SMALLHOLDER FIRE PREVENTION AND BURNING ACTIVITIES UNDER THE THREAT OF ACCIDENTAL FIRE: A HOUSEHOLD MODEL APPLICATION FROM THE TAPAJÓS NATIONAL FOREST IN THE STATE OF PARÁ, BRAZIL

by

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Smallholder fire prevention and burning activities under the threat of accidental fire: A household model application from the Tapajós National Forest in the state of Pará, Brazil

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Abstract

Land-clearing fires set by settlers in the Brazilian Amazon give rise to large scale wildfires that threaten mature forests, agricultural plantations, and settlement areas. Our purpose is to examine labor devoted to fire prevention (firebreak establishment) and burning for crop production for subsistence smallholders in the Tapajós National Forest in Pará, Brazil. Both the decision to engage in each activity and the scale of the activity are examined. A household model addressing decision-making under risk is estimated using survey data from 220 households. We find economic variables such as the opportunity cost of household time, market conditions, and the hiring wage to be important predictors of both decisions (often these are more important than household or demographic considerations), as is household reliance on standing forest resources for non-timber products. We also find that the involvement of NGOs and the government plays an important role in encouraging fire prevention behavior. Our results provide support for programs that emphasize economic parameters and for considering smallholder productivity in policies that target accidental fire prevention or reduction in burning activity.

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I. Introduction

Deforestation in the Brazilian Amazon region has become a concern to Brazil and to the rest of the world. The implications for global warming and biodiversity loss are troubling, and the social and economic contributors are complex (Keller et al., 2004, Carvalho et al., 2004). Slash-and-burn land clearing[1] is a primary contributor to deforestation in Brazil, giving rise annually to accidental wildfires affecting the landscape on a regional scale (de Mendonça et al., 2004). During dry years corresponding to El Niño events such as the 1997-1998 dry season and the 2005-2006 dry season, the largest of wildfires have extended up to 1000 km^2 threatening pasture, primary forests and settlement areas (Holdsworth and Uhl, 1997; Cochrane and Schulze, 1998). Because susceptibility of forest land to wildfire increases in areas that have been previously burned, logged, and fragmented, a positive feedback loop is created whereby forests are degraded, burned, and converted to alternative land uses (Nepstad et al., 2001; Barlow and Peres, 2004; Uhl and Kauffman, 1990).

The costs of widespread fire in the region are economic and social in addition to environmental. Vast clouds of smoke from widespread burning may result in increased incidence of respiratory illness, airport closings and other transportation impediments, as well as exacerbated drought conditions. Small

[1] Slash-and-burn agriculture as used in this paper should not be equated with traditional shifting cultivation. It is, rather, an intermediate between traditional shifting cultivation and permanent high-yield agriculture as described by Boserup (1965) and Boserup (1981) (see also Salehi-Isfahani 1988). Households in this study clear primary forest or areas regenerated in secondary succession within their informal property boundaries using slash-and-burn technology. More extensive forms of cultivation employing plowing and fertilization are not observed.

landowners sustain crop losses, short-term degradation of pasture for livestock, fence-post damage, and loss of timber resources and non-timber forest products in their legal reserves (de Mendonça et al., 2004). Forest industry may lose marketable timber as a result of tree death from forest understory fires, which are becoming increasingly prevalent. Fire is therefore a risk to human health, farmer welfare, and economic development, as well as a key player in deforestation and environmental degradation.

Slash-and-burn and pasture fires are used as a land management tool in the Brazilian Amazon for the clearing of forested land and for the maintenance of cleared areas for agricultural use. Fire use by small landowners is an important substitute for mechanical and chemical inputs in the production process and for human labor in the land-clearing process (Varma, 2003). Because of the incentives to burn, the potential for policies that can target reduction of wildfire risk is high. Policies that promote low-impact selective logging may reduce fire risk (Holdsworth and Uhl, 1997). The enforcement of property rights and the implementation of programs designed to educate landowners about burning may encourage increased investment in fire prevention and in community associations that target fire reduction (Nepstad et al., 2001).

Our purpose is to examine the use of fire in the production process and the fire prevention behavior of smallholders in the Brazilian Amazon. We study these aspects of smallholder behavior using a survey questionnaire collected from 220 households in 15 communities of the Floresta Nacional do Tapajós (hereby referred to as the 'FLONA') in the state of Pará, Brazil. Communities in the FLONA present a unique opportunity to study the drivers of fire prevention behavior, because smallholders there face low levels of accidental fire risk and tend to engage in high levels of prevention behavior when compared to studies of fire in larger settlements along the Transamazon, or in areas to the north of the FLONA. Further, the active work of the Brazilian environmental regulatory agency IBAMA (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis), IPAM (Instituto de Pesquisa Ambiental do Amazônia), and other NGOs in the Floresta Nacional do Tapajós allows us to address the role of education and community involvement by these organizations in influencing household burning and fire prevention behavior while controlling for various economic factors.

Our approach follows the well-known theory of economic household modeling. We use household data to estimate a subsistence household model of expected utility maximization with 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 Jacoby, 1993; Singh et al., 1986). Several studies have used economic household survey data in the Brazilian Amazon to address the role of risk and income in smallholder decision-making. Caviglia-Harris (2004) incorporates risk into a household model to study its effects on smallholder forest clearance, finding that participation in milk markets and concentration on cattle ownership increases both the stock deforested and percent deforestation by these households. Using household data from the municipality of Uruará in the state of Pará, Perz (2004) finds agricultural diversification to be positively related to smallholder income, and both income and agricultural diversification to be negatively related to forest cover.

Studies of fire and smallholders in the Amazon region find that smallholder burn efficiency is high (46.7% to 57.5%) and that accidental fire is a frequent and serious occurrence, often causing smallholders to weigh the dangers associated with burning during the dry season against the benefits of increased burn efficiency during this period (Sorrenson, 2000). Toniolo (2004) goes further to characterize fire prevention behavior of smallholders, including their use of *aceiros* (clearing of vegetation around an area intended for burning), *vigia* (watching of fires to keep them from spreading), group burning or communication with neighbors, and careful timing of burnings to coincide with low wind speeds or a recent rain event.

While a vast body of evidence suggests that the degree of economic risk posed by risk of accidental fire to smallholders in the Brazilian Amazon region is high, studies of the fire prevention and burning tendencies of smallholders in the face of accidental fire risk are absent from the economic household literature. Existing studies focusing on fire use and smallholder behavior in the region neglect to consider important economic variables related to fire prevention and burning decisions, and we find no literature that addresses the linkages between fire prevention, household production, land clearing, and the allocation of labor time for smallholders in Brazil or elsewhere. Thus, our application of smallholder survey data to the modeling of household decisions regarding fire prevention activities and burning behavior is a novel and important contribution to the literature. This analysis will provide empirical guidance for policy instruments currently being considered and for those already in place that attempt to target reduction in smallholder incentives for burning and promote investment in fire prevention measures in the region.

II. Smallholder decision-making under uncertainty

In order to assess the role of fire risk in smallholder decision-making we first develop a suitable household subsistence framework. Decision-making by the subsistence household assumes an expected utility maximization framework comprised primarily of on-farm own labor allocation between various productive activities and time allocated to leisure (Jacoby, 1993). Central to econometric applications of household models when labor markets are found to be incomplete is the estimation of a 'shadow wage,' which expresses the opportunity cost of time of adult labor to household production. Jacoby (1993) shows that the empirical realization of the shadow wage is simply the value marginal product of labor as allocated to on-farm labor activities. We assume incomplete labor markets in our sample because smallholders routinely have difficulty obtaining off farm work given that settlements are spread over large areas, and transportation costs and infrastructure are such that off-farm wage employment opportunities are extremely limited in the FLONA. In most cases, off farm work is accomplished via the smallholder traveling to the relatively distant city of Santarém during the off-season to work for extended periods. The estimation of a shadow wage rather than use of a market wage becomes necessary under these circumstances.

Many household studies have addressed how varying degrees of integration into formal labor markets affect household decisions such as level of forest clearing and the corresponding effects on household income and welfare (Shively, 2001a; Pendleton and Howe, 2002; Shively and Fisher, 2004; Angelsen, 1999). The application of household models to examine effects of market characteristics, land policy, technological change and conservation initiatives on subsistence households provides us with a starting point to assess the ways in which accidental fire, fire prevention, and slash-and-burn agriculture enter into the household decision-making process.

The introduction of fire risk into the traditional agricultural household model framework presents itself as a natural extension of the existing literature. Subsistence households face diverse risks including illness (Amacher et al., 2004), crop loss (Kochar, 1999; Fafchamps, 1993), price stochasticity (Barrett, 1999 & Saha, 1994), land confiscation (Amacher et al., 2004) and environmental disasters (Takasaki et al., 2004; Rosenzweig and Binswanger, 1993). It has been demonstrated that household behavior diverges from that of profit maximization in the presence of risk (Barrett, 1999), and subsistence households are therefore assumed to be risk averse. Tradeoffs associated with risk mitigation are reflected in smallholder reluctance to adopt newer or riskier technologies (Shively, 2001b & Amacher et al., 1992), and in risk aversion to potentially productive but less secure economic opportunities (Morduch, 1995 & Rosenzweig and Binswanger, 1993).

Household responses to risk are diverse and include household saving and asset accumulation (Behrman et al., 1997), diversification of production (Rosenzweig and Binswanger, 1993), or increased labor market participation (Bluffstone, 1995 & Rose, 2001). Additionally, households may receive gifts or loans in response to an adverse shock from friends or family members in a sort of informal credit arrangement (Howe, 2003). Sales of assets such as livestock (Fafchamps, 1998), increased forest clearing (Pendleton and Howe, 2002; Anglesen, 1999; Amacher et al., 2004), non-timber forest product collection (Pattanayak and Sills, 2001 & McSweeney, 2004) or increases in hours of work (Kochar, 1999) are other methods employed by the small farm household to hedge against the presence of risk.

III. A household model with risk of accidental fire

As previously discussed, our purpose is to develop a model to be investigated empirically that expands upon a classic household expected utility maximization problem to include exogenous risk of accidental fire. We are primarily interested in examining the household choice variables of labor spent in fire prevention, land area burned to create agricultural plantations, and labor allocated to non-timber forest product collection in the presence of accidental fire risk. Assume that household decisions are made ex-ante to the realization of accidental fire in a given year. Let the exogenous probability of an accidental fire occurring be denoted P, such that $(1-P)$ is the probability that a smallholder does not experience accidental fire in the next year. The expected level of household utility is defined by the probability that the household experiences a fire multiplied by the utility obtained in the case of fire (U^F) plus the probability that the household does not experience a fire multiplied by the utility obtained without fire (U^O),

$$U = P \cdot U^F(\cdot) + (1-P) \cdot U^O(\cdot). \tag{1}$$

The concave utility function of a representative smallholder in our sample is assumed to be an increasing function of its arguments in each case:

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

where utility is derived from consumption of agricultural goods, Q_c, non-timber forest products, N, and other goods, X, as well as from leisure time, l, which is equivalent to the total time allocation to the household minus time spent in household labor activities ($l = T - L$), where T is total time and L is a vector of labor time spent in agriculture, non-timber forest product collection, and in fire prevention. Smallholder 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 non-timber forest 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 afforded by fire prevention exercised by the household. Fire prevention, α, increases household production possibilities should a fire occur and is assumed to be an increasing function of household labor spent in fire prevention, $\alpha \equiv \alpha(L_p)$, where $\alpha(L_p)$ represents some protection to non-timber forest goods afforded by fire prevention, and where $\alpha'(L_p) > 0$ and $\alpha''(L_p) < 0$. Non-timber forest production by the household in non-fire and fire cases is then written:

$$N^O \equiv N(L_N, A_F; \Omega) \text{, and} \tag{3a}$$

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

Agricultural production in the case of accidental fire (Q_p^F) and without (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 purposes of the model, we assume land area burned for agriculture is equivalent to the area planted by the household.[2] As in the case of non-timber forest production, we include level of fire prevention, $\alpha(L_p)$, in the agricultural production function in the case of accidental fire, so that:

$$Q_p^O \equiv Q_p[A_B, K, L_A, L_H; \Omega] \text{, and} \tag{4a}$$

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

Fire prevention represents an opportunity cost to both smallholder 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 the household land available for production, ($A_B \equiv A - A_F - A_E$), where A is the total endowment of land in hectares, A_B is area burned for agriculture, A_F is land area in forest, and A_E is area cleared as a firebreak, or 'aceiro'. A_E is simply a direct function of labor allocated to fire prevention ($A_E \equiv A_E(L_p)$) because this activity is largely labor dependent.

The household cash budget constraint becomes:

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

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.

[2] We later relax this assumption in our econometric analysis.

The household maximizes (1) subject to (3a)-(3b), (4a)-(4b), (5), the exogenous probability of accidental fire (P), and a non-negativity constraint for fire prevention labor ($L_p > 0$). The smallholder expected utility maximization problem can be written formally as:

$$
\begin{aligned}
\underset{\{A_B, L_p, L_N\}}{Max}\,\zeta = \; & P \cdot U^F[X, N^F(\alpha, L_N, A_F; \Omega), Q_c^F, l; \Omega] + (1-P)U^O[X, N^O(L_N, A_F, \Omega), Q_c^O, l; \Omega] \\
& + \lambda \begin{bmatrix} P_c[P(Q_p^F[\alpha, A_B, K, L_A, L_H; \Omega] - Q_c^F) \\ +(1-P)(Q_p^O[A_B, K, L_A, L_H; \Omega] - Q_c^O)] \\ + I - w_H L_H + p_x X] \end{bmatrix} + \gamma L_p + \mu(T - L_A - L_P - L_N)\,,
\end{aligned} \tag{6}
$$

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. The first order conditions of (6) with respect to area burned for agriculture (A_B) and labor allocated to fire prevention (L_p), can be obtained following substitution of the land constraint ($A_B \equiv A - A_F - A_E(L_p)$) and production functions (4a)-(4b) into (5):[3]

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

$$\frac{\partial \zeta}{\partial L_N} = P\left(\frac{\partial U^F(\cdot)}{\partial N^F}\frac{\partial N^F(\cdot)}{\partial L_N}\right) + (1-P)\left(\frac{\partial U^O(\cdot)}{\partial N^O}\frac{\partial N^O(\cdot)}{\partial L_N}\right) - \mu = 0 \tag{7}$$

Thus, the utility maximizing smallholder 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 smallholder non-timber forest product collection decision.

$$\frac{\partial \zeta}{\partial A_B} = -P\left(\frac{\partial U^F(\cdot)}{\partial N^F}\frac{\partial N^F(\cdot)}{\partial A_F}\right) - (1-P)\left(\frac{\partial U^O(\cdot)}{\partial N^O}\frac{\partial N^O(\cdot)}{\partial A_F}\right) + \lambda P_c\left[P\left(\frac{\partial Q_p^F(\cdot)}{\partial A_B}\right) + (1-P)\left(\frac{\partial Q_p^O(\cdot)}{\partial A_B}\right)\right] = 0 \text{, and} \quad (8)$$

$$\frac{\partial \zeta}{\partial L_p} = A_E'(L_p)\left[-P\left(\frac{\partial U^F(\cdot)}{\partial N^F}\frac{\partial N^F(\cdot)}{\partial A_F}\right) - (1-P)\left(\frac{\partial U^O(\cdot)}{\partial N^O}\frac{\partial N^O(\cdot)}{\partial A_F}\right)\right] + P\alpha'(L_p)\left(\frac{\partial U^F(\cdot)}{\partial N^F}\right) + \lambda A_E'(L_p)P_c\left[-P\left(\frac{\partial Q_p^F(\cdot)}{\partial A_B}\right) - (1-P)\left(\frac{\partial Q_p^O(\cdot)}{\partial A_B}\right)\right] + \lambda P_c P\alpha'(L_p)Q_p^F + \gamma - \mu = 0. \quad (9)$$

The interpretation of (8) is straightforward. The smallholder 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 smallholder utility from decreased non-timber forest product collection on less forested land resulting from increased land burned. Condition (9) shows that the smallholder will undertake fire prevention so as to equate the expected marginal benefits 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 to utility (through a decrease in non-timber forest product collection) of clearing aceiros (the two terms that include $A_E'(L_p)$) and the opportunity cost of time.

Condition (9), the first order condition for labor allocation to fire prevention, can be rearranged to obtain the corner solution. Here, $L_p = 0$, and thus γ in (9) is strictly positive. In this case, for (9) to hold, it must be true that:

$$P\alpha'(L_p)\left(\frac{\partial U^F(\cdot)}{\partial N^F}\right) + \lambda P_c P\alpha'(L_p)Q_p^F <$$

$$\left\{ \begin{array}{l} A_E'(L_p)\left[P\left(\frac{\partial U^F(\cdot)}{\partial N^F} \frac{\partial N^F(\cdot)}{\partial A_F} \right) + (1-P)\left(\frac{\partial U^O(\cdot)}{\partial N^O} \frac{\partial N^O(\cdot)}{\partial A_F} \right) \right] \\ + \lambda A_E'(L_p) P_c \left[P\left(\frac{\partial Q_p^F(\cdot)}{\partial A_B} \right) + (1-P)\left(\frac{\partial Q_p^O(\cdot)}{\partial A_B} \right) \right] + \mu \end{array} \right\} \quad \Leftrightarrow \quad L_p = 0. \tag{10}$$

Thus, the smallholder will not engage in fire prevention if the sum of the indirect expected marginal benefit to utility from the effect of fire prevention on non-timber forest product collection in the case of fire and the direct expected marginal benefit to income from the effect of fire prevention on agricultural production in the case of fire 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 to available agricultural land from land cleared for fire prevention, plus the opportunity cost of household time, μ. If this is not true, and L_p >0, then we can assume that the multiplier on the non-negativity constraint for fire prevention labor, γ, will be zero and the smallholder will allocate labor to fire prevention according to (9), above.

Our task is to estimate equations explaining the decision to engage in fire prevention and labor time spent in fire prevention, as well as the decision to burn, land area burned, and the decision to collect non-timber forest products using smallholder survey data. Equation (9) can be estimated using a Probit regression, with the dependent variable defined as one if the smallholder engages in fire prevention and zero otherwise, and where explanatory variables are those variables important to utility, prices, production and fire related variables, and opportunity cost of time variables. From (9) we expect participation to increase as the smallholder'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. If participation occurs, then the smallholder's level of fire prevention will be determined by these variables. Thus, the corresponding econometric model for fire prevention consists of two equations:

$$\Pr(L_p = 1) = \frac{e^{\beta Z}}{1 + e^{\beta Z}} \text{, and} \tag{11}$$

$$L_p = G(Z, \alpha; \varepsilon) \; if \; L_P > 0 \text{,} \tag{12}$$

where (11) assumes an error from an extreme value distribution, and ε has a censored Normal distribution. Equation (11) is the participation Probit regression, and equation (12) is the level of participation estimated as a Tobit model to account for censoring of the dependent variable, conditional on fire prevention being observed for the smallholder in the sample. The parameter β is a vector of coefficients to estimate in the participation decision, α is a vector of coefficients to estimate for the level of participation, Z is the vector of explanatory variables suggested by the above first order conditions, and $G(.)$ is a reduced form equation containing the same explanatory variables as the discrete decision to participate in (11). The land burning participation and level decisions can be examined in a similar manner, with explanatory variables following from equation (8).

There are several econometric issues to address when estimating the above equations. First, some of the explanatory variables in Z are potentially endogenous and correlated with the errors implicit in each decision. These include household income, the smallholder 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 (8)-(10)). 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. 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 smallholders 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 both the fire prevention and land burning decisions, since not all households in the sample engaged in these activities. Selection bias implies that 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 (11) and (12), as well as for the land burned decision (e.g., see Greene, 1997). We will test for selection bias by estimating a Tobit type II model and examining the significance of the selection parameter. As we will discuss later, these parameters were insignificant for all decisions where non-participation was observed, confirming the approach set forth in (11)-(12). Finally, heteroskedasticity may be present in the cross sectional data, and we will correct for this using White's consistent covariance method.

IV. Data and Descriptive Statistics

In order to estimate the above decisions, a recall-based questionnaire was applied to smallholder households by a team of six enumerators in March and April of 2006. The sample consisted of 220 households in 15 communities within the Floresta Nacional Tapajós in the state of Pará, Brazil (Figure 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 activities. Interviews were conducted during the wet season, so that the year's worth of information collected pertained to the last dry season and preceding wet season of 2005 (see Appendix A). Sampling was conducted by first opportunity, and all households approached agreed to be interviewed. This type of approach has been used before in sampling of rural households (See e.g. Godoy, 1998; McSweeney, 2004; Perz, 2004; and Perz, 2005). Our sample of 220 households is a representative one of the approximately 500 households in the FLONA by virtue of the high percentage of total households sampled, and because households were sampled in all accessible communities.[4] Household characteristics of our data such as household size, number of dependents and land tenure are similar to Pattanayak and Sills (2001) and Sills and Harris (2005). Moreover, there is no variation in the types of smallholder systems or types of inputs used by households in the FLONA.

Detailed information was also collected about time spent in a range of labor activities for each member of the household as well as area planted and amount produced, bought, and sold for each crop and consumer agricultural good. Price information was recorded (when available) for agricultural goods, fish, and non-timber forest products. A major portion of the questionnaire was

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[4] Pattanayak and Sills (2001) assume a population size of approximately 3,000 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.

dedicated to the burning and fire prevention behavior of the household. This segment 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 called 'aceiros', an easily quantifiable form of investment in fire prevention.[5] In addition, we collected information about household experience with accidental fire. We present descriptive sample statistics in Table 1, and proceed with a discussion of sample households.

In 1974, The Floresta Nacional Tapajós became the first state environmental reserve created in the legal Amazon region of Brazil (Ioris, 2005). The FLONA was created to promote frontier expansion in the Amazon region as well as to encourage extraction of valuable timber resources. 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, the average sample household contains 4.81 members, approximately two of which are dependents under the age of 15.[6] Access to secondary education is limited but improving—elderly household members

[5] The practice of clearing an aceiro is a widely used and labor-intensive type of fire prevention incorporated by households in our sample, whereby the household clears a firebreak of .5-5m around agricultural plantations or around the area to be burned (Toniolo, 2004)

[6] Average household size and number of dependents are consistent with or slightly lower than averages obtained from other studies conducted of subsistence households in the region, while number of years on lot is longer for our sample (Walker et al., 2004; Perz and Walker, 2002; Vosti et al., 2003).

frequently reported only 1-2 years of education while many current dependents had received secondary schooling.

Most households practice subsistence agriculture, with manioc flour being the primary crop grown for sale. Some households hunt (24%) or collect non-timber forest products (19%), and virtually all households engage in crop production. Many engage in fishing for household consumption, and the majority of non-timber forest product collection is for household consumption.[7] Threats to agricultural crop production include accidental fire and pests such as leaf-cutter ants. Ranching is not a predominating land use in the area (4 head of cattle are owned per household, on average), but many households have cattle, chicken, or ducks.

With respect to infrastructure and market proximity, 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.[8] Eighteen percent of sample households were located in the four northernmost communities of the national forest, and these are therefore the four communities closest to Santarém (see Figure 1). For our purposes, these communities were considered to have

[7] Products commonly collected by sample households include açaí, bacaba, palha, breu, cipó, mel de abelha, leite de sucuba, piquiá, and uxí. Some households sell curaua (a type of fiber), and others extract rubber (seringa) or establish groves of trees for extraction.

[8] The FLONA Tapajós 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.

improved market access in comparison to communities located along the river bank or to communities located close to the road entering at km 83. [9]

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 working in the area. The active presence of IBAMA and other organizations is particularly relevant when studying fire prevention in the region; programs targeting burning behavior have been implemented in recent years by IBAMA and by the Instituto de Pesquisa Ambiental da Amazônia (IPAM), a non-governmental organization. Work in communities by these organizations and the development of local community organizations has been promoted as one strategy to limit use of fire for land clearing and to encourage investment in fire prevention by communities and by individuals, but studies concerning the effectiveness of this involvement have been inconclusive (Simmons et al., 2004). Tied to the involvement of IBAMA and IPAM in the FLONA is a system of acordos comunitarios (community agreements) adopted by most communities which stipulate specific precautions to be taken when burning. A high percentage of our sample households (84%)

[9] Presence of a road may be only a limited indicator of market access, particularly during the wet season when roads are often impassable.

cited being aware of the fire prevention work of IBAMA or of IPAM in their community.

Because of the heavy organizational presence and work with communities on fire prevention techniques that is unique to the FLONA, we asked households as part of the interview to list all organizations working with fire in their community. As mentioned previously, there are two major organizations working with fire (IPAM, IBAMA)—yet the specific programs targeting fire prevention (PREV-FOGO, Bom Manejo do Fogo) were also listed as additional responses in this open ended question. From this question, we constructed a measure of household knowledge about the involvement of these organizations as well as a measure of the presence of the organizations in the area.[10]

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.[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

[10] A household that listed all four entities (IPAM, IBAMA, PREV-FOGO, Bom Uso do Fogo) received a four for the variable 'number of organizational entities listed as working with fire in their community,' even though there may be only two distinct organizations at work in the area.

[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. Our incidence of accidental fire at 21% is lower than the average obtained from studies conducted in communities outside the FLONA Tapajós in the last five years—Perz (2004) finds that 28% of households in his Uruará survey have experienced damage to vegetation due to fire.

to diminish the importance of fire prevention (or of adhering to fire prevention rules); 73% of sample households reported clearing aceiros during the past year. This is higher than in Sorrenson (2000), who finds that in the region to the north of the FLONA, only 25% of smallholders engage in any type of fire prevention behavior. Roughly a third of sample households (35%) report that they burned land to create agricultural plantations during the past dry season. This would indicate that many households in our sample engage in fire prevention even in years when they do not burn to clear land for agriculture.

V. Results

Table 2 reports results from estimation of a Tobit model of smallholder agricultural production (Equations (4a)-(4b)).[12] The dependent variable is the annual value of crops ($R) produced in the past year by the household.[13] Variables in the agricultural production function estimation that are significant 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 (roça) in hectares (+), mandays spent planting by the household (+), mandays spent harvesting by the household (+), mandays hired by the household (+), and the dummy variable for

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[12] Because nearly all households reported producing agricultural goods we use a Tobit estimation of production.

[13] 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.

whether the household allocates labor to clearing aceiro for the purposes of fire prevention (+).

Signs of significant coefficients in our estimation of the household agricultural production function 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 might explain the positive contribution of land tenure to agricultural production.[14] An interesting result for our purposes is the significant and positive relationship to production of household investment in fire prevention through clearing of aceiros. We suggest that 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 accompanied by a corresponding investment in fire prevention.

Probit estimation of the household decision to burn land for creation of agricultural plantations in the last year and Tobit estimation of amount of land burned for this purpose in the last year are depicted in Tables 3 and 4.[15] The dependent variable for the Probit regression equals one if the smallholder

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[14] The positive contribution of land tenure to agricultural production in this part of Brazil is well-documented in the literature (Caviglia-Harris, 2004; Perz, 2004; Merry and Amacher, 2006; Perz and Walker, 2002).

[15] Selection bias for smallholder burning and fire prevention regressions was determined to be insignificant. The selection parameters are insignificant (see notes of Tables 4 and 7) when two-stage estimation of a Heckman Tobit model is used.

burned land for agriculture in the past dry season and zero otherwise. The dependent variable for the Tobit estimation is the number of hectares burned for agriculture by the smallholder during the past dry season. Significant to the household decision to burn land for agricultural plantations in the last year at the 10% level or better are the number of years household has lived on the lot (-), the hiring wage (-), shadow wage of planting labor (+), household size (-) and number of dependents (+), value of crops produced in the last year (+), and whether the household hunts (-). The wage at which household hires labor (-), the shadow wage of planting labor (+), number of household members (-), number of dependents (+), value of crops produced in the last year (+),the price of manioc flour (-), and whether the household hunts (-) are also determinants of how much land was burned by the household for agricultural plantations in the last year.

The negative coefficient on land tenure in our Probit estimation of whether the household burned land during the last year for agricultural plantations may reflect the positive relationship between amount of time on lot and smallholder deforestation;[16] households with more years on their lot burn less land for agriculture because it is already deforested.[17] The effects of household size (-) and number of dependents (+) on the decision to burn and on

[16] See for example: Merry and Amacher (2006), Godoy et al. (1998), and Pichón (1997).
[17] Due to inconsistent household responses about total land clearing and a sense of common property that prevails within the FLONA Tapajós, we are unable to directly examine the relationship between area of land already cleared and whether the household burned in the last year.

amount of land burned are also to be expected; larger households are better able to use adult labor inputs for agricultural production, while a greater number of dependents may cause the household to rely more heavily on clearing of additional land for subsistence.

The negative relationship of the hiring wage to the probability that the household burns and the amount of land burned for agricultural plantations may indicate a decreased investment in agriculture productivity by those who rely on fire for land clearing, and the weak significance of the negative coefficient on the price of manioc flour in the Tobit estimation probably reflects a negative relationship between additional land clearing for agriculture and degree of market integration.[18] In both estimations, we find households that realized higher levels of agricultural production following last year's wet season were more likely to burn land. This supports the finding that households with a higher shadow wage of planting labor are more likely to burn land and to burn a greater land area for agriculture when compared to less productive households, highlighting the importance of the economic approach to understanding incentives for burning.

We consider hunting to be both a subsistence activity (food procurement) and a potential source of leisure for the household.[19] This said, the negative

[18] Pendleton and Howe (2002) find increased rates of market integration to be positively related to smallholder forest clearance, but find forest clearance and distance to market centers to be indirectly related. We speculate, as they do, that land availability is an increasing function of distance from market centers.
[19] Merry and Amacher (2006) also consider hunting to be a potential leisure activity.

coefficient on hunting in the burning regressions suggests that households that are less time constrained (and therefore better able to engage in leisure activities) will be less likely to burn land to create agricultural plantations. Additionally, if hunting is considered 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.[20]

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 5. The dependent variables for both regressions are one if the smallholder 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. We suggest that hunting is also employed for this purpose, but

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

find that motivations for hunting and non-timber forest product collection in all other respects differ significantly.

Variables significant at the 10% level or better for the household decision to hunt are number of cattle owned (-) and price of manioc flour (-). These appear to reflect the limited market integration of households that hunt, as hunting itself is an activity that relies on vast areas of intact forest. We also find household collection of non-timber forest products to be complementary to other income diversification and risk management efforts engaged in by the household[21] such as accessing formal credit (+), burning to improve quality of pasture (+) (which implies household emphasis on livestock),[22] 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,[23] 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.[24]

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[21] Other studies have considered the role of non-timber forest product collection in household subsistence, demonstrating that for households with limited market integration, non-timber forest products may serve as a form of natural insurance (McSweeney, 2004; Takasaki et al., 2004).

[22] Fafchamps et al. (1998) demonstrate that household investment in livestock plays a partial role in ex-ante risk management behavior of the subsistence household.

[23] 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.

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

Finally, we examine the results from Probit estimation of the household decision to engage in fire prevention (Table 6) and from Tobit estimation of household labor expenditure on clearing of aceiros in the past year (Table 7). The dependent variable for the Probit estimation is one if the household reported spending any mandays in clearing aceiros and zero otherwise, and the dependent variable for the Tobit estimation is the total number of mandays spent clearing aceiros by the household. Variables in our Probit estimation that are significant at the 10% level or better are the shadow wage of planting labor (+), number of organizational entities listed by the household as working with fire (+), price of manioc flour (+), and whether the household hunts (+). The shadow wage of planting labor (+), number of organizational entities listed by the household as working with fire (+), and whether the household hunts (+), remain significant in the Tobit estimation of household labor time spent clearing aceiros.

Important in both the Probit and Tobit estimations of fire prevention are the shadow wage of planting labor (+), the number of organizational entities listed by the household as being involved with fire prevention (+), and whether the household hunts (+). The importance of the shadow wage for planting indicates that more productive households, which were significantly more likely to burn land, are also more inclined to engage in fire prevention. Again, we suspect that if hunting is reflective of a less-binding household time constraint or considered to be a subsistence activity, the household will be more likely to engage in fire prevention either as a result the less-binding household time constraint or due to reliance on standing forest resources as a source of animal protein. Household awareness of organizations working with fire is unambiguously linked to greater household fire prevention, both in determining whether the household clears aceiros and how much labor they allocate to doing so.[25]

VI. The importance of economic variables *vs*. household characteristics

In general, our results confirm that economic variables rather than household characteristics appear to be most important in determining household behavior with respect to fire prevention and slash-and-burn land clearing. We find that more productive households are more likely to burn land for agriculture, but also are more likely to engage in fire prevention to protect their investments. Households that hire labor at a lower rate and receive lower prices at market are more likely to burn land, burn more land, and engage in fire prevention less often. Yet, remote households that hunt in their forest reserves burn less frequently and burn less land area, while also engaging in fire prevention more frequently and to a greater degree than households that do not hunt.

Involvement in community agreements that mandate fire prevention and increased knowledge about costs, benefits, and techniques for fire prevention (at

[25] As previously discussed, the variable 'number of organizational entities listed by the household as working with fire' is not purely a measure of the active presence of IBAMA and NGOs in the area, but rather also potentially a measure of household community involvement and knowledge about accidental fire and fire prevention.

least in the case of clearing of aceiros) are effective in increasing both probability that the household engages in fire prevention and how much time is allocated. This result lends support to recent efforts by IBAMA and IPAM to educate landowners about the dangers of accidental fire and the benefits of fire prevention in communities of the FLONA. We do not find, however, that household awareness of the community agreements or work with fire prevention in the region has any effect on whether the household uses fire for land clearing for agricultural plantations or how much land the household burns. This would suggest that educational programs and community agreements may be effective in encouraging fire prevention behavior and may thereby reduce risk of accidental fire in the area, but are probably not directly affecting the degree of deforestation from intentional clearing for agricultural production.

Again, especially with respect to fire prevention behavior, we find that household characteristics such as household size and number of dependents, level of education, land tenure and experience with fire are generally not statistically significant in determining fire prevention and burning behavior, and further these are overshadowed by economic variables such as the marginal productivity of the household, reliance on standing forest reserves for hunting, and fire-specific education and community involvement of IBAMA and IPAM. While we anticipated that past household experience with accidental fire would be an important determinant in household fire prevention behavior, there is no indication that experience with accidental fire motivates decision-making about current investment in fire prevention for communities in the FLONA Tapajós.

In order to formally examine the extent to which economic and household variables are important to the household decisions to burn and to engage in fire prevention, we present likelihood ratio test statistics in Table 8. The table elements were computed by dropping groups of household characteristic variables and economic variables and then testing these restricted models against the unrestricted regressions presented earlier. We find likelihood ratio tests for household characteristics were insignificant in Probit and Tobit models for fire prevention. Household characteristics were significant at the 10% level in determining the decision to burn, but were insignificant in determining the extent of burning. Economic variables, in contrast, were highly significant at the 1% level for all of the decisions examined, confirming the importance of accommodating economic and market features in the design of any fire prevention policy.

VII. Conclusions

In this study, we estimate a subsistence model of household decisions made under risk of accidental fire with data from 220 households in the Floresta Nacional do Tapajós in the state of Pará, Brazil. We focus on household decisions regarding burning land for agriculture, hunting on smallholder forest resources, collection of non-timber forest products, and the propensity to engage in the clearing of firebreaks (acieros) for the purposes of fire prevention. 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 slash-and-burn agriculture 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. 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. Similarly, the active work with fire prevention by organizations in the region has allowed us examine the effectiveness of this involvement within an economic context. Our work improves upon existing studies of fire in the economic literature that are largely limited to cost-benefit analyses and consideration of the role of slash-and-burn forest clearing in the agricultural production process.

Our study is the first to consider how risk of accidental fire affects decision-making of the subsistence household by using a household risk model. Household risk models have been used in the past to address the role of environmental disasters, price fluctuations, and illness in household decision-making, but accidental fire has not been considered in this context. 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. Community work with fire prevention by IBAMA and by IPAM in the FLONA Tapajós is an important factor influencing fire prevention behavior by the households in our study, but it seems to have little impact on household decisions to burn land for agriculture or on how much land is burned by the household.

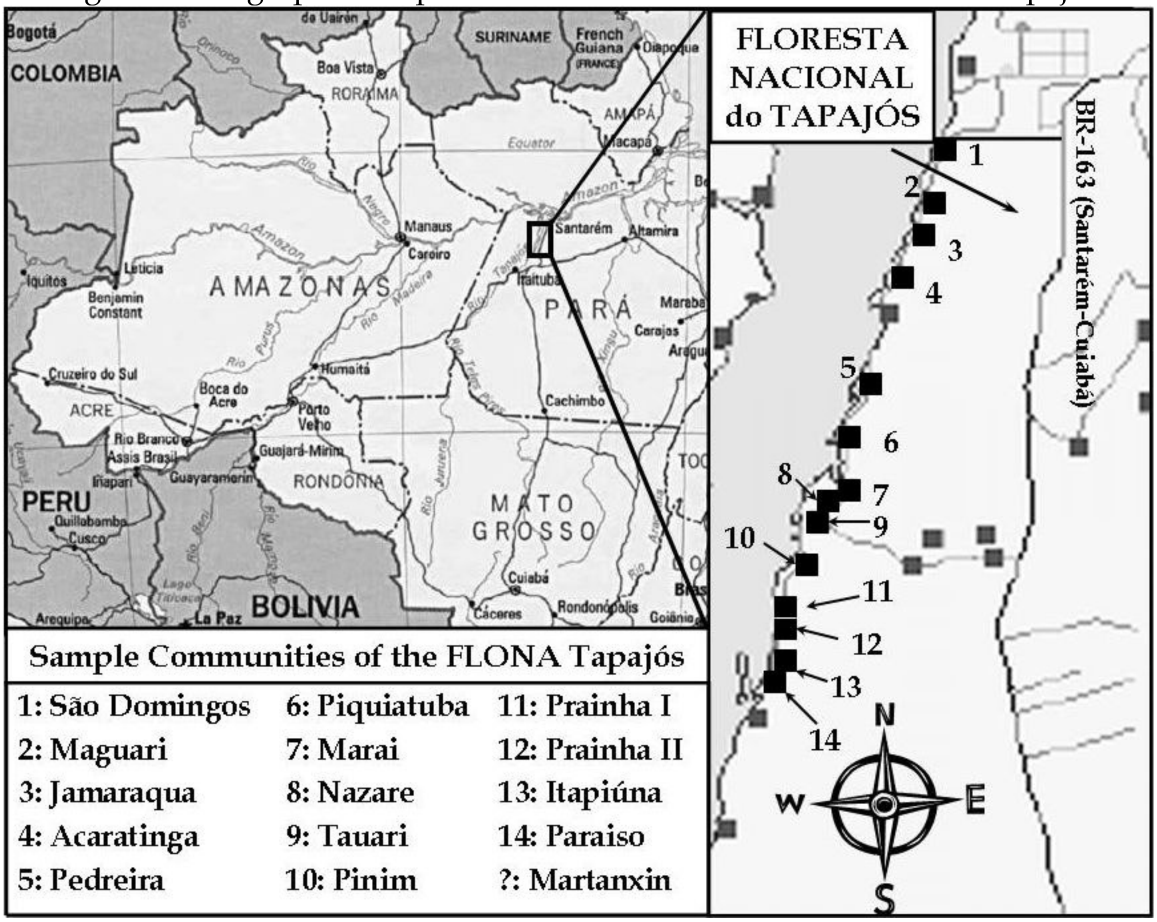
Our findings are important to identifying effective regional conservation and development policies targeting fire reduction and promoting prevention of accidental fire. The role of economic variables such as prices, wages, and household shadow wages in determining household behavior with respect to fire use and prevention highlights the need for consideration of key economic variables in policy making. We find that increasing household productivity and degree of market integration, while making households more likely to engage in fire prevention measures, also creates incentives for the household to burn additional land for agricultural production. Programs that improve household welfare and increase real incomes to households will likely support investment by the household in fire prevention, as will educational programs and community associations that emphasize education. These same programs will likely be ineffective in reducing land area burned, however, and improvements in household welfare and incomes will continue to put pressure on forests as a result of increased productivity. Thus, reduction in widespread accidental fire may follow as a natural result of increased income to smallholders and development in the region, thereby reducing the economic and environmental impacts of accidental fires. These factors, however, are unlikely to slow deforestation unless combined with other measures.

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 that prevail in communities of the FLONA make it difficult to consider the role of property rights and tenure security in fire use and prevention behavior by the household. Similarly, because ranching is not a primary land use in the FLONA, we are unable to examine the role of cattle ranching and pasture fires in fire risk or in household decision-making about fire prevention. Households in the FLONA, in contrast to those in settlement areas outside Santarém or along the expanding Transamazon highway, are almost completely removed from markets and experience much less settlement pressure by comparison. This limits the potential to study market-related variables such as transportation costs, and also to study fire prevention behavior in areas experiencing heightened risk of accidental fire.

In order to more completely examine the role of economic variables in burning and fire prevention decisions of smallholders, studies similar to this one should be conducted in regions with differing degrees of market integration and in regions where there is little work with fire prevention. As an extension of this work, we hope to apply a similar survey to households in the Transamazon region. We acknowledge that certain assumptions of our study merit further consideration, notably the assumption that the probability that a household experiences accidental fire is exogenous to the household. More realistically, the probability that a household experiences a fire probably differs according to surrounding land uses, activities of neighboring households, and decisions about burning and fire prevention that are endogenous to the subsistence household.

The probability of accidental fire may be endogenous to household decision-making in several ways. It is possible that engaging in fire prevention not only protects agricultural and non-timber forest product investments should a fire occur, but prevention might also reduce the probability that a smallholder will experience an accidental fire. Similarly, smallholder land use or burning activities may be directly related to the probability of accidental fire; positive feedback theories about fire and land use would suggest that the more a smallholder burns, the more degraded their land and their forest area, and thus the more likely they are to be susceptible to accidental fire. There is potential for application of land-use/land-cover and hot pixel satellite data for creation of a differential and exogenous measure of probability of accidental fire to be used in future economic studies about fire risk and prevention behavior.

Figure 1: Geographical representation of the Floresta Nacional do Tapajós



Sources: Ioris (2005) and a Political map of Brazil (1994), from the Perry-Castañeda Library Map Collection of the University of Texas

Table 1 Descriptive statistics for sample households n=219		
	Sample Mean	**SD**
Number of household members	4.81	2.25
Number of children age <15 years old	2.01	1.77
Sum of years of education of all household members	17.52	11.10
Expenditure on household structure in Reais[a]	1498.12	2489.30
Number of years household has lived on current lot	30.56	18.12
Household has access to Santarém by road to the North (four northernmost communities) (0,1)	0.18	0.39
Size of agricultural plantation in hectares	0.42	0.45
Mandays spent planting by the household	16.08	27.69
Mandays spent harvesting by all household	54.16	77.47
Mandays hired by household in the last year	4.10	11.25
Value of crops produced in the last year in Reais	1000.53	1607.85
Price reported of manioc flour in Reais/sack[b]	39.11	9.76
Head of cattle owned by household	4.12	34.03
Household hires labor (0,1)	0.39	0.49
Wage at which household hires labor in Reais/day	11.87	2.51
Household hunts (0,1)	0.24	0.43
Household collects non-timber forest products (0,1)	0.19	0.39
Burned majority of land in the past year during month of October (0,1)	0.30	0.46
Burned majority of land in the past year during month of November (0,1)	0.28	0.45
Household burns to clear land for crop production (0,1)	0.50	0.50
Household burned last year to clear land for crop production (0,1)	0.35	0.48
Hectares burned to clear land for crop production in the past year	0.33	0.64
Household burns to improve quality of pasture (0,1)	0.10	0.30
Hectares burned to improve quality of existing pasture in the past year	0.28	1.60
Household reported experiencing an accidental fire in the past (0,1)	0.21	0.41
Number of years since most recent accidental fire experienced by the household	5.95	4.64
Household has lost agricultural plantations as a result of accidental fires in the past (1,0)	0.09	0.29
Hectares of cropland lost during the most recent accidental fire	0.29	2.73
Household clears land in aceiro for fire prevention (1,0)	0.73	0.44
Number of organizational entities listed by household as working with fire in their community	1.22	0.79
Household took out a formal loan in the past year (0,1)	0.16	0.37
Value of formal loan to household in Reais	285.18	843.42
Value of fishing capital owned by household in Reais	895.99	3183.33
Exogenous income to the household in the past year in Reais	1066.48	8154.12
Shadow wage of planting labor in Reais/day	27.42	57.96

[a] $2.37 Brazilian Reais=$1.00 U.S. Dollar (as of July, 2005)
[b] one sack of manioc flour=approximately 60 kg

Table 2
Tobit estimation of Production

Independent Variable	Coefficient
Sum of years of education of all household members	0.090 (0.267)[a]
Number of years household has lived on lot	0.721*** (0.245)
Size of agricultural plantation (last year) in hectares	2.312*** (0.703)
Days spent planting by all household members in the last year	0.646*** (0.199)
Days spent harvesting by all household members in the last year	0.221* (0.116)
Days hired by household in the last year	0.409** (0.184)
Hectares of land burned for planting of crops in the last year	-0.167 (0.602)
Household clears land in aceiro for fire prevention (1,0)	1.465** (0.591)
Household has lost agricultural plantations as a result of accidental fires in the past (1,0)	1.047 (0.737)
Sigma	2.793*** (0.164)

[a] Asymptotically robust standard errors of coefficients reported in parentheses
Functional form: log-log
n=206
LM test [df] for Tobit = 85.692[10]
Log likelihood = -443.0895

*** <0.01, ** <0.05, * <0.10

Table 3
Probit estimation of the Household Decision to Burn land for Crop Production

Independent Variable	Coefficient	Marginal Effect
Sum of years of education of all household members	0.139 (0.175)[a]	0.390
Number of years household has lived on lot	-0.238* (0.137)	-0.799
Wage at which household hires labor ($R/day)	-3.201*** (1.135)	-8.439
Shadow wage of planting labor ($R/day)	0.215** (0.087)	0.472
Household has access to Santarém by road to the North (four northernmost communities) (0,1)	-0.035 (0.347)	-0.007
Number of organizational entities listed by household as working with fire in their community	0.068 (0.313)	0.057
Household reported experiencing accidental fire in the past (0,1)	0.062 (0.770)	0.014
Household burns to improve quality of pasture (0,1)	-0.444 (0.450)	-0.048
Household took out a formal loan in the past year (0,1)	-0.267 (0.423)	-0.044
Number of household members	-0.772* (0.397)	-1.240
Number of children age <15	0.505* (0.275)	0.446
Head of cattle owned by household	-0.240 (0.229)	-0.112
Exogenous income to the household in the past year ($R)	0.035 (0.053)	0.104
Price of manioc flour ($R/sack)	-0.754 (0.615)	-2.917
Value of crops produced in the last year ($R)	0.125** (0.051)	0.689
Household collects non-timber forest products (predicted (0,1))	0.694 (1.265)	.1404
Household hunts (predicted (0,1))	-4.193** (1.895)	-1.081

[a] Asymptotically robust standard errors of coefficients reported in parentheses
n=206
All independent variables in log form
Log likelihood = -112.5675
Restricted log likelihood = -135.6273
Percent dependent variable correctly predicted = 71

*** <0.01, ** <0.05, * <0.10

Table 4
Tobit estimation of Hectares of Land Burned for Crop Production

Independent Variable	**Coefficient**
Sum of years of education of all household members	0.180 (0.114)[a]
Number of years household has lived on lot	-0.109 (0.087)
Wage at which household hires labor ($R/day)	-1.964*** (0.691)
Shadow wage of planting labor ($R/day)	0.188*** (0.054)
Household has access to Santarém by road to the North (four northernmost communities) (0,1)	-0.066 (0.226)
Number of organizational entities listed by household as working with fire in their community	0.0477 (0.204)
Household reported experiencing accidental fire in the past (0,1)	-0.201 (0.496)
Household burns to improve quality of pasture (0,1)	-0.425 (0.292)
Household took out a formal loan in the past year (0,1)	-0.361 (0.270)
Number of household members	-0.568** (0.253)
Number of children age <15	0.300* (0.173)
Head of cattle owned by household	-0.148 (0.144)
Exogenous income to the household in the past year ($R)	0.037 (0.034)
Price of manioc flour ($R/sack)	-0.746* (0.388)
Value of crops produced in the last year ($R)	0.058* (0.033)
Household collects non-timber forest products (predicted (0,1))	1.118 (0.828)
Household hunts (predicted (0,1))	-2.944** (1.201)
Sigma	0.734*** (0.068)

[b] Asymptotically robust standard errors of coefficients reported in parentheses
n=206
Functional form: log-log
Log likelihood = -148.7540
Selection Lambda = -0.748 (.866) is non-significant.

*** <0.01, ** <0.05, * <0.10

Table 5
Probit estimation of Hunting and Household Collection of non-timber forest products

	Probit estimation of Hunting		Probit estimation of Collection of NTFP	
Independent Variable	**Coefficient**	**Marginal Effect**	**Coefficient**	**Marginal Effect**
Sum of years of education of all household members	0.024 (0.176)[a]	0.087	-0.179 (0.188)[a]	-0.771
Number of years household has lived on lot	-0.057 (0.142)	-0.248	-0.028 (0.163)	-0.144
Size of agricultural plantation (last year) in hectares	-0.467 (0.364)	-0.244	0.991** (0.392)	0.613
Wage at which household hires labor ($R/day)	-1.072 (0.943)	-3.647	0.836 (1.145)	3.366
Shadow wage of planting labor ($R/day)	0.061 (0.107)	0.172	-0.113 (0.113)	-0.378
Household has access to Santarém by road to the North (four northernmost communities) (0,1)	-0.226 (0.284)	-0.056	-0.630 (0.411)	-0.185
Number of organizational entities listed by household as working with fire in their community	-0.251 (0.296)	-0.272	-0.070 (0.344)	-0.090
Household reported experiencing accidental fire in the past (0,1)	0.484* (0.248)	0.139	1.665*** (0.298)	0.565
Household burns to improve quality of pasture (0,1)	0.150 (0.426)	0.021	0.679* (0.410)	0.113
Household took out a formal loan in the past year (0,1)	-0.653 (0.402)	-0.139	0.998** (0.470)	0.252
Number of household members	-0.087 (0.399)	-0.181	0.094 (0.470)	0.231
Number of children age <15	0.122 (0.271)	0.139	0.081 (0.319)	0.109
Head of cattle owned by household	-0.499** (0.202)	-0.299	-0.086 (0.168)	-0.061
Exogenous income to the household in the past year ($R)	0.046 (0.044)	0.176	-0.138** (0.060)	-0.626
Price of manioc flour ($R/sack)	-0.995** (0.448)	-4.972	0.301 (0.522)	1.780
Value of crops produced in the last year ($R)	0.032 (0.052)	0.223	0.021 (0.061)	0.175

[a] Asymptotically robust standard errors of coefficients reported in parentheses
n=206
All independent variables in log form
Hunting: Log likelihood = -101.5017 Restricted log likelihood = -114.1638
Percent dependent variable correctly predicted = 76

NTFP collection: Log likelihood = -73.499 Restricted log likelihood = -99.959
Percent dependent variable correctly predicted = 86

*** <0.01, ** <0.05, * <0.10

Independent Variable	Coefficient	Marginal Effect
Hectares of land burned to create agricultural plantations in the past year (predicted value)	-0.168 (0.230)[a]	-0.056
Sum of years of education of all household members	-0.053 (0.212)	-0.031
Number of years household has lived on lot	-0.018 (0.166)	-0.013
Wage at which household hires labor ($R/day)	2.748 (1.80)	1.514
Shadow wage of planting labor ($R/day)	0.763*** (0.151)	0.351
Household has access to Santarém by road to the North (four northernmost communities) (0,1)	0.690 (0.432)	0.028
Number of organizational entities listed by household as working with fire in their community	0.736* (0.397)	0.129
Household reported experiencing accidental fire in the past (0,1)	-1.248 (1.141)	-0.058
Household burns to improve quality of pasture (0,1)	0.323 (0.615)	0.007
Household took out a formal loan in the past year (0,1)	0.410 (0.580)	0.014
Number of household members	0.623 (0.508)	0.209
Number of children age <15	-0.112 (0.361)	-0.021
Head of cattle owned by household	0.400 (0.348)	0.039
Exogenous income to the household in the past year ($R)	-0.057 (0.067)	-0.035
Price of manioc flour ($R/sack)	2.027** (0.919)	1.639
Value of crops produced in the last year ($R)	-0.101 (0.066)	-0.116
Household collects non-timber forest products (predicted (0,1))	0.775 (1.703)	0.033
Household hunts (predicted (0,1))	6.368** (2.936)	0.343

Table 6
Probit estimation of Household Clearing of Aceiro for Fire Prevention

[a] Asymptotically robust standard errors of coefficients reported in parentheses
n=206
All independent variables in log form
Log likelihood = -68.99369 Restricted log likelihood = -113.0127
Percent dependent variable correctly predicted = 81

*** <0.01, ** <0.05, * <0.10

Table 7 Tobit estimation of Labor Allocation to Fire Prevention in Aceiro	
Independent Variable	**Coefficient**
Hectares of land burned to create agricultural plantations in the past year (predicted value)	-0.037 (0.086)[a]
Sum of years of education of all household members	-0.002 (0.082)
Number of years household has lived on lot	0.041 (0.067)
Wage at which household hires labor ($R/day)	0.707 (0.493)
Shadow wage of planting labor ($R/day)	0.200*** (0.044)
Household has access to Santarém by road to the North (four northernmost communities) (0,1)	0.014 (0.166)
Number of organizational entities listed by household as working with fire in their community	0.306** (0.149)
Household reported experiencing accidental fire in the past (0,1)	-0.233 (0.371)
Household burns to improve quality of pasture (0,1)	0.062 (0.212)
Household took out a formal loan in the past year (0,1)	0.135 (0.207)
Number of household members	0.316 (0.193)
Number of children age <15	-0.025 (0.132)
Head of cattle owned by household	0.036 (0.112)
Exogenous income to the household in the past year ($R)	-0.013 (0.025)
Price of manioc flour ($R/sack)	0.368 (0.288)
Value of crops produced in the last year ($R)	-0.024 (0.026)
Household collects non-timber forest products (predicted (0,1))	-0.006 (0.621)
Household hunts (predicted (0,1))	1.523* (0.879)
Sigma	0.644*** (0.039)

[a] Asymptotically robust standard errors of coefficients reported in parentheses
n = 206
Functional form: log-log
Log likelihood = -196.7633
LM test [df] for Tobit = 62.607[19]
Selection Lambda = 0.043 (.237) is insignificant.
*** <0.01, ** <0.05, * <0.10

Table 8
Likelihood Ratio tests of household characteristics and economic variables in land burned and fire prevention regressions

	Land burned for agriculture		**Labor time spent clearing aceiros**	
	Probit	Tobit	Probit	Tobit
Household characteristics[a]	8.013*	7.448	2.896	6.946
Economic variables[b]	34.030***	38.115***	55.977***	30.699***

[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, 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, value of crops produced in the last year

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Appendix A: Household Survey Instrument

Please read before the interview.

We are conducting a socioeconomic survey. The objective of this survey is to obtain information about production and consumption of households and determine the ways in which accidental fire may affect household decision-making. This research is in conjunction with the Instituto de Pesquisa Ambiental da Amazônia (IPAM). All answers will be completely confidential. Thank you for your cooperation.

Note: If there is no answer to a question, please fill in --------, if the true value is zero, please fill in 0

1. Date: ____/____/____

2. Interviewer: ____

3. Interviewed: ____

4. Community: ____

6. GIS Location Points:__________________X______________________Y

7. How many people live in your house or depend on the income generated from your property? (**beginning with the person being interviewed, who will have ID Code of 1**)?

ID CODE	Name	Male (M) Female (F)	Age	Years of education (#)
1		M F		
2		M F		
3		M F		
4		M F		
5		M F		
6		M F		
7		M F		
8		M F		
9		M F		
10		M F		
11		M F		
12		M F		

8. Do you own this house? S N

9. Who built your house? (SEE CODE 9)__________________ (Other:_________________________)

10. If you built yourself, how much did you spend to build your house? ________________$R NS NR

11. In what year was your house built? ____________________ (year) NS NR

12. Do you have formal title to your property? S N NS NR

13. How far is your house from the nearest:

	Name, if applicable	Distance in km
a) all-weather (gravel) road		
b) dirt road		
c) path		
d) town		

14. For how long have you lived in this location? ________________ year(s) _________________ months NS NR

15. Where does your water come from? (SEE CODE 15) ___________________ (Other_______________________)

16. Approximately how far away from your house is your water source? (SEE CODE 16) ________________ (UNIT CODE) ________

17. a) Are there any organizations that you are aware of that work with fire in your area? S N NS NR

b) if S, please list/describe:

18. How big was your garden/field (roça) last year? (SEE CODE 18) _______________ (UNIT CODE)_______ NS NR

19. How far is your roça from your house? (SEE CODE 19) _____________ (UNIT CODE)_________ NS NR
20. How long does it take you to walk to your roça ____________minutos caminhando NS NR

21. How do you transport the products from your roça to market? (SEE CODE 21) _______________

22. How many trips to market products from your roça do you make during the wet and dry seasons of this past year:
   a) Wet season: _____________________ trips
   b) Dry season: _____________________ trips

23. How long does it take you to get to the market in which you sell the products from your roça using the above form(s) of transportation?
__________hrs NS NR

24. How much does each trip to market cost including transportation and lodging? ________________________ $R

25. How many days (including travel) do you spend making each trip? ____________________________ days

26. Which members of your household make these trips? (list I.D. codes) ______________________________

27. The following asks about what you produced for consumption or sale in your roça during the past year, and whether you bought any of these products for consumption.

OBSERVAÇÃO- Favor de colocar * se é consorciado

	Area planted (CODE 27a)	**Volume produce d last year (CODE 27b)**	**Volume sold last year? (CODE 27b)**	**Price in $R per unit bought/ sold**	**Volume consumed last year (CODE 27b)**	**Volume bought last year for consumption (CODE 27b)**
Annual Crops						
Abacaxi						
Arroz						
Banana						
Feijão						
Farinha de mandioca						
Macaxeira						
Milho						
Melancia						

	Area planted (CODE 27a)	Volume produce d last year (CODE 27b)	Volume sold last year? (CODE 27b)	Price in $R per unit bought/ sold	Volume consumed last year (CODE 27b)	Volume bought last year for consumption (CODE 27b)
Perennial Crops						
Graviola						
Café						
Côco						
Seringa						
Urucu						
Pimenta do Reino						
Citrus						
Cupuaçu						
Cacau						
Pecuária						
Queijo						
Leite						
Carne						

28. The following asks about what products you collected from the forest in the past year, how much of these products you sold and consumed, and whether you bought any forest products.

	Volume collected last year (CODE 28)	**How much did you consume of what you collected? (CODE 28)**	**Volume sold last year? (CODE 28)**	**Price in $R per unit bought/sold**	**Volume bought last year for consumption (CODE 28)**
Açaí					
Andiroba					
Bacaba					
Breu					
Casca de Ipê					
Castanha do Brasil					
Cipó					
Copaíba					
Cumarú					
Leite de Amapá					
Leite de Mururé					
Mel de abelha					
Palha					
Patauá					
Piquiá					
Plantas medicinais					
Sucuba					
Tucumã					
Uxi					

29. How many animals do you have? How many did you buy or sell in the past year?

Animal	Number owned	Value in $R/animal	Quantity sold in the last year	Quantity bought in the past year
1. Cattle				
2. Sheep				
3. Goats				
4. Fowl				
5. Pigs				
6. Horses				

30. Please complete the following table regarding the labor of each member of your household.

		DRY SEASON	WET SEASON		
	ID CODE: ______________	# Days	# Days	Do you do this together with another activity? Which? (list all, USE CODE)	
CODE	**On-farm production activities**				
a	tirar estaca (build fences)				
b	broca				
c	Derruba				
d	Aceiro				
e	Roçar				
f	Burning				
g	Preparação da terra				
h	Plantio (planting)				
i	Capina (weeding)				
j	Colheita (harvest)				
k	NTFP collection				
l	hunting				
	Time sick				

m	sick while working				
n	sick, stayed home				
o	home, caring for sick				
	Off-farm activities				**WAGE (CODE 30)**
p	travel to engage in off-farm labor				
q	Floresta (exploração madeireira) (logging)				
r	Pecuária (business)				
s	Extractivismo				
t	Mão de obra não qualificada (diarista) (unskilled labor)				
u	Exchange labor				
v	looking for work				
	Other (list):				
w	Pesca				
x					
y					

31. a) Do you hire labor? S N
    b) If S, at what wage? _____________ $R/day

32. a) How many days of labor (one person for one day=one day of labor) did you hire during the last wet season? _______________ days
    b) How many days of labor did you hire during the last dry season? ___________________ days

33. What percent of your property is forested? ____________________ % of property NS NR
34. What percent of your property is in pasture? _____________________ % of property NS NR

35. How much forest have you cleared since you moved to this lot? ____________________ha NS NR
36. How much forest did you clear in the past year? ______________________ha NS NR
37. a) How much (if any) did a logging company clear? _________________________ha NS NR
b) How much were you paid for this contract with the logging company? __________________ $R
38. List sales of timber that you have made in the past year independent of any contracts with logging companies:

Sale:	# trees from pasture	Value ($R)/tree from pasture (if known)	Total value of sale from pasture ($R)	# trees from legal reserve	Value ($R)/tree from legal reserve (if known)	Total value of sale from legal reserve ($R)	who did you sell to? (list)
1.							
2.							
3.							
4.							
5.							
6.							

Fire Use

For which of the following reasons do you use fire?

Do you use fire for:	39.	40. Name the month(s) during which you burn for this purpose (SEE CODE 40)	41. How often do you burn for this purpose? Every _________ year(s):	42. Area (ha) burned for this purpose during the past dry season
a) Clearing of forest to convert to pasture	S N			____________________ha
b) Clearing of forest to convert to fields for agriculture	S N			____________________ha
c) Burning of pasture to improve quality	S N			____________________ha

43. During the last dry season, how many total days did you burn for any of the above reasons? ________________ days

44. During the past year, did you do any of the following when burning:

a)	**Apply for permission to burn from IBAMA**	S	N	NR
b)	**Clear land around crops to prevent crop damage (aceiro)**	S	N	NR
c)	**Dig trenches or construct other fire barriers**	S	N	NR
d)	**Intentionally burn at the driest month**	S	N	NR
e)	**Avoid burning during the driest month**	S	N	NR
f)	**Watch the fire to make sure it does not damage your property**	S	N	NR
g)	**Watch the fire to make sure it does not damage your neighbors' property**	S	N	NR
h)	**Inform your neighbors of when you were going to be burning**	S	N	NR

45. Are there other precautions that you take when burning to limit the damage to your own property or to that of your neighbor? Please describe:

46. During which week of the last dry season would you say you burned the most land? _____________seimana de _____________(SEE CODE 46)

47. What is the total area you estimate that you burned during the above week of this year? _________________ha

Experience with accidental fire

48. Has a fire from a neighboring landowner or a fire that you did not start ever burned a piece of your property? S N NR

49. Has a fire that you started ever crossed your property boundaries onto the property of a neighboring landowner? S N NR

50. **For how many total days did accidental fires (use definition from 48) burn on your property during the last dry season?**
___________________ **days**

51. **Please answer the following questions about the accidental fires you have experienced:**

	Year	Month	Fire source (CODE 51a) Write in, if other	Area burned of legal reserve (%)	Cropland area burned (ha)	Pasture area burned (ha)	Did you experience a physical loss?	Type of loss (CODE 51b), specify if other	Value of loss ($R)
1							S N		
2							S N		
3							S N		
4							S N		
5							S N		
6							S N		

Comments:

	52. In response to these fires, did you ever have to:		Fire #s (from above)		
a)	Sell livestock to pay for fire damage	S N NR		Value of sale ($R):	
				Value of sale ($R):	
b)	Sell timber to pay for fire damage	S N NR		Value of sale ($R):	
				Value of sale ($R):	
c)	Clear additional land for crops	S N NR		amount of additional land, in ha:	
				amount of additional land, in ha:	
d)	Take a new job or look for off-farm employment	S N NR		:	
e)	Move to a new location	S N NR			
f)	Borrow money from a friend or family member	S N NR		value ($R):	
				value ($R):	
g)	Accept a gift of money from a friend or family member	S N NR		value ($R):	
				value ($R):	
h)	Accept a gift (non-monetary) from a friend or family member	S N NR		describe gift:	
				describe gift:	
i)	Taken out a loan to pay for fire damage	S N NR		value ($R):	
				value ($R):	
j)	Apply for a loan that was refused	S N NR			
k)	Borrow pasture from a neighbor because pasture had	S N NR			

	been burned				
l)	**Rent pasture from a neighbor because pasture had been burned**	S N NR		value ($R):	
				value ($R):	
m)	**Increase/decrease collection of NTFP**	S N NR		Increase or Decrease?	
n)	**Hunt more/less**	S N NR		More? Less?	

	53. During the past year, have you done any of the following in response to a specific event other than a fire?		Reason (CODE 53), specify if other	
a)	Sell livestock	S N NR		# and type of livestock:
b)	Sell timber	S N NR		value ($R):
c)	Clear additional land for crops	S N NR		amount of additional land, in ha:
d)	Take a new job or looked for off-farm employment	S N NR		distance in km:
e)	Move to a new location	S N NR		value ($R):
f)	Borrow money from a friend or family member	S N NR		value ($R):
g)	Accept a gift of money from a friend or family member	S N NR		value ($R):
h)	Accept a gift (non-monetary) from a friend or family member	S N NR		describe gift:
i)	Taken out a loan to pay for fire damage	S N NR		value ($R):
j)	Apply for a loan that was refused	S N NR		value ($R):
k)	Increase/decrease collection of NTFP	S N NR		Increase or Decrease?
l)	Hunt more/less	S N NR		More? Less?

FISHING ACTIVITY

54. Do you fish? S N NS NR At what age did you start fishing?__________

55. For what reasons do you fish? (SEE CODE 55)_____________

56. Which months do you fish during the year? (SEE CODE 40)_________
Summer:____________
Winter:______________

57. Do you own or rent any of the following items?

Description	Do you use or rent?	Number	Value, if owned (R$)	Value paid to rent per use in the past year ($R)
Malhadeira	S N			
Tarrafa	S N			
Espinhel	S N			
Barco de pesca (fishing boat)	S N			
Canoa (canoe)	S N			
Motor do barco	S N			
Other:______________				

58. Tell us about the productivity of your fishery:

	Summer		Winter	
Number of trips/month				
Catch per trip (kg/trip)				
Time spent fishing (hr/day)				
Number of fishermen/trip				
Length of trip (out)				
Length of trip (back)				

59. At what price did you sell your fish, if any?

Type of fish	R$/kg	R$/fish
Pescada Amarela		
Pescada Branca		
Tambaqui		
Filhote		
Tucunaré		
Surubim		
Acari		
Manpará		
Dourada		
Sarda		
Pacú		

60. Do you sell your fish? (SEE CODE 60) ___________________

61. Do you hire fishermen? S N NS NR

62. If so, how many people do you hire? ____________ people

63. How many days per month do you hire people? ______________ days/month

64. How much do you pay your fishermen per day? ____________R$/day

Vita

Maria Bowman was born on May 6, 1983 in Harrisonburg, Virginia. During her childhood years, Maria lived in Virginia, Pennsylvania, and spent two years in Spain, one in Granada and one in Barcelona. In high school, Maria developed a passion for the natural world and for international travel, which led her to pursue a B.S. degree in Environmental Science from Juniata College in Huntingdon, Pennsylvania. As part of her time at Juniata, Maria spent a year in Ecuador, three months of which was spent interning with the Foundation for Integrated Education and Development in the village of Mondaña, Ecuador and working with a project introducing animal protein to rural communities in the form of the capybara (Hydrochaeris hydrochaeris). Maria left Juniata College to pursue an M.S. degree in Forestry under the guidance of Gregory S. Amacher at the Virginia Polytechnic Institute and State University in Blacskburg, Virginia.

Maria has enjoyed working at the Juniata College Raystown Field Station, as the accompanist for the Juniata College Concert Choir, and in the Harrisonburg City School System as a summer school teaching assistant for ESL students. She leaves Virginia Tech to work as a research assistant for the Woods Hole Research Center in the city of Belo Horizonte, Brazil, and intends at some point in the future to pursue a Ph.D. in Applied Economics.