears land in firebreaks for fire prevention (1,0)	1.475** (0.590)
Sigma	2.794*** (0.164)

Functional form: log–log.
$n=206$.
LM test [df] for Tobit = 85.048[10].
Log likelihood = −443.0956.
*** <0.01, ** <0.05, * <0.10.
[a] Asymptotically robust standard errors of coefficients reported in parentheses.

might explain the positive contribution of time the smallholder has lived on the lot to agricultural production.[13] An interesting result for our purposes is the significant and positive relationship to production of household investment in fire prevention through clearing of firebreaks. This is one indication that the opportunity cost of labor spent in fire prevention and of land taken out of production is outweighed by the associated benefits to the sample household, or perhaps that increased investment in agriculture by the household is consistent with corresponding investments in fire prevention.

Tobit estimation of area of land burned for agricultural production in the last year is depicted in Table 3.[14] The dependent variable is the number of hectares burned for agriculture by the household during the past dry season. Significant variables at the 10% level or better are the household size (–), number of dependents younger than 15 (+), head of cattle owned by the household (–), shadow wage of planting labor (+), the hiring wage (–), the price of manioc flour (–), and whether the household hunts (–).

The effect of household size (–) and number of dependents (+) on the amount of land burned is to be expected; larger households are better able to use adult labor inputs for agricultural production, while households with a greater number of dependents may be more subsistence constrained and require more land for production. Households with more cattle may burn less land for agriculture as a result of the reduction in available labor time due to cattle management requirements. The negative relationship of the hiring wage to the amount of land burned for agricultural plantations may imply the use of hired labor in land clearing and burning activities — households that hire labor at a higher wage may therefore burn less or clear less land if this higher price reflects limited labor availability. The negative coefficient on manioc flour price is indicative of a negative relationship between land clearing for agriculture and degree of market

Table 3 – Tobit estimation of hectares of land burned for crop production

Independent variable	Coefficient
Household has access to Santarém by road to the North (four northernmost communities) (0,1)	−0.080 (0.252)[a]
Number of household members	−0.618** (0.255)
Number of children age <15	0.329* (0.174)
Number of years household has lived on lot	−0.125 (0.092)
Sum of years of education of all household members	0.182 (0.117)
Household reported experiencing accidental fire in the past (0,1)	−0.038 (0.581)
Head of cattle owned by household	−0.254** (0.128)
Shadow wage of planting labor ($R/day)	0.206*** (0.056)
Value of crops produced in the last year ($R)	0.055 (0.034)
Wage at which household hires labor ($R/day)	−2.083*** (0.715)
Household took out a formal loan in the past year (0,1)	−0.485 (0.319)
Exogenous income to the household in the past year ($R)	0.049 (0.038)
Price of manioc flour ($R/sack)	−0.954** (0.374)
Household collects non-timber forest products (predicted (0,1))	0.839 (0.997)
Household hunts (predicted (0,1))	−3.666*** (1.252)
Sigma	0.743*** (0.069)

$n=206$.
Functional form: log–log.
Log likelihood = −150.0228.
Selection Lambda = −0.617(0.845) is non-significant.
*** <0.01, ** <0.05, * <0.10.
[a] Asymptotically robust standard errors of coefficients reported in parentheses.

[13] The positive contribution of land tenure to agricultural production in this part of Brazil is well-documented in the literature (Perz and Walker, 2002; Caviglia-Harris, 2004; Perz, 2004).
[14] Tests ruled out selection bias in household burning and fire prevention regressions. Referring to Tables 4, selection parameters are insignificant when two-stage estimation of a Heckman Tobit model is used.

integration.[15] That is, households with better access to markets, and thus a higher price for agricultural products, burn a smaller area to satisfy their needs because they are better able to trade, are more efficient, and rely less on subsistence production. Households with a higher shadow wage of planting labor burn a larger area. This makes sense given the definition of the shadow wage in this type of model as the value marginal product from crop production; as the shadow wage increases, there are greater incentives to clear land for crop production. This clearly highlights the role access to labor markets plays in determining burning (a similar story will hold below concerning the fire prevention decision).

We consider hunting to be both a subsistence activity (food procurement) and a potential source of leisure for the household. Our results, which suggest that the more you hunt the less you burn, bear this out. If we also consider hunting to be an important subsistence activity, this negative coefficient implies households that rely more heavily on forest resources for animal protein are less likely to engage in burning behavior if it threatens standing forest reserves.[16] If indeed hunting is at some level a leisure activity, our results imply that households that are less time constrained, and this better able to indulge in leisure (hunting), will burn less.

To further examine determinants of household hunting and non-timber forest product collection, we present the results of Probit estimations of hunting and collection of non-timber forest products in Table 4. The dependent variables for both regressions are one if the household reported engaging in the activity and zero otherwise. Having experienced accidental fire is, in fact, the only positive predictor common to whether the household hunts or collects non-timber forest products. In a study of non-timber forest product collection in the FLONA, Pattanayak and Sills (2001) also found that households having experienced accidental fire were significantly more likely to engage in non-timber forest product collection. This supports the idea that households in our sample may use non-timber forest product collection to cope with the shock of accidental fire; hunting may also be employed for this purpose, but we find that motivations for hunting and non-timber forest product collection differ significantly in all other respects.

Other significant indicators at the 10% level or better for the household decision to hunt are number of cattle owned (–), whether the household took out a formal loan (–), and price of manioc flour (–). These variables may be a reflection of limited market integration of households that hunt, as hunting itself is an activity that relies on vast areas of intact forest. We find household collection of non-timber forest products to be complementary to other income diversification and risk management efforts engaged in by the household[17] such as accessing formal credit (+), and investment in crop production as reflected by the size of last year's agricultural plantation (+). Our results suggest that, for remote households such as those of the FLONA,[18] past experience with accidental fire and limited sources of exogenous income are related to household risk management of diverse forms, including the collection of non-timber forest products.[19]

Finally and most importantly, we turn to the results from Probit estimation of the household decision to engage in fire prevention and from Tobit estimation of household labor use on clearing firebreaks in the past year (Table 5). The dependent variable for the Probit estimation is one if the household reported spending any mandays in clearing firebreaks and zero otherwise, and the dependent variable for the Tobit estimation is the total number of mandays spent clearing firebreaks by the household. Variables in our Probit estimation that are significant at the 10% level or better are the shadow wage of planting labor (+), the price of manioc flour (+), and whether the household hunts (+). The shadow wage of planting labor (+) and whether the household hunts (+) remain significant in the Tobit estimation of household labor time spent clearing firebreaks.[20]

Important in both the Probit and Tobit estimations of fire prevention are the shadow wage of planting labor (+) and whether the household hunts (+). Like with the burning decision, as the shadow wage increases, households are more productive from a crop production perspective, and therefore we expect the greater firebreak application shown in Table 5. This is because households with higher shadow wages have greater incentives to protect production. We would expect higher shadow wages for those households with better access to crop markets or those with higher prices, or for those households who are more productive in their own fields.

Finally, given that hunting is reflective of a less-binding household time constraint and considered to be a subsistence activity, the household will be more likely to engage in fire prevention either as a result of greater time available, or due to

[15] Pendleton and Howe (2002) find increased rates of market integration to be positively related to household forest clearance, but find forest clearance and distance to market centers to be indirectly related. Land availability in this case may be an increasing function of distance from market centers, but is probably also related to land tenure and forest governance issues specific to the location of the study area.

[16] Pendleton and Howe (2002), in contrast, find level of hunting to be positively correlated with forest clearance.

[17] Other studies have considered the insurance role of non-timber forest product collection for households with limited market integration (McSweeney, 2004; Takasaki et al., 2004).

[18] Perz (2005) finds that household asset diversification, per sé, is not responsible for any differences in household welfare in the small-farm colony of Uruará along the Transamazon highway.

[19] Our measure of exogenous income was constructed by summing, for each household, formal and informal loans, and monetary gifts from family members.

[20] The inclusion of burned area in Table 5 as an explanatory variable, which is statistically insignificant, shows that the scale of burning does not appear to be an important determinant of the firebreak decision (this regression coefficient measures the effect of area burned holding all other variables constant). This makes sense given that most agricultural plots are fairly uniform across smallholders in our sample, and are typically quite small (ranging from less than 1 to 2 ha). Further, since fire breaks are a labor intensive activity, the use of labor as a dependent variable in the regression is essentially a proxy for area cleared.

Table 4 – Probit estimation of hunting and household collection of non-timber forest products

Independent variable	Probit estimation of Hunting		Probit estimation of collection of NTFP	
	Coefficient	Marginal effect	Coefficient	Marginal effect
Household has access to Santarém by road to the North (four northernmost communities) (0,1)	−0.247 (0.279)[a]	−0.061	−0.744* (0.409)[a]	−0.214
Number of household members	−0.104 (0.399)	−0.215	0.190 (0.457)	0.459
Number of children age <15	0.131 (0.271)	0.149	0.032 (0.309)	0.042
Number of years household has lived on lot	−0.084 (0.139)	−0.362	−0.048 (0.156)	−0.243
Sum of years of education of all household members	0.010 (0.175)	0.035	−0.186 (0.185)	−0.787
Household reported experiencing accidental fire in the past (0,1)	0.455* (0.251)	0.130	1.659*** (0.292)	0.554
Head of cattle owned by household	−0.422** (0.173)	−0.253	−0.077 (0.138)	−0.054
Size of agricultural plantation (last year) in hectares	−0.496 (0.367)	−0.259	0.765** (0.377)	0.466
Shadow wage of planting labor ($R/day)	0.088 (0.109)	0.248	−0.108 (0.114)	−0.356
Value of crops produced in the last year ($R)	0.022 (0.052)	0.159	0.035 (0.060)	0.292
Wage at which household hires labor ($R/day)	−1.152 (0.926)	−3.917	0.657 (1.153)	2.605
Household took out a formal loan in the past year (0,1)	−0.763* (0.404)	−0.163	0.849* (0.483)	0.211
Exogenous income to the household in the past year ($R)	0.062 (0.045)	0.213	−0.108* (0.060)	−0.435
Price of manioc flour ($R/sack)	−0.942** (0.442)	−4.699	0.300 (0.500)	1.747

$n=206$.
All independent variables in log form.
Hunting: Log likelihood = −101.3979.
Restricted log likelihood = −114.1638.
Percent dependent variable correctly predicted = 75.243.
NTFP collection: Log likelihood = −76.338.
Restricted log likelihood = −99.959.
Percent dependent variable correctly predicted = 84.951.
*** <0.01, ** <0.05, * <0.10.
[a] Asymptotically robust standard errors of coefficients reported in parentheses.

the reliance of standing forest resources as a source of animal protein for household members.

4. Economic parameters versus household characteristics

Our results appear to suggest that economic variables rather than household characteristics are most important in determining the area burned by the household and the application of fire prevention activities. We find that households with a higher shadow wage burn more land for agricultural production, but are also more likely to engage in fire prevention to protect their investments. These households engage in agricultural production to a greater extent, so this makes sense. Households that pay more for hired labor burn less land, and households that receive lower prices at market burn more land and engage in fire prevention to a lesser degree. These findings imply that access to well-functioning markets for labor and agricultural products may have conflicting effects on burning and fire prevention activities; readily available labor may allow a household to burn more land for production, yet higher market prices for agricultural goods such as manioc may leave the household better able to meet subsistence needs thereby providing for reduction in burning and increased fire prevention. Finally, households that hunt in their forest reserves burn less land area, while also engaging in fire prevention more frequently and to a greater degree than households that do not hunt, supporting either the idea that households that are less time constrained are better able to devote time to hunting and to fire prevention, or that households that place value on their forest reserves for non-timber production are more concerned with reducing the risk of accidental fire.

To formally test the extent to which economic variables or household characteristics drive our models, we can perform

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Table 5 – Household decision to allocate labor to firebreak clearing

Independent variable	Stage I Probit		Stage II Tobit
	Coefficient	Marginal effect	Coefficient
Household has access to Santarém by road to the North (four northernmost communities) (0,1)	0.537 (0.463)[a]	0.021	0.039 (0.182)[a]
Number of household members	0.500 (0.504)	0.164	0.308 (0.191)
Number of children age <15	0.008 (0.358)	0.001	−0.005 (0.132)
Number of years household has lived on lot	0.029 (0.175)	0.020	0.062 (0.069)
Sum of years of education of all household members	−0.011 (0.219)	−0.006	0.006 (0.084)
Household reported experiencing accidental fire in the past (0,1)	−0.744 (1.322)	−0.034	−0.268 (0.425)
Head of cattle owned by household	0.273 (0.270)	0.026	0.047 (0.096)
Hectares of land burned to create agricultural plantations in the past year (predicted value)	_0.286 (0.282)	−0.084	−0.063 (0.104)
Shadow wage of planting labor ($R/day)	0.769*** (0.155)	0.343	0.203*** (0.045)
Value of crops produced in the last year ($R)	−0.090 (0.067)	−0.101	−0.025 (0.027)
Wage at which household hires labor ($R/day)	2.641 (1.732)	1.416	0.815 (0.502)
Household took out a formal loan in the past year (0,1)	0.414 (0.075)	0.014	0.175 (0.238)
Exogenous income to the household in the past year ($R)	−0.060 (0.075)	−0.033	−0.016 (0.027)
Price of manioc flour ($R/sack)	1.462* (0.806)	1.151	0.360 (0.275)
Household collects non-timber forest products (predicted (0,1))	−0.252 (2.146)	−0.010	−0.069 (0.745)
Household hunts (predicted (0,1))	5.328* (2.806)	0.280	1.684* (0.907)
Sigma			0.643*** (0.039)

n=206.
All independent variables in log form.
Stage I Probit: Log likelihood=−68.843.
Restricted log likelihood=−113.013.
Percent dependent variable correctly predicted=81.068.
Stage II Tobit: Log likelihood=−196.4232.
LM test [*df*] for Tobit=61.688 [17].
Selection Lambda=0.079(0.244) is insignificant.
*** <0.01, ** <0.05, * <0.10.
[a] Asymptotically robust standard errors of coefficients reported in parentheses.

likelihood ratio tests by creating restricted models through dropping of either economic or household variables. The results are presented in Table 6.

Household characteristics dropped were household size and number of dependents, level of education, land tenure and past experience with fire. Economic parameters dropped

Table 6 – Likelihood ratio tests of household characteristics and economic variables in land burned and fire prevention regressions

	Land burned for agriculture	Labor allocated to firebreak clearing	
	Tobit	Probit	Tobit
Household characteristics[a]	8.658*	3.222	8.210*
Economic variables[b]	36.533***	56.622***	32.172***

[a] Household characteristics dropped for estimation of restricted models: sum of years of education, number of years household has lived on lot, number of household members, and number of dependents.
[b] Economic variables dropped for estimation of restricted models: hiring wage, shadow wage of planting labor, exogenous income, price of manioc flour, and value of crops produced in the last year.

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included the opportunity cost of household time, the hiring wage, the price of manioc flour, exogenous income, and the value of crops produced by the household in the last year.

Referring to the results, we find that likelihood ratio tests for household characteristics were insignificant in the Probit model for fire prevention, but were significant at the 10% level in determining the amount of land burned by the household for agriculture and the extent to which the household allocated labor to fire prevention. Economic variables were more significant than household variables for each of the decisions examined, confirming the importance of accommodating economic and market features in the design of any fire prevention policy. Clearly, one cannot ignore economic variables when predicting the propensity of households in our sample to make fire prevention decisions.

5. Conclusions

In this study, we estimate a subsistence model of household decisions made under risk of accidental fire. Decisions examined include burning land for agriculture, hunting on household forest reserves, collection of non-timber forest products, and most importantly the propensity to engage in the clearing of firebreaks (*aceiros*) for the purposes of fire prevention. We use data from 220 households in the Floresta Nacional do Tapajós in the state of Pará, Brazil. In contrast to other studies of fire use and accidental fire in the region that use a land-use/land-cover change framework or that focus mainly on household characteristics and social variables, we examine household use of fire for agricultural land clearing and use of fire prevention measures in a household utility maximization framework. We examine differences in household fire use and prevention behavior among a relatively homogenous group of subsistence households using similar crop and fire prevention production technologies. The relative lack of diversity in household livelihoods and income sources has allowed us to concentrate on the role of productivity in agriculture and other economic variables specific to the subsistence household in decisions made about fire use and fire prevention. We find economic variables such as the opportunity cost of household labor time, the hiring wage, and prices to be important drivers of household burning and fire prevention behavior. We also find that household experience with accidental fire increases household reliance on the forest for hunting and for non-timber forest product extraction.

The role of economic variables such as prices, wages, and household opportunity cost variables in determining household behavior with respect to fire use and prevention highlights the need for consideration of key economic variables in policy making. Increasing household productivity in terms of crops grown and harvested will increase fire prevention (although land clearing through burning will also increase). An example would be to find ways of increasing access to markets with stable prices for crops, as well as improving labor markets through better access and higher labor pools. Further, the results show that programs which improve household real incomes will likely support greater investment of smallholders in fire prevention, especially if coupled with programs and community associations that emphasize education. Possible instruments that would support these changes include cost or labor sharing for firebreaks, subsidies for investments in capital that would reduce the need for land clearing through improved productivity, and, most importantly, improvements in infrastructure that reduce travel times to markets and increase labor supply for existing settlements. Improvements in infrastructure could also open or make accessible through decreased travel time new markets for non-timber forest products and other forest-based production activities, which might provide further incentives for fire protection and reduced burning according to our results. Ultimately, these changes might reduce the danger of accidental fires and the damages caused as a result, although more work is needed to study the complex interaction of these decisions.

The limitations presented by studying fire use and prevention behavior of remote subsistence households in the FLONA lead to additional research issues. Elements of common property forests that prevail in the FLONA make it difficult to consider the role of private property rights and tenure security, but these could be important to decisions in other regions. Similarly, because ranching is not a primary land use in the FLONA, we are unable to carefully examine the role of pasture fires in household decision-making about fire prevention.

In order to more completely examine the role of economic variables in burning and fire prevention decisions of households, studies similar to this one could be conducted in regions with differing degrees of market integration and in regions where there is little work with fire prevention. Further, one could relax our assumption that the probability of accidental fire is exogenous to the household. While this is probably true for a single household, if many households cooperated, fire risk almost certainly depends on their collective action. Finally, our fire results could be integrated into a regional scale model of policy design. Nepstad et al. (2006) suggest that protected areas such as indigenous lands and national parks and forests are an effective way to curb incidence of accidental fire, and Campos and Nepstad (2006) highlight the importance of engaging small landowners in newly-proposed conservation initiatives that establish vast protected areas along the BR-163 in a new forest district. The drivers of fire that we identify clearly demonstrate that, in the presence of adequate information about fire, as communities have better access to labor and agricultural markets or become wealthier, they will engage in greater fire prevention activity. The extent to which this prevention reduces accidental fires remains as an interesting empirical future study.

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