Do Liquidity Constraints Help Preserve Tropical Forests? Evidence from the Eastern Amazon

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Abstract

This article examines the determinants of forest cover and land use efficiency in a shifting cultivation system. A conceptual model demonstrates that liquidity constraints encourage farmers to allocate more land to forest fallow and less to cultivation by limiting input purchases. Data from farm households in the Eastern Brazilian Amazon allow me to test whether farmers allocate land between cropping and fallow efficiently from an individual or a community perspective. I find that many farmers devote more land to fallow than is privately optimal, benefiting community income as a whole due to positive local externalities provided by secondary forest. I also estimate the effect of a variety of socioeconomic and agroecological factors on fallow allocation and land use efficiency. I find over-fallowing to be negatively associated with commercial credit use, suggesting that liquidity constraints do hinder agricultural intensification.

Do Liquidity Constraints Help Preserve Tropical Forests? Evidence from the Eastern Amazon

With growing public interest in reducing deforestation and forest degradation to stem climate change and biodiversity loss, the land use decisions among farmers living at the forest margins are of considerable policy interest. Much evidence has mounted about the drivers of land clearing in virgin forests; empirical studies from across the tropics have revealed factors such as proximity to markets and transportation, high agricultural commodity prices, and beneficial agroecological characteristics to encourage land conversion to agriculture (e.g, Angelsen and Kaimowitz 1999; Cropper, Puri, and Griffiths 2001). Credit access has also been discussed as a potential factor spurring deforestation, though empirical evidence on this issue is mixed (e.g., Pfaff 1999; Deininger and Minten 2002). Much of this literature aims to predict the location of future deforestation in an effort to help slow the loss of forests and the global public goods they provide. However, these studies have not explicitly considered whether credit constraints or other market failures affect the efficiency of land use patterns from the perspective of local farmers and communities.

This article examines the determinants of forest cover and the efficiency of land use decisions in a shifting cultivation agricultural system, a form of farming relied upon by approximately 300 million people worldwide. In some tropical forested areas where shifting cultivation is a mainstay of the economy, such as the Zona Bragantina in the Eastern Brazilian Amazon, farmers maintain large amounts of land under forest fallow. Secondary forests make up a considerable portion of once-deforested land throughout the Amazon—around 30%, by some estimates (Houghton et al. 2000)—underscoring the importance of understanding the drivers of this land use. However, the determinants of forest cover in agricultural systems have received less attention relative to natural ecosystems (Blackman et al. 2008).

Forest fallow provides on-site benefits to farmers, such as soil restoration, erosion prevention, and weed and pest curtailment. It also provides off-site services, supplying some of the same local and global public goods as mature forests, including hydrological regulation, carbon sequestration, and biodiversity protection. However, ecological studies documenting the restorative effects of fallowing on soil quality do not consider the tradeoffs inherent in allocating land to fallow rather than cultivation. While long fallow periods can be a cost-effective way to restore soil quality, they become more costly when the opportunity costs of land and labor are considered. Land must remain out of cultivation for years at a time to ensure sustainability, and land clearing requires large investments of labor. Indeed, a study from Pará calculated that converting fallow to cultivated land and replacing the lost soil nutrients entirely with chemical fertilizer would increase farm profits, though it did not account for positive fallow externalities (Toniolo and Uhl 1995). The total returns to fallowing thus depend on the relative contributions of fallow and cultivated land to farm income once all costs are considered.

This study examines potential barriers to efficient fallow management, focusing on liquidity constraints that may promote fallowing at the expense of intensified cultivation. I use data from the Zona Bragantina, a region unique in the Amazon for its long history of colonization, high population density, and secondary forest-dominated landscape. Economic development and land use patterns in Bragantina could provide insights for frontier regions now being rapidly settled throughout the Amazon. While Klemick (2007) showed that forest fallow provides positive local externalities in the

Bragantina, these ecological services provide a social, but not individual, rationale for the maintenance of larger fallow areas than is privately optimal. Credit constraints and other market failures offer a possible explanation for the persistence of these large fallow areas.

As has been widely documented, liquidity constraints can limit agricultural investments, fostering rural poverty (e.g., Zeller et al. 1997; López and Romano 2000; Feder, Just, and Zilberman 1985). They can also affect farmers' natural resource management decisions, sometimes encouraging overexploitation of the resource base (Barbier and López 1998). Farmers face pervasive barriers to credit access throughout Latin America; a six-country survey found credit accessible to only 8-33% of farmers (López and Valdéz 2000).

This article presents a conceptual model of shifting cultivation in the context of the optimal control literature on soil fertility and fallow management. The model distinguishes between the on-site benefits and positive externalities of forest fallow. I use this model to explore the implications of decentralized versus collective management and liquidity constraints for land use efficiency. The model indicates that liquidity constraints can encourage over-allocation of land to fallow by limiting purchased inputs used in cultivation. The implications of such constraints for community welfare depend on whether fallow is managed collectively to account for positive fallow externalities. Market imperfections that encourage fallowing could be welfare-improving, though constraints that are too tight may lead to welfare losses by hindering farmers' expansion of profitable agricultural activities.

I empirically test the predictions of the theoretical model using cross-sectional farm-level survey data from the Zona Bragantina. I use the value of forest fallow services and cultivated land estimated by Klemick (2007) to examine whether farmers in the Zona Bragantina are allocating land between cultivation and fallow efficiently from both the individual and community perspectives. Because fallow provides local positive externalities, optimal land management from the private perspective could lead to excessive forest clearing at the community level.

I then jointly estimate a system of two equations to examine the determinants of (1) the amount of land allocated to fallow and (2) whether this land allocation is optimal from the farmer's perspective. I consider various socioeconomic and agroecological factors affecting land use decisions, using the results of previous studies on tropical deforestation to inform the analysis. In particular, I consider the effects of commercial credit and off-farm employment to test the hypothesis that liquidity constraints are associated with inefficient fallow management.

In the next section I present the conceptual model of shifting cultivation. In the following section, I discuss the study area, data, and estimates of the value of cultivated and fallow land. I then test whether farmers in the sample allocate land efficiently from either a private or social perspective. I estimate a system of equations to determine what factors affect fallow land allocation and management efficiency in the next section. In the conclusion, I discuss the implications for tropical forest policy.

Conceptual Model of Shifting Cultivation with Fallow Externalities

Managing land quality through shifting cultivation entails allocating land between fallow and cultivation to balance current and future productivity. Models of shifting cultivation (e.g., Larson and Bromely 1990; Barrett 1991; Krautkraemer 1994) specify land quality as a function of fallow length or area. López (1993, 1997) considers the fallow biomass stock to be a village-level common property resource that contributes to productivity by providing environmental services. In the absence of community-level management, individual households undervalue the shadow cost of lost biomass and allocate too much land to cultivation, decreasing income for the village as a whole.

Here I examine the inefficiencies that can arise in fallow management even under private land ownership when externalities associated with forest clearing still create the scope for inefficient management.[1] Farm-level fallow biomass (θ(t)) equals the land area left fallow ($\bar{X}_i - x_i(t)$) multiplied by the average biomass density (η(t)).

$$\theta_i(t) = \eta_i(t)\left(\bar{X}_i - x_i(t)\right)$$

I use the biomass density growth function proposed by López (1993) to reflect the relationship between fallow and cultivation: a greater fraction of land under cultivation entails shorter fallow periods on average and hence less biomass accumulation because land is regularly rotated between cropping and fallow. Average biomass density on fallow land is thus assumed to decline with the biomass extracted during land clearing and increase at a constant rate (b) according to the following equation.

$$\dot{\eta}_i(t) = b - \frac{\eta_i(t)x_i(t)}{\bar{X}_i}$$

While López treats the village-level stock of fallow biomass as one factor of production, I allow fallow to boost productivity through two separate effects—average on-farm biomass and local or village-level biomass. These two effects capture the private soil-enhancing benefits and positive hydrological or other externalities of forest fallow. I

[1] Empirical studies have shown that off-farm forest cover is an important input to agricultural productivity in the Zona Bragantina (Klemick 2007) and in other tropical farming systems (Lopez 1993, 1997; Pattanayak and Kramer 2001; Pattanayak and Butry 2005).

also assume private land ownership so that fallow biomass is not a common property resource, but rather a private resource supplying externalities.

The production function for farm i is given by

$$f^i\left(x_i(t), l_{ci}(t), z_i(t), \theta_i(t), \sum_j^{N_i} \theta_j(t)\right)$$

where x(t) is cultivated area and $l_c(t)$ is cultivation labor. I introduce a choice variable to represent purchased inputs, such as chemical fertilizer (z(t)). The production function is increasing and concave in all inputs. I assume all factors to be gross complements. N is the total number of farms in the sub-watershed, while N_i represents the number of farms that provide ecological services to farm i.

On-farm fallow biomass has an additional productive use as a source of forest products that can be harvested for consumption or sale. Forest product harvests are a function of harvesting labor and fallow biomass, as well as off-farm fallow if hydrological or other ecological services also improve forest product yields, as below:

$$h^i\left(l_{hi}(t), \theta_i(t), \sum_j^{N_i} \theta_j(t)\right)$$

I assume that the fallow product harvesting function is increasing and concave in labor and on- and off-farm biomass, and that these factors are all gross complements.[2]

Cultivated land area and biomass density also increase the cost of land clearing, as in Dvorak's (1992) model of shifting cultivation. To ensure concavity of the objective function, I assume clearing costs (c) to be linear in land area and biomass density.

[2] Unlike crop production, I assume that no purchased inputs are used in forest product collection. This assumption is borne out in the current conditions of the Zona Bragantina but could easily be relaxed.

Each farm's profits encompass the revenue from crops and forest products, minus the costs of land clearing, labor, and purchased inputs. The price of fallow products is given by q, and p, v, w, and r represent output and input prices, the wage rate, and the discount rate, respectively. Suppressing the time argument, the farm profit function is

$$\Pi_i = qh^i\left(l_{hi,} \theta_i , \sum_j^{N_i} \theta_j \right) + pf^i\left(x_i , l_{ci} , z_i , \theta_i , \sum_j^{N_i} \theta_j \right) - cx_i \eta_i - w(l_{hi} + l_{ci}) - vz_i \qquad (1)$$

If households have access to well-functioning markets, farm production is recursive and independent of household characteristics. However, even when access to markets is imperfect, household production behavior can be represented by profit maximization rather than utility maximization under the assumption of fixed leisure. Each farm household thus confronts the following problem.

$$\max_{x_i, l_{hi}, l_{ci}, z_i} \int_0^\infty \Pi e^{-rt} dt \text{ s.t. } \dot{\eta}_i = b - \frac{\eta_i x_i}{\overline{X}_i}, \eta_i(0) = \eta_0 , x_i \leq \overline{X}_i$$

Now I turn to the conditions characterizing farmer choices under different institutional arrangements. I consider three cases: centralized fallow management, decentralized fallow management, and decentralized management under liquidity constraints. I focus on liquidity constraints because access to purchased inputs has important implications for fallow maintenance.

Case 1: Centralized Fallow Management

Under centralized fallow management, the optimal input levels are determined by maximizing the sum of farm profits over the entire sub-watershed. The Hamiltonian and necessary conditions (assuming an interior solution) for this problem are

$$H = \sum_{i}^{N} \left\{ qh^{i}\left(l_{hi}, \theta_i, \sum_{j}^{N_i} \theta_j \right) + pf^{i}\left(x_i, l_{ci}, z_i, \theta_i, \sum_{j}^{N_i} \theta_j \right) - cx_i \eta_i \right\}$$

$$- \sum_{i}^{N} \left\{ w(l_{hi} + l_{ci}) - vz_i \right\} + \mu_i \left(b - \frac{\eta_i x_i}{\overline{X}_i} \right)$$

$$H_{x_i} = -q\eta_i h_2^i - q\eta_i \sum_{j}^{N_j} h_3^j + pf_1^i - p\eta_i f_4^i - p\eta_i \sum_{j}^{N_j} f_5^j - c\eta_i - \frac{\mu_i \eta_i}{\overline{X}_i} = 0 \qquad (2)$$

$$H_{l_{hi}} = qh_1^i - w = 0 \qquad (3)$$

$$H_{l_{ci}} = pf_2^i - w = 0 \qquad (4)$$

$$H_{z_i} = pf_3^i - v = 0 \qquad (5)$$

$$H_{\eta_i} = q\left(\overline{X}_i - x_i\right)h_2^i + q\left(\overline{X}_i - x_i\right)\sum_{j}^{N_j} h_3^j + p\left(\overline{X}_i - x_i\right)f_4^i + p\left(\overline{X}_i - x_i\right)\sum_{j}^{N_j} f_5^j \qquad (6)$$

$$-cx_i - \frac{\mu_i x_i}{\overline{X}_i} = r\mu_i - \dot{\mu}_i$$

$$b - \frac{\eta_i x_i}{\overline{X}_i} = \dot{\eta} \qquad (7)$$

$$\lim_{t\to\infty} e^{-rt}\mu_i \geq 0, \lim_{t\to\infty} e^{-rt}\mu_i\eta_i = 0 \qquad (8)$$

The first condition (equation (2)) states that the marginal benefit of land under cultivation should equal the marginal costs in terms of land clearing, foregone net revenue of forest products, foregone positive externalities to other farms, and the shadow value of the lost fallow biomass density. Labor is allocated to equate the marginal benefits of harvesting forest products and cropping with the wage rate, from equations (3) and (4). Purchased inputs are similarly chosen to equalize the marginal value of increased productivity and the price (equation (5)). The shadow value of the biomass density stock evolves with the discount rate minus the marginal contribution of biomass density to farm profits (equation (6)).

In the long run equilibrium, at which η and μ reach steady state levels, biomass density and total biomass are inversely proportional to the share of land under cultivation such that $\eta_i = \frac{b\overline{X}_i}{x_i}$ and $\theta_i = b\overline{X}_i\left(\frac{\overline{X}_i}{x_i} - 1\right)$. Table 1 shows the steady state comparative statics to infer how the price parameters affect the level of fallow maintained by farmers.[3]

Unsurprisingly, forest product prices increase fallow biomass and reduce cultivated land. Increases in the wage rate affect land allocation ambiguously. If the marginal productivity of land used in forest product harvesting exceeds that used in cultivation, a wage increase draws labor out of farm production, dampening the pressure to expand cultivation and exploit biomass. The reverse may be true if labor has a higher marginal productivity in crop production. This result depends on the existence of perfect labor markets, an assumption I relax below.

Increases in the crop output and input prices also have unclear effects on fallow management without further knowledge about the production functions. Assuming Cobb-Douglas technology for both crops and forest products, higher crop output prices cause an expansion in cultivated area and a contraction of fallow. Similarly, increases in purchased input prices cause a contraction in the cultivated area and an expansion of fallow because the marginal cost of forest product harvesting remains the same, while that of cultivation rises. Even without the Cobb-Douglas assumption, this result still holds if purchased inputs complement cultivated land more strongly than fallow.

Case 2: Decentralized Fallow Management

In the absence of any central coordination, farmers have no incentive to weigh foregone externalities as a cost when allocating land. The necessary conditions for profit maximizing land allocation and biomass density when farmers fail to internalize the biomass externality are now given by

[3] Derivations of the comparative statics results are available from the author.

$$L_{x_i} = -q\eta_i h_2^i + pf_1^i - p\eta_i f_4^i - c\eta_i - \frac{\mu_i \eta_i}{\overline{X}_i} = 0 \quad (9)$$

$$L_{\eta_i} = q(\overline{X}_i - x_i)h_2^i + p(\overline{X}_i - x_i)f_4^i - cx_i - \frac{\mu_i x_i}{\overline{X}_i} = r\mu_i - \dot{\mu}_i \quad (10)$$

These conditions correspond to the Nash equilibrium solution for the choice of cultivated land and fallow density. The marginal value of the externality is not weighed in the land allocation decision or in the evolution of the biomass shadow value, so farmers prefer to expand the area under cultivation. Aggregate community welfare under these conditions is necessarily lower due to underprovision of the externality.

Case 3: Decentralized Fallow Management with Liquidity Constraints

Now I consider a situation in which farmers do not coordinate fallow management but are constrained in their inputs purchases by a limited cash budget comprised of credit and off-farm wage income. I introduce a labor market restriction to capture the limited off-farm employment opportunities typical of rural developing country settings. Wage labor is positive when family members work off-farm, but it cannot exceed the employment constraint M. Negative wage labor implies that labor is hired in for agricultural activities, as may be the case during peak periods. I use the equality $L = l_h + l_c + M$, where L represents the household's labor endowment and substitute out l_h. The Lagrangian for this problem is

$$L = qh^{i}\left(L - M - l_{ci}, \theta_i, \sum_{j}^{N_i} \theta_j\right) + pf^{i}\left(x_i, l_{ci}, z_i, \theta_i, \sum_{j}^{N_i} \theta_j\right) - cx_i\eta_i$$

$$+ \lambda_i\left(R + wM - vz_i\right) + \mu_i\left(b - \frac{\eta_i x_i}{\overline{X}_i}\right)$$

$$L_x = -q\eta_i h_2^i + pf_1^i - p\eta_i f_4^i - c\eta_i - \frac{\mu_i\eta_i}{\overline{X}_i} \le 0, x_i \ge 0, L_{x_i}x_i = 0 \tag{11}$$

$$L_{lc} = -qh_1^i + pf_2^i \le 0, l_{ci} \ge 0, L_{l_{ci}}l_{ci} = 0 \tag{12}$$

$$L_z = pf_3^i - \lambda v \le 0, z_i \ge 0, L_{z_i}z_i = 0 \tag{13}$$

$$L_\lambda = R + wM - vz_i \ge 0, \lambda \ge 0, L_{\lambda_i}\lambda_i = 0 \tag{14}$$

$$L_\eta = -qx_i h_2^i + p\left(\overline{X}_i - x_i\right)f_4^i - cx_i - \frac{\mu_i x_i}{\overline{X}_i} = r\mu_i - \dot{\mu}_i \tag{15}$$

$$b - \frac{\eta_i x_i}{\overline{X}_i} = \dot{\eta}_i \tag{16}$$

$$\lim_{t\to\infty} e^{-rt}\mu_i \ge 0, \lim_{t\to\infty} e^{-rt}\mu_i\eta_i = 0 \tag{17}$$

The liquidity constraint for input purchases is given by $R + wM = vz$, where R represents access to credit, wM is cash income from off-farm employment (or expenditures for hired labor if M is negative), and λ is the shadow value of loosening this constraint. If the constraint is binding, purchased inputs are underused relative to the privately optimal amount such that $z_i = \frac{R + wM}{v}$.

Still assuming Cobb-Douglas technology, table 2 presents comparative statics for the effects of the off-farm wage rate, employment constraint, and credit constraint. The effect of the off-farm employment constraint is ambiguous because it is not clear whether decreases in fallow or cropped area productivity dominate when less farm labor is supplied. The off-farm wage rate leads to increased input use and cultivated area and diminished fallow; since the wage rate does not directly determine labor allocation, it affects production only through the liquidity constraint. Unsurprisingly, increased credit also causes farmers to expand crop production at the expense of fallow area.

These results provide the basis for considering liquidity constraints a second best policy to minimize inefficiencies caused by decentralized fallow management. I further examine the implications of credit access by deriving its effect on aggregate welfare. Differentiating the Lagrangian representing social welfare, which is simply the sum of profits over all farms in the sub-watershed, and using the envelope theorem to drop those terms equal to zero according to the necessary conditions for individual profit maximization yields the following expression

$$\left(-p\eta_i \sum_{j\neq i}^{N_i} f_5^j - q\eta_i \sum_{j\neq i}^{N_i} h_3^j\right)\frac{dx_i}{dR} + \left(p\left(\overline{X}_i - x_i\right)\sum_{j\neq i}^{N_i} f_5^j + q\left(\overline{X}_i - x_i\right)\sum_{j\neq i}^{N_i} h_3^j\right)\frac{d\eta_i}{dR} + \left(\frac{p}{v} f_3^i - 1\right) \quad (18)$$

This expression illustrates the ambiguous effect of improved credit access for community-level income. The first two terms are negative and represent the marginal value of the lost externality caused by a slackening of the constraint. The final term is positive and denotes the marginal value of increased input use due to improved credit access. As the constraint slackens, the marginal value of additional inputs approaches zero, while the marginal value of the lost externality remains negative. Although this expression cannot be signed definitively, I expect the first two terms to dominate when the constraint is relatively relaxed. This result implies that a credit constraint, if not too severe, can improve welfare when fallow management is decentralized.[4]

These stylized scenarios illustrate the importance of institutional conditions on the use of fallow even under secure property rights. Case 3 presents a plausible, though

[4] Note that in the absence of productive local externalities to forest fallow, both centralized and decentralized management of fallows will be efficient, and liquidity constraints and transportation costs will necessarily decrease welfare. Constrained input use or decreased marginal output value in this case leads to underexploitation of the fallow biomass relative to efficient use.

obviously simplified, scenario to explain the persistence of fallow under conditions like those found in the Zona Bragantina, where farmers have some access to land and labor markets but may underexploit fallow relative to the privately optimal level due to liquidity constraints limiting the use of soil-enhancing inputs.

Study Region and Data

The Zona Bragantina offers a compelling case study as a region with over one hundred years of agricultural settlement where shifting cultivation persists as the principal means of livelihood. Despite integration into regional markets through railways and roads, perennial cash-crop agro-processing, and government programs to encourage agricultural intensification, shifting cultivation dominates other land-use practices in the region, and liquidity constraints are pervasive.

Data for the study were collected as part of the SHIFT (Studies on Human Impact on Forests and Floodplains in the Tropics) project, an initiative to study tropical livelihoods and ecosystem dynamics in Brazil. Three municipios out of the 14 that comprise the Zona Bragantina were chosen for study to capture regional variation in distance to commercial centers, agricultural intensification, and rainfall (Mendoza 2004). In late 2002, 271 households in 22 villages were randomly selected and surveyed. Tables 3 and 4 present the mean values for selected household and community characteristics. Most of the sampled households are considered smallholders by Brazilian standards, with median landholdings of 25 hectares.[5] While family labor and manual land clearing and cultivation predominate, hired labor and mechanized equipment can also be used for labor-intensive tasks like land preparation, weeding, and harvesting. A typical one to two

[5] Ninety-four percent of the farmers' landholdings are 100 hectares or less, the common definition for smallholders in Brazil.

year cropping sequence includes maize, upland rice, and cowpea, with cassava grown as the final crop while fallow vegetation reestablishes (Holscher et al.1997). These annual crops are used for home consumption and sale to regional markets. Since the mid twentieth century, smallholders have also branched into perennials like black pepper, passion fruit, oranges, and coconut, as well as cattle production.

Sampled households were poor even for Pará, earning B$1625 per capita annually, compared to the state average of B$3804 (Verner 2004). Close to two-thirds of income was earned from farm activities, while 37% came from off-farm sources. Old-age pensions comprised the bulk of off-farm earnings. Annual crops, produced by 90% of the farmers, dominated farm activities and contributed 54% to farm income on average. Perennial crops were produced by 46% of households and made up 24% of farm income. The other major source of farm earnings was non-timber forest product harvests (14%).[6] Most farms were semi-commercialized, retaining some produce for home consumption and selling the remainder in regional markets. Sixty-two percent of farms used electricity, and only 13 out of the 22 communities had access to a telephone, indicating a lack of access to infrastructure by some households.

Farmers in the Brazilian Amazon can access commercial credit through the FNO (Fundo Constitucional de Financiamento do Norte), a program making low-interest loans to smallholders since the late 1980s. However, despite the FNO's mandate to target small farmers, complicated bureaucracy and other transaction costs often render the loans inaccessible (Andrae and Pingel 2001). Even access to FNO credit might not alleviate liquidity constraints entirely, since loans are rationed to $B5000 per farmer (Borner

[6] Ranching and animal products (dairy and eggs) made up the remainder of agricultural activities, comprising 8% of farm income. Ranching is less common in the Zona Bragantina than cropping and forest product harvesting. Pasture is found on only 28% of sampled farms, comprising 5% of land on average.

2005). Only 30% of sampled farmers obtained any credit from a bank during the previous decade, 61% of whom used the FNO program. In addition, 24% of farmers using credit obtained loans through PRONAF (National Program for the Strengthening of Smallholder Agriculture), a late-1990s government initiative to fund agro-industrial projects. Of farmers who used commercial credit, 67% reported having difficulties with repayment. The meager use of credit cannot be attributed to land tenure insecurity, as prevails in much of the Amazon; 65% of sampled farmers held legal title to their land.

Farmers in the Zona Bragantina allocate a large portion of their land to fallow. Virtually all virgin forest in the region has been cleared for several decades, but secondary vegetation covers approximately 75% of total land area (Kato et al. 1999). Surveyed farmers allocated over 50% of their land to fallow on average, though it is worth noting that 14% did not devote any land to fallow; land in the region can be continuous cultivated with intensive use of chemical inputs.

Klemick (2007) estimated the contributions of cultivated land and on-farm and upstream forest fallow to crop production and non-timber forest product harvests, reproduced in Table 5.[7] The elasticities of on-farm and upstream fallow account for their respective contributions to both crop and forest product income and vary by farm with the share of income from each activity, while the elasticity of cultivated area only reflects its contribution to crop revenues and is constant across farmers. The positive and significant mean fallow elasticities underscore their importance in providing both consumable

[7] Klemick (2007) estimated four specifications for the crop and non-timber harvest production functions. They varied in the data used to define the upstream fallow variable (survey-reported fallow area vs. GIS forest cover data) and the use of instrumental variables to control for potential endogeneity of the on-farm and upstream fallow variables. All four specifications provided qualitatively similar results. Here I report the parameter estimates from Model 1, which I use for the analysis discussed in this article. Model 1 used survey data to define the upstream fallow variable and did not estimate an instrumental variable model.

products and ecological support services in the Zona Bragantina. The significance of the upstream fallow elasticity indicates that secondary forest provides important hydrological spillovers to downstream farmers in the Zona Bragantina.

Unsurprisingly, cultivated land also makes an important contribution to farm income. Indeed the elasticity of cultivated land is considerably higher than the elasticity of on-farm fallow. Given the direct tradeoff between land used for cultivation and fallow, there may be gains to farmers from reallocating land between fallow and cropping—an issue I examine in the following section. Of course, any such gains would be individual to the farm, to the detriment of downstream farmers who benefit from forest hydrological services upstream.

Do Farmers Allocate Land Efficiently? An Empirical Test

The conceptual model provides the basis for empirically testing whether farms allocate land efficiently between cultivation and fallow. I construct two measures of land allocation between cultivation and fallow similar to López (1997). The first, which I term the private income elasticity of cultivated land, represents the percent change in individual farm income from a 1% expansion of cultivated area into fallow area. It corresponds to the first order condition for efficient land allocation under decentralized fallow management, given by equation (11) (substituting in for the steady state values of μ and η given by (15) and (16)). This term simply subtracts the marginal costs of cultivated area accruing to the farmer—namely, the marginal value of the lost fallow land and labor clearing costs[8]—from the marginal benefits of increased crop production. Written in elasticity form, the term is given by

[8] Manual slash-and-burn is more common in the region than renting expensive mechanized equipment, and farmers in the Zona Bragantina spend 30 days per year clearing land on average. Each additional hectare of

$$\varepsilon^{i}_{priv} = \frac{r^{i}_{crop}}{\pi^{i}}\left(\varepsilon_{x} - \frac{x^{i}}{r^{i}_{crop}}c\right) - \frac{x^{i}}{\pi^{i}}\left(\frac{1+r}{r + x^{i}/\overline{X}^{i}}\right)\left(\varepsilon_{\theta}\frac{r^{i}_{crop}}{\overline{X}^{i} - x^{i}} + \xi_{\theta}\frac{r^{i}_{for}}{\overline{X}^{i} - x^{i}}\right) \tag{19}$$

The private income elasticity of cultivated land varies with the amount of land under cultivation (x) and fallow ($\overline{X} - x$), the contributions of cropping and forest products to income (r_{crop}, r_{for}), total farm profits (π), and marginal land-clearing costs (c), factors that vary across all farms in the sample. It also depends on the elasticities of crop output with respect to cultivated area (ε_x) and on-farm fallow (ε_θ), and on the elasticity of forest product harvests with respect to on-farm fallow (ξ_θ), which can be approximated by the parameters from the crop and forest product equations estimated in Klemick (2007). Finally, the rate of interest (r) is an important determinant of the optimal allocation of land between cultivation and fallow. Higher interest rates justify lower levels of fallow biomass since the future value of fallow is discounted more heavily (López 1997). In the absence of primary data on interest rates in the region, I allow the interest rate to take on different values representing a range of plausible conditions in the Zona Bragantina.[9]

I also create a second measure of land use efficiency that I term the social income elasticity of cultivated land. This measure accounts for the contribution of fallow externalities to neighbors' farm profits, corresponding to the first order condition for land allocation under centralized fallow management (equation (2), substituting in (6) and (7)). This measure can be written as

land under production requires approximately 3 days of labor at a cost of $B 25. I derive marginal land clearing labor, which I value at the agricultural wage rate, by regressing land clearing labor on cultivated and fallow land (with a quadratic term for land). These regression results are available upon request.

[9] I consider interest rates of 6%, 10%, and 20% to reflect the range in subsidized credit programs and market interest rates faced by farmers in the region. The FNO credit program offers subsidized credit of up to $B5000 to farmers at 6% interest (Borner 2005). Meanwhile, market interest rates available to farmers in Brazil tend to fall within 16-20% (ERS/USDA 2005).

$$\varepsilon^i_{soc} = \frac{r^i_{crop}}{\pi^i}\left(\varepsilon_x - \frac{x^i}{r^i_{crop}}c\right) - \frac{x^i}{\pi^i}\left(\frac{1+r}{r + x^i/\bar{X}^i}\right)\left(\varepsilon_\theta \frac{r^i_{crop}}{\bar{X}^i - x^i} + \xi_\theta \frac{r^i_{for}}{\bar{X}^i - x^i} + \eta^i \sum_j^N \frac{1}{\eta^j(\bar{X}^j - x^j)}\left(\varepsilon_{\Sigma\theta} r^j_{crop} + \xi_{\Sigma\theta} r^j_{for}\right)\right) \tag{20}$$

This term represents the impact of a 1% increase in cultivated area on not only farm i's profits, but also accounting for the value of the lost externality to all N farms downstream. It includes the elasticities of crop output and forest product harvests with respect to upstream fallow ($\varepsilon_{\Sigma\theta}$, $\xi_{\Sigma\theta}$), also estimated in Klemick (2007). I calculate this term using these estimated parameters, as well as data on land use and farm income from the surveyed farmers, adopting the assumptions that fallow biomass density (η) is equal across farms within a sub-watershed and that farm revenues and fallow area among the sampled farms are typical of all of farm i's downstream neighbors.[10] I also estimate the variance of the private and social income elasticities using the variance-covariance matrices from the crop and forest product production functions.

Efficient allocation of land between cultivation and fallow from the individual farmer's perspective implies that the private income elasticity of cultivated land is equal to zero. If the elasticity is significantly greater than zero at the 1% level, I consider the farm to be over-fallowing from an individual perspective; if it is significantly less than zero, the farm is under-fallowing.[11] Socially efficient land allocation means that the

[10] Unfortunately, I have data only on fallow area, not biomass density, so I must assume that biomass density is equal across all farms to calculate the social income elasticity (allowing the η terms to cancel out). This assumption means that I will over(under)estimate the social income elasticity for farms with lower (higher) average biomass density than their downstream neighbors. In addition, since I do not have comprehensive data on farm income and fallow area among all farms in the surveyed communities, I approximate crop and non-timber product revenues and fallow area using per-hectare averages from downstream farmers included in the survey.

[11] It is worth noting as a caveat that the condition for optimal land allocation assumes that farmers are risk neutral and that fallow has no effect on crop yield risk. However, if farmers are risk averse and fallowing is

social income elasticity of cultivated land is equal to zero. If it is greater (less than) zero, the farm is over-(under-)fallowing with respect to community-level income.

Tables 6 and 7 present fallow management efficiency indicators for the sample of farmers who allocate some land to fallow.[12] Table 6 reports the private income elasticity of cultivated land (sample median) and binary indicators for over-, under-, and optimal fallowing across a range of interest rates. I find that 41-60% of farmers are fallowing optimally from an individual perspective, depending on the interest rate. Perhaps surprisingly, close to an equal number of farmers allocate too much land to fallow for individual profit maximization (40-59%). Indeed, the median farm could significantly increase farm profits by reallocating land—by around 0.33% for every 1% expansion of cultivation into fallow area. This elasticity corresponds to a gain in income of $B 212.79 from shifting one hectare of fallow into cultivation. Only one farmer in the sample devotes too little land to fallow from an individual perspective. Unsurprisingly, the appearance of over-fallowing increases if farms face a higher interest rate.

Turning to the social income elasticity of cultivated land in table 7, I cannot reject the hypothesis of optimal land allocation for the vast majority of farms (86-87%). Few farms (2-5%) over-fallow once beneficial externalities are accounted for. Perhaps more surprising is that few farmers under-fallow either—only 9-13%, depending on the interest rate. While community income would decrease if the median farmer converted land from fallow to cultivation, this effect is not statistically significant. Whether or not farmers

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a risk-mitigating input, then optimal land management may entail a greater allocation of land to fallow but appear as over-fallowing.

[12] Note that expressions (19) and (20) are undefined for farms that allocate no land to fallow (14% of the sample). I also exclude farms with negative profits (13%) from the analysis, as the expression for fallow management efficiency leads to a trivial and potentially misleading result—that such farms always over-fallow; the remaining sample includes 201 farmers. One farm has no fallow upstream, and so the social income elasticity of cultivated land is not defined, reducing the sample to 200.

deliberately account for the beneficial spillovers experienced by their downstream neighbors, the end result is that a socially efficient pattern of land management predominates. This pattern prevails to the detriment of some individual farmers, who could increase their individual incomes by expanding cultivated area.

These results contrast those of López (1993, 1997), who finds farmers in Ghana and Cote d'Ivoire holding fallow in common property to clear excessive amounts of fallow for cultivation relative to the social optimum, indicating that private property ownership may improve the efficiency of land management. They also raise the question of whether private over-fallowing that leads to beneficial community-level land management can be explained by market failures such as credit market failures or other constraints to intensification, an issue I explore in the next section.

Econometric Model of Fallow Management

I now consider what drives land allocation decisions among sampled farmers in the Zona Bragantina, many of whom appear to be allocating too much land to fallow from an individual perspective while making land use decisions that benefit the community. I jointly examine the determinants of (1) the private income elasticity of cultivated land (a measure of over-fallowing) and (2) the percent area allocated to fallow to investigate potential constraints to efficient land use.[13] While area in fallow and over-fallowing are certainly related, they may be prompted by different factors. The conceptual model suggests that fallow allocation responds to market and agro-ecological conditions, while

[13] I originally included the social income elasticity of cultivated land in this analysis as well, but the explanatory variables explained very little of the variation in this measure of over-fallowing. Since the two over-fallowing measures are highly correlated, I focus on the private income elasticity of cultivated land to draw intuition about the drivers of inefficient land management among the sampled farmers.

fallowing more than the optimal amount of land could be caused by liquidity market failures that restrict input purchases.

Building on the literature on the causes of tropical deforestation, I consider a variety of socioeconomic and agroecological variables that may drive land-use decisions. Recent studies using satellite data have demonstrated the importance of spatial characteristics like slope, soil quality, rainfall, and distance to roads and markets as determinants of land conversion. Research focusing specifically on land allocation to forest fallow in the Amazon has highlighted off-farm income, distance from markets, soil quality, and land and labor availability (Scatena et al. 1996; Coomes et al. 2000; Perz and Walker 2002). These studies offer intuition about the expected effects of a range of variables on land allocation and management efficiency.

Farms could be constrained in the amount of land they can profitably cultivate if they lack sufficient savings, cash income from off-farm sources, or credit to purchase optimal quantities of inputs or make capital investments important for continuous cultivation. However, recent studies from tropical forested regions have reached no firm conclusions about the role of credit in forest and fallow management. Municipio-level credit infrastructure did not significantly affect Amazonian deforestation levels when controlling for population and road density (Pfaff 1999). Commercial credit use among households in a Pará frontier community had no impact on the share of land under fallow, but off-farm income and ownership of mechanized equipment were negatively associated with fallowing, suggesting that liquidity could affect fallow management (Perz and Walker 2002). Land clearing among small-scale Brazilian farmers in Pará and Rondônia was associated with increased chemical input use, a finding consistent with the hypothesis that credit constraints limit expansion of cultivated area (Caviglia-Harris and Sills 2005). Municipio-level use of subsidized credit was associated with deforestation in a study of Chiapas and Oaxaca, Mexico (Deininger and Minten 2002). A review of several empirical studies found deforestation to be positive associated with credit availability but negatively correlated with off-farm income opportunities (Angelsen and Kaimowitz 1999). Liquidity constraints have also been associated with suboptimal input use in El Salvador (López and Romano 2000).

I use farmer-reported commercial credit use and off-farm income (separated into wage income from agricultural and non-agricultural activities, and non-wage income such as pensions, scholarships, and remittances) as three binary measures of liquidity. Actual credit use may be arguably endogenous, depending not only on access to credit but also risk preferences, shocks, and farm technology choice. In addition, credit access could be vulnerable to reverse causality with land and input management if farmers parlay better farm management abilities into improved credit-worthiness. However, including this variable serves as an indicator of the correlation between credit availability and land and input management even if I cannot draw firm conclusions about the direction of causality. This analysis also offers a complementary perspective to studies examining municipio-level credit availability by examining household credit use. Off-farm income could also be endogenous if better management skills lead to improved off-farm employment opportunities, again preventing strong conclusions about the direction of causality, but still demonstrating whether indicators of liquidity are correlated with fallow and input use.

While evidence on the role of credit and land use remains ambiguous, the effect of transportation infrastructure on forest cover is quite robust across many studies. Road density and distance to capital cities significantly predicted deforestation in the Amazon (Pfaff 1999; Chomitz and Thomas 2003). The road infrastructure-deforestation relationship has also been found in other tropical forested regions, including Belize, Mexico, and Thailand (Chomitz and Gray 1996; Nelson and Hellerstein 1997; Cropper, Puri, and Griffiths 2001). The relationship has only been shown to be reversed for Mexican shade coffee plantations, which rely on tree cover as a factor of production (Blackman et al. 2008). I include village-level transportation frequency and household-level distance to market to capture the effect of transportation infrastructure.

Agroecological factors such as soils and slope can make fallowing more attractive on certain farms than others. Studies from the Amazon (Chomitz and Thomas 2003; Pfaff 1999) and elsewhere (Cropper, Puri, and Griffiths 2001; Chomitz and Gray 1996; Nelson and Hellerstein 1997; Deininger and Minten 2002) have showed that deforestation is more likely to occur on land with good quality soil and flatter slopes.

Commodity prices are also potentially important determinants of land allocation. As indicated by the conceptual model, higher forest product prices and fertilizer prices encourage fallowing, while higher crop prices spur more cultivation. Community-level characteristics of relevance for land use might include land size, population, and infrastructure. Population density has been shown to be an important deforestation determinant in several studies (e.g., Cropper and Griffiths 1994; Deininger and Minten 2002), though in the Amazon the effect is more pronounced in less populous municipios (Pfaff 1999). I include telephone access an indicator of infrastructural development.

Other potential determinants of fallow management include education and extension assistance. I use the household head's years of schooling and use of extension as indicators of farm management ability and access to information about agricultural technology. Farm ownership could also be an indicator of liquidity and land tenure security, which has been found to be associated with deforestation (Angelsen and Kaimowitz 1999). I include farm landholdings and household size to examine whether land or family labor constraints affect land allocation decisions. Municipality dummies are also included in the regressions.

Econometric Issues

The private income elasticity of cultivated land is measured with error because of its construction using estimated parameters from the econometric analyses in Klemick (2007). Measurement error in the dependent variable is subsumed by the error term of the equation (Greene 2000), so as long as the explanatory variables are unrelated to the measurement error of the constructed over-fallowing variable, regression estimates are consistent despite the measurement error problem.

The private income elasticity of land is undefined for farms that allocate no land to fallow, so I must exclude 14% of farms from the analysis. To account for potential selection bias, since farms that use continuous cultivation likely use a different production system than those reliant on fallowing, I estimate a first-stage probit equation for the farm's decision to allocate any land to fallow. I construct the inverse Mills ratio using the parameters from the probit estimation to include in the percent fallow area and over-fallowing equations as test for selection bias, per Heckman (1979).[14]

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[14] The conceptual model provides little guidance as to valid exclusion restrictions that affect the decision of whether to fallow but not the amount of land or extent of over-fallowing. I include dummy variables

Because the private income elasticity of cultivated land was constructed from parameters estimated from equations involving variables that could be important determinants of fallow management—in particular, prices, slope, farmer education, and extension assistance—these variables must be excluded from the elasticity equation due to endogeneity concerns.[15] These variables can, however, be included as right hand side variables in the percent fallow area equation.

Spatial autocorrelation in the error terms of the equations due to unobserved factors important in fallow management that vary across space could lead to inefficient parameter estimates. Diagnostic tests indicate that spatial autocorrelation is not important in the over-fallowing and percent area under fallow equations,[16] so I do not account for spatial autocorrelation in the reported regression results. I do increase the efficiency of the parameter estimates by jointly estimating the two equations with a seemingly unrelated regression (SUR) model.

Results

The probit estimates for the determinants of allocating some land to fallow give some initial intuition as to the characteristics important for land management among the sampled farmers (table 8). Farmers who own their land, have larger landholdings, and have poor quality soil are more likely to devote land to fallow, suggesting that greater access to land allows farmers to use fallow rather than relying on chemical inputs to

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indicating production of perennial crops and three soil types—poor (*arisca*), black clay (*massape*), and charcoal-enriched (*preta*)—in the fallow selection equation but not the two continuous equations. Theses variables are not significant in explaining the percent area in fallow or over-fallowing (p = 0.74).

[15] If these variables are included in the private income elasticity of cultivated land equation, they are not jointly significant (p = 0.54), and the coefficient estimates of the remaining variables do not change.

[16] A Lagrange multiplier test indicates that the error term of the over-fallowing equation is not significantly spatially autocorrelated (p = 0.53), and while the percent area in fallow equation error is spatially autocorrelated (p = 0.03), the spatial autocorrelation coefficient in a spatial regression estimation of percent area under fallow is not significantly different from zero. In addition, a Lagrange multiplier tests rejects the hypothesis of spatial lags in the two dependent variables (p = 0.68, 0.29).

improve soil fertility. Those who grow perennial crops and have telephone access in the community are more likely to practice continuous cultivation that requires no fallowing.

Table 9 gives the SUR estimation results for the private income elasticity of cultivated land and the percent area under fallow. The error terms of the two equations are positively and significantly correlated, indicating a gain in efficiency from estimating the system jointly. Selection bias does not appear significant in either equation as indicated by the coefficient on the inverse Mills ratio from the probit model of fallowing.

Of particular interest are the effects of the liquidity indicators on fallowing. Commercial credit use is negatively and significantly correlated with over-fallowing. It also has a negative but not significant effect on percent area under fallow, suggesting that lack of access to credit encourages fallowing, but the effect is more pronounced for those farmers who stand to gain the most from expanding cultivation. Farmers without off-farm wage and non-wage income are also more likely to over-fallow, though neither effect is statistically significant. However, non-wage income has a positive and significant effect on area under fallow. Since most non-wage income among sampled farmers comes from pensions, this finding could indicate that farmers of retirement age work their land less intensively, though the household head's age, which was included in a previous specification of the equation, had no effect on fallow management.

These results suggest that credit constraints may play a role in restricting farmers' opportunities for expanding cultivated land at the expense of fallow, whether through purchasing sufficient inputs, investing in capital or infrastructure, or other channels. Off-farm income constraints appear to be less important in land management decisions.

Transportation indicators have no significant effect on the private income elasticity of cultivated land but do appear to be important in explaining area under fallow. Village-level transportation frequency is negatively and significantly associated with fallow area, and the household's distance from local markets has a positive (though not significant) effect. These findings echo those from other studies showing a strong link between market access and deforestation, even in a long-settled region like the Zona Bragantina, where proximity to regional markets is relatively high. However, the results do not apply to the private income elasticity of land; lack of access to markets does not appear to drive farmers to under-allocate land to cultivation.

Farm size is also an important determinant of over-fallowing, suggesting that some farms hold excess land that they could productively cultivate but do not, though farm size does not affect the total allocation of land to fallow. Other household characteristics—farm ownership, the household head's education level, and use of extension services—have no discernable impact on fallow management. Forest product prices encourage greater allocation of land to fallow, as predicted by the conceptual model, though crop output and fertilizer prices have no noticeable effect. Slope also seems to be unimportant in determining the share of land under fallow, in contrast to other empirical studies of the Amazon (though the sign is negative as expected), possibly because there is little steeply sloped land in the Zona Bragantina.

Community-level characteristics also appear important in explaining fallow management decision. Farms located in more densely populated communities, as indicated by a negative and significant coefficient on physical size and a positive coefficient on the number of families, tend to over-fallow more, while the opposite holds true for percent area under fallow. The latter result is consistent with previous empirical work in the Amazon, showing deforestation to be correlated with population density. It is possible that the former result arises if farmers are aware of beneficial hydrological externalities from fallow and more densely settled communities are more effective at encouraging socially efficient land use. Farms in communities without phone access are also more likely to over-fallow, possibly indicating that there are infrastructural barriers to agricultural intensification in these areas.

Conclusions & Implications for Tropical Forest Policy

The empirical findings are consistent with predictions from the theory that liquidity constraints limit overexploitation of fallow biomass resources. Because fallow provides positive externalities to downstream farms, these liquidity constraints could act as a second-best option to keep excessive land clearing in check and prevent loss of community income due to diminished hydrological services from forest cover. Some farmers—in particularly those who do not use commercial credit—bear private costs in the form of reduced income from cultivation.

The findings on the role of credit constraints in land use have important implications for policy-makers pursuing the objectives of poverty alleviation and forest conservation in the Amazon. The existence of beneficial spillovers implies that removing liquidity constraints or other barriers to agricultural intensification has ambiguous implications for community-level income. Most sampled farmers' land allocation is already socially optimal (and, on balance, tends toward under-fallowing once positive externalities are considered), implying that increased use of commercial credit to expand cultivation under the current production system is likely to lead to income losses from reduced hydrological services. Current Brazilian government proposals to increase credit availability to smallholders through new subsidized programs (e.g., Proambiente) should be assessed in light of these findings. Nonetheless, shying from economic development that would bring improved access to financial services to the region is not likely to be a desirable strategy in meeting the dual objectives of poverty alleviation and environmental protection.

The findings on liquidity constraints, coupled with the importance of local hydrological externalities, add to the growing evidence suggesting that direct payments to farmers for conserving forest or fallow on a per-hectare basis offer a more compelling solution to raise incomes while expanding forest cover. Such schemes have received considerable attention lately as a strategy to promote reduced emissions from deforestation and forest degradation (e.g., Myers 2007, *The Economist* 2008). Such payments could theoretically be set at a level to achieve the socially optimal allocation of land between cultivation and fallow. They could also serve to alleviate liquidity constraints hindering optimal input use, leading to a first-best outcome for the community income. While such programs will no doubt be expensive to fund, direct payments for forest land may be the approach with the most potential to achieve the elusive “win-win” scenario for tropical forest livelihoods.

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Table 1 Comparative Statics with Centralized Management and Complete Markets (Cobb-Douglas Production)

	dq	dp	dw	dv
dx_i	-	+	?	-
$d\theta_i$	+	-	?	+

Table 2 Comparative Statics with Decentralized Management and Incomplete Labor and Credit Markets (Cobb-Douglas Production)

	dM	dw	dR
dx_i	?	+	+
$d\theta_i$	?	-	-

Table 3 Household Characteristics (271 households)

	Mean	Standard deviation
Farm size (ha)	40.73	(47.97)
Percent area under fallow	54%	(31%)
Allocate some land to fallow 1 = yes, 0 = no	0.86	(0.35)
Household size (members)	6.18	(2.78)
Own farmland (legal title) 1 = yes, 0 = no	0.65	(0.48)
Household head education (years)	3.77	(2.91)
Use extension services 1 = yes, 0 = no	0.24	(0.43)
Distance from household to market (km)	23.68	(12.41)
Farm profits ($B[17])	4079.78	(9345.83)
Farms with wage income 1 = yes, 0 = no	0.52	(0.50)
Farms with non-wage income 1 = yes, 0 = no	0.56	(0.50)
Use of commercial credit (from bank) 1 = yes, 0 = no	0.30	(0.46)

[17] US$1 = $B 2.97, 2002 average

Table 4 Community Characteristics (22 communities)

	Mean	Standard deviation
Transportation frequency 1 = 1x/week, 2 = 2x/week, 3 = 3x/week, 4 = 1x/day, 5 = >1x/day	3.86	(1.37)
Number of families	136.28	(96.54)
Community diameter (km)	7.26	(4.98)
Phone in community 1 = yes, 0 = no	0.60	(0.49)

Table 5 Income Elasticities of Cultivated Land, On-farm Fallow, and Upstream Fallow (reproduced from Klemick 2007)

	Mean	Standard deviation
Income elasticity of cultivated land	0.41***	(0.10)
Income elasticity of on-farm fallow	0.11*	(0.06)
Income elasticity of upstream fallow	0.42**	(0.16)

Table 6 Fallow Management Indicators for Individual Profit Maximization (201 obs)

	6% interest rate	10% interest rate	20% interest rate
Private income elasticity of cultivated land (sample median)[18]	0.32** (0.14)	0.33** (0.13)	0.35*** (0.13)
Over-fallow (1 = yes, 0 = no)	0.40	0.49	0.59
Under-fallow (1 = yes, 0 = no)	0.005	0.005	0.005
Optimal fallow (1 = yes, 0 = no)	0.60	0.51	0.41

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 7 Fallow Management Indicators for Community Profit Maximization (200 obs)

	6% interest rate	10% interest rate	20% interest rate
Social income elasticity of cultivated land (sample median)	-0.43 (0.34)	-0.29 (0.30)	-0.15 (0.24)
Over-fallow (1 = yes, 0 = no)	0.02	0.04	0.05
Under-fallow (1 = yes, 0 = no)	0.13	0.12	0.09
Optimal fallow (1 = yes, 0 = no)	0.86	0.85	0.87

* significant at 10%; ** significant at 5%; *** significant at 1%

[18] The net elasticity of cultivated land is only defined for farms with some amount of fallow land.

Table 8 Probit Estimates: Farm Allocates Some Land to Fallow (1 = yes, 0 = no)

Commercial credit use (binary)	0.375
	[0.416]
Wage income (binary)	-0.225
	[0.309]
Non-wage off-farm income (binary)	0.104
	[0.295]
Distance from market (km)	0.041
	[0.027]
Transportation frequency	0.213
	[0.183]
Log farm size	0.344***
	[0.126]
Log household size	0.332
	[0.299]
Household head years of education	-0.03
	[0.046]
Use extension services (binary)	0.66
	[0.494]
Farm owner (binary)	1.106***
	[0.342]
Slope (degrees)	0.106
	[0.093]
Poor (*arisca*) soil	1.263**
	[0.611]
Black clay (*massape*) soil	0.025
	[0.705]
Charcoal enriched (*preta*) soil	0.795
	[0.684]
Grow perennial crops	-1.191***
	[0.405]
Forest product price (farmer-reported)	0.087
	[0.061]
Crop output price index	0.506
	[0.355]
Fertilizer price index	2.356
	[2.693]
Number of families in community	-0.001
	[0.003]
Community diameter (km)	0.047
	[0.062]
Phone in community (binary)	-1.664**
	[0.700]
Castanhal municipality (binary)	0.282
	[0.720]
Igarapé Açu municipality (binary)	0.55

	[0.725]
Constant	-5.385
	[3.371]
Observations	271
Pseduo R-squared	0.50
Log likelihood	-54.95

Standard errors in brackets
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 9 Seemingly Unrelated Regression Estimates: Over-fallowing and Percent Area in Fallow

	Income elasticity of cultivated land	Percent area in fallow
Commercial credit use (binary)	-0.509**	-0.065
	[0.252]	[0.044]
Wage income (binary)	-0.329	0.024
	[0.209]	[0.034]
Non-wage off-farm income (binary)	-0.104	0.063*
	[0.221]	[0.035]
Distance from market (km)	0.001	0.004**
	[0.009]	[0.002]
Transportation frequency	0.116	-0.016
	[0.092]	[0.016]
Log farm size	0.411***	0.029
	[0.115]	[0.018]
Log household size	-0.084	-0.037
	[0.231]	[0.036]
Household head years of education		0.005
		[0.006]
Use extension services (binary)		-0.045
		[0.046]
Farm owner (binary)		0.051
		[0.041]
Slope		-0.002
		[0.007]
Forest product price (farmer-reported)		0.002*
		[0.001]
Crop output price index		0.031
		[0.035]
Fertilizer price index		-0.228
		[0.284]
Number of families in community	0.003	-0.001*
	[0.002]	[0.000]
Community diameter (km)	-0.084**	7.62e5
	[0.034]	[0.005]
Phone in community (binary)	-0.882**	0.012

	[0.391]	[0.073]
Inverse mills ratio (fallow selection)	-0.064	-0.072
	[0.612]	[0.111]
Castanhal municipality (binary)	0.737*	0.124
	[0.438]	[0.079]
Igarapé Açu municipality (binary)	0.610**	0.167**
	[0.305]	[0.071]
Constant	-0.858	0.623*
	[0.780]	[0.326]
Observations	201	201
R-squared	0.17	0.23

Breusch-Pagan test of independence of residuals: chi2(1) = 6.26 (p = 0.01)
Standard errors in brackets
* significant at 10%; ** significant at 5%; *** significant at 1%