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Constraints or Cooperation? Determinants of Secondary Forest Cover Under Shifting Cultivation

Heather Klemick

This study examines the drivers of land use in a shifting cultivation system with forest fallow. Forest fallow provides on-farm soil quality benefits, local hydrological regulation, and global public goods. An optimal control model demonstrates that farmers have an incentive to fallow less than is socially optimal, though market failures limiting crop production can have a countervailing effect by encouraging fallow. An econometric model estimated using data from the Brazilian Amazon suggests that fallowing does not result from internalization of local fallow services but instead is associated with poor market access and labor and liquidity constraints.

Key Words: forest, farms, fallow, ecosystem services, land use, spatial econometrics, Brazil, credit

About 300 million people worldwide practice shifting cultivation, or slash-and-burn farming, making it a critical driver of carbon cycling in the tropics. Secondary forests growing on fallow land make up a considerable portion of once-deforested land throughout the Amazon—around 30 percent, by some estimates (Houghton et al. 2000)—underscoring the importance of understanding this land-use pattern. Recent research has called attention to the contribution of secondary forest growth to mitigating the loss of ecosystem services caused by tropical deforestation (Wright and Muller-Landau 2006, Stokstad 2009). However, the determinants of forest cover in agricultural systems have received little attention relative to natural ecosystems (Blackman et al. 2008).

This study examines the drivers of farmers' allocation of land to secondary forest fallow. I use household survey and satellite data from the Bragantina area of the Brazilian Amazon, an area that is well-poised to provide insights about future land-use patterns in frontier regions being rapidly settled throughout the Amazon due to its long history of colonization and secondary-forest–dominated landscape.

Forest fallow provides on-site benefits to farmers, such as soil restoration, erosion prevention, and weed and pest control. 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, long fallow periods are a cost-effective way to restore soil quality only where the opportunity cost of land is low. Agronomic studies documenting the restorative effects of fallowing on soil quality rarely consider the tradeoffs inherent in keeping land out of cultivation.

I present a conceptual model of shifting cultivation that distinguishes between the on-site benefits and local positive externalities of fallow. Others have noted that excessive land-clearing can

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occur in order to establish property rights. This model instead highlights the potential for beneficial spillovers to lead to inefficient fallow management even when farmers have secure tenure. In the presence of local fallow externalities, individual profit maximization could lead to excessive forest-clearing. The model also illustrates how cooperative land management and market failures that limit use of agricultural inputs are two alternative (though not mutually exclusive) reasons why farmers might devote more land to fallow than would maximize individual profits.

I then use cross-sectional farm survey data from the Bragantina area of the Brazilian Amazon to examine the factors that affect farmers' allocation of land to fallow. A related study using the same data found that farmers' allocation of land between cultivation and fallow often exceeded the individual profit-maximizing level but was efficient from the perspective of the entire community (Klemick 2011). Positive local externalities provide a social, but not individual, rationale for the maintenance of large fallow areas. It is possible that community management institutions, market failures limiting agricultural expansion, or other factors encourage farmers to devote excess land to fallow.

I estimate a spatial econometric model to examine several potential drivers of fallowing decisions. The presence of hydrological externalities that flow from upstream to downstream suggests a test of the cooperative management hypothesis, since under cooperative institutions, upstream farmers should maintain more fallow than their neighbors downstream. I include indicators of market access such as credit access, off-farm income, and transportation infrastructure to test whether market failures play a role in fallow allocation. I also consider other drivers suggested by the conceptual model and previous literature, including land tenure, land quality, household characteristics, and market prices.

Drivers of Tropical Deforestation and Fallow Management

Much of the literature on deforestation is based on the land-rent model, noting that the net benefits to different land uses vary with agroclimatic and socioeconomic characteristics. These studies have drawn attention to the roles of soil quality, market access, population density, and off-farm work in land conversion in the Amazon (Pfaff 1999, Chomitz and Thomas 2003) and elsewhere (Chomitz and Gray 1996, Nelson and Hellerstein 1997, Cropper, Puri, and Griffiths 2001, Deininger and Minten 2002, Angelsen and Kaimowitz 1999).[1]

Evidence on the effects of land tenure security and credit availability on deforestation has been mixed (Angelsen and Kaimowitz 1999). Secure land tenure has tended to reduce the probability of deforestation in empirical household-level studies (Pínchon 1997, Godoy et al. 1998), unless land-clearing is undertaken in order to establish tenure. Deforestation has often been positively associated with credit availability, though a study from the Amazon including municipality credit infrastructure found no correlation between the two (Pfaff 1999).

Research focusing on secondary forest fallow in shifting cultivation systems raises similar issues, highlighting off-farm income, distance from markets, soil quality, credit availability, and land tenure. Perz and Walker (2002) found that off-farm businesses were negatively associated with secondary forest growth, while credit use was unrelated. Tenure insecurity in communal property arrangements in West Africa has been shown to be associated with inadequate fallowing (Goldstein and Udry 2008, López 1993, 1997). Family labor availability and the labor-leisure tradeoff are important for land use under incomplete labor markets (Coomes, Grimard, and Burt 2000, Perz and Walker 2002, Caviglia-Harris 2004). Land availability also plays a role, with several studies finding that smaller farms cultivate land more intensively (Scatena et al. 1996, Smith et al. 1999). A bio-economic farm-level linear programming model calibrated using the same data as this paper found that payments for ecosystem services, a tightening of the legal restrictions on forest-clearing, and adoption of Brazil's proposed *Proambiente* smallholder credit program that promotes mechanical mulching of fallow and restricts chemical fertilizer use would lead to in-

[1] Some of these results have been shown to be reversed in Mexican shade coffee plantations, which rely on tree cover as a factor of production (Blackman et al. 2008).

creases in secondary forest cover, though the latter two policies would do so at the expense of farm income (Borner, Mendoza, and Vosti 2007).

A few studies have explored how cooperative management affects land-clearing. Cooperative natural resource management has been found in situations where social cohesion fosters effective communication and enforcement mechanisms (Ostrom 1990). Alix-Garcia, de Janvry, and Sadoulet (2005) found that Mexican agricultural communities' use of common-property forests depended on the number of households expected to gain from cooperation.[2]

Recent studies have also noted the importance of the location of farms not just in relation to geographical features like roads, but to each other. Alix-Garcia (2007) showed that the location of deforestation on communal property in Mexico depended on not just the absolute but the relative quality of land parcels within the community. Several studies have found a spatial lag in deforestation, indicating that farmers' land-clearing decisions were influenced by their neighbors, though the direction of the effect is not consistent across studies (Robalino, Pfaff, and Sanchez-Azofeifa 2007, Caldas et al. 2007, Nelson and Hellerstein 1997). This study builds on the literature by investigating the effect of spatial interactions, community cooperation, and missing markets on privately owned land managed in a shifting cultivation system.

Conceptual Model of Shifting Cultivation with Fallow Externalities

Shifting cultivation involves a tradeoff between expanding cultivation today and restoring land quality for cultivation in the future. Models of shifting cultivation have specified land quality as a function of fallow length or area (Larson and Bromley 1990, Barrett 1991, Krautkraemer 1994). López (1993, 1997, 1998) modeled the fallow biomass stock as a village-level common property resource that contributed to productivity. In the absence of community-level management, individual households undervalued biomass and allocated too much land to cultivation, decreasing income for the village as a whole.

I examine the inefficiencies that can arise in fallow management under private land ownership when local externalities associated with forest cover create the scope for inefficient management.[3] The tenure security assumption obviates the need to examine land-clearing as an investment decision to establish use rights in an open-access regime (Takasaki 2007). Under private land ownership, fallow biomass is not a common property resource, but rather a private resource supplying beneficial spillovers.

Total fallow biomass on farm i, $\theta_i(t)$, is equal to the farm's average fallow biomass density, $\eta_i(t)$, times the land area left fallow. Letting A_i represent total farm area and $x_i(t)$ cultivated area, this relationship can be written $\theta_i(t) = \eta_i(t)[A_i - x_i(t)]$. Average biomass density is a stock variable that captures the relationship between fallow and cultivation: a greater fraction of land under cultivation leads to shorter average fallow periods and less biomass accumulation (López 1993). Average biomass density on fallow land thus declines with the biomass extracted during land-clearing, which is proportional to the fraction of land under cultivation, and increases at a constant exogenous rate b:

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

López included the village-level stock of fallow biomass as a factor of production. In contrast, I allow fallow to boost crop productivity through two separate effects—average on-farm biomass and local off-site biomass. These two effects capture the private soil-enhancing benefits and potential hydrological or other externalities of forest fallow.[4] On-farm fallow biomass can also yield forest products like wood or honey that can be harvested for consumption or sale.

[2] Other research has used game theoretic models to highlight the potential for conflict over land-clearing decisions (Angelsen 2001, Alston, Libecap, and Mueller 2000).

[3] This discussion expands on a similar optimal control model that appears in an online appendix to Klemick (2011), which can be accessed at http://aere.org/journals/.

[4] Local externalities with the potential to boost farm productivity include moderation of soil water flows and availability of pollinators for crop and honey production. Empirical studies have shown that off-farm forest cover is an important input to agricultural productivity in the Bragantina (Klemick 2011) and in other tropical farming systems (López 1993, 1997, Pattanayak and Kramer 2001, Pattanayak and Butry 2005).

The production function for farm i's crop and forest product output is

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

where $z_i(t)$ represents a vector of variable inputs like fertilizer and $l_i(t)$ represents farm labor. The production function is increasing and concave in all inputs, and all factors are gross complements. N is the total number of farms in the community, N_i represents the number of farms that provide ecological services to farm i, and

$$\sum_j^{N_i} \theta_j(t)$$

is the total fallow biomass on these farms. Since this paper considers a hydrological externality, N_i is the number of farms upstream of farm i.

The household maximizes the present value of the stream of revenues from crops and forest products, minus input and land-clearing costs, plus off-farm income. For the sake of tractability, I focus on profit maximization rather than utility maximization.[5] The household faces a labor endowment (net of leisure) L_i. Off-farm wage income is equal to the wage rate times this endowment minus farm labor; if farm labor exceeds the labor endowment, this indicates that labor is hired to work on the farm at the prevailing wage. A liquidity constraint limiting purchased input costs to the sum of off-farm income plus a capital endowment K_i is given by

$$vz_i(t) \le K_i + w[L_i - l_i(t)],$$

representing an illustrative market failure that could limit agricultural production. Assuming a discount rate δ, output price p, input price v, wage rate w, and land-clearing cost c, the household chooses land area, purchased inputs, and farm labor to maximize

$$\max_{x_i, z_i, l_i} \int_0^\infty \Pi_{it} e^{-\delta t} dt \text{ s.t. } \dot{\eta}_i = b - \frac{\eta_i(t) x_i(t)}{A_i}, \eta_i(0)$$

$$= \eta_0, x_i(t) \le A_i, vz_i(t) \le K_i + w[L_i - l_i(t)],$$

where

$$\Pi_{it} = pf^i\left(x_i(t), z_i(t), l_i(t), \theta_i(t), \sum_j^{N_i} \theta_j(t)\right)$$
$$-cx_i(t) - vz_i(t) + w[L_i - l_i(t)].$$

A social planner maximizing community-wide farm profits confronts a similar problem but instead chooses land, purchased inputs, and labor for all local farms:

$$\max_{x_i, z_i, l_i \forall i} \int_0^\infty \sum_i^N \Pi_{it} e^{-\delta t} dt \quad \text{s.t.} \quad \dot{\eta}_i = b - \frac{\eta_i(t) x_i(t)}{A_i},$$

$$\eta_i(0) = \eta_0, x_i(t) \le A_i, vz_i(t) \le K_i + w[L_i - l_i(t)].$$

Suppressing the time argument, the current value Hamiltonian for this problem is

$$H = \sum_i^N \begin{Bmatrix} pf^i\left(x_i, z_i, l_i, \theta_i, \sum_j^{N_i} \theta_j\right) - cx_i - vz_i \\ + w(L_i - l_i) + \mu_i\left(b - \dfrac{\eta_i x_i}{A_i}\right) \\ + \lambda_i[K_i + w(L_i - l_i) - vz_i] \end{Bmatrix}.$$

The Hamiltonian represents the current value of the sum of farm profits for the entire community, where μ is the costate variable representing the shadow value of the fallow biomass stock.

At steady-state levels of η and μ, long-run equilibrium biomass density and total biomass are inversely proportional to the share of land under cultivation such that

$$\eta_i = \frac{bA_i}{x_i} \text{ and } \theta_i = bA_i\left(\frac{A_i}{x_i} - 1\right).$$

Using these equalities and the necessary conditions for land allocation and the evolution of the biomass shadow value, the farmer's steady-state land allocation decision can be written as

$$(1) \quad pf_1^i - c - \left(\frac{\delta + 1}{\delta + x^i / A^i}\right)\eta_i \left\{pf_4^i + \sum_k^{M_i} pf_5^k\right\} = 0.$$

This condition illustrates that the marginal benefit of land under cultivation should equal the mar-

[5] The use of profit maximization to describe farm production decisions typically assumes that production is independent of household preferences. This assumption may be simplistic, as noted by other research on smallholder agriculture emphasizing the importance of the household production framework and labor-leisure tradeoff (Singh, Squire, and Strauss 1986, Caviglia-Harris 2004).

ginal costs in terms of land-clearing, foregone soil quality on-farm, and reduced positive externalities to other farms downstream, now and in the future. M_i is the number of farms downstream to which farm i provides hydrological services, and f_5^k is the marginal productivity of off-farm fallow on these farms. Without the steady-state assumption, equation (1) would contain an extra term

$$-\frac{\eta_i}{A^i(\delta + x^i/A^i)}\dot{\mu}_i,$$

which represents an additional cost to expanding cultivation if the biomass stock is declining over time rather than stable, implying a rising shadow value (López 1998). Conversely, if biomass is growing over time, expanding cultivation is less costly.

I derive comparative statics to infer how various parameters affect the amount of cultivated land and fallow maintained by farmers, depending on whether the liquidity constraint is binding.[6] I retain the steady-state assumption and also assume that other farms are in equilibrium for the sake of tractability, but the results are not materially affected by these assumptions.[7] Table 1 indicates that higher discount rates and crop prices always encourage expansion of cultivated area at the expense of fallow. An increase in the number of downstream farms, M_i, boosts fallowing if farm i accounts for the positive externalities it provides, as assumed under cooperative management. More fallow on neighboring farms upstream has a direct positive effect on cultivated area, but when the household is liquidity-constrained, the net impact is ambiguous because on-farm labor and purchased inputs cannot both be increased as well; an increase in either of these inputs must be accompanied by a decrease in the other.

The effects of input prices and labor and capital endowments also depend on the liquidity constraint. If it is not binding, then increases in both input prices and wages discourage cultivation by drawing inputs and labor off-farm, respectively, and capital and labor endowments have no effect on land allocation decisions. If the household is liquidity-constrained, then purchased inputs and labor are underused relative to the optimal level, similar to López and Romano (2000). Rising input prices have an ambiguous effect on land allocation: they limit cultivation by making inputs more expensive, but also encourage on-farm work because off-farm labor is less effective in purchasing inputs. An increase in the wage rate has the opposite effect: it encourages a shift in labor from on- to off-farm activities but (assuming the household does not hire farm labor) allows increased input purchases. As the capital and labor endowments rise, the household has more capacity to increase both purchased inputs and labor used on-farm, leading to an expansion of cultivated area. Thus, households with limited access to capital and labor may devote more land to fallow than would be optimal if unconstrained, suggesting that market failures could have important impacts on land management patterns.

The optimal control model can be extended to consider a case without centralized or cooperative fallow management, in which farmers have no incentive to weigh foregone externalities as a cost. When farmers fail to internalize the biomass externality, they expand the area under cultivation. Aggregate community welfare in this case is lower due to underprovision of the externality. Assuming a steady state,[8] the land allocation condition becomes

$$(2) \qquad pf_1^i - c - \left(\frac{\delta+1}{\delta + x^i/A^i}\right)\eta_i\left\{pf_4^i\right\} = 0\,.$$

This expression is similar to equation (1), but it excludes the final term, which represents the value of the ecological services provided by farm i to downstream farmers, indicating that without cooperative institutions, farmers are expected to allocate too much land to cultivation. However, as

[6] Necessary conditions and steady-state comparative statics derivations are available from the author.

[7] If the steady-state assumption is relaxed to consider what happens if the fallow biomass stock declines over time (a situation of concern in many tropical forest margins), the comparative static results for land allocation remain qualitatively the same as those reported in Table 1, though if the biomass stock grows, it is theoretically possible that the results for the impact of the discount rate on cultivated land could reverse.

[8] The effect of the steady-state assumption in the individual profit-maximization case echoes that in the cooperative management case: if fallow biomass is declining, then clearing fallow has an additional cost, but the impacts of key parameters on land allocation remain qualitatively unchanged.

Table 1. Steady-State Comparative Statics

	$d\delta_i$	dp	dv	dw	dK_i	dL_i	dM_i	$d\sum_{j\neq i}^{N_i}\theta_j$
No liquidity constraints, cooperative profit maximization								
dx_i	+	+	-	-	0	0	-	+
$d\theta_i$	-	-	+	+	0	0	+	-
Binding liquidity constraints, cooperative profit maximization								
dx_i	+	+	?	?	+	+	-	?
$d\theta_i$	-	-	?	?	-	-	+	?
Binding liquidity constraints, individual profit maximization								
dx_i	+	+	?	?	+	+	0	?
$d\theta_i$	-	-	?	?	-	-	0	?

noted in the previous case, liquidity and labor constraints could be a countervailing factor curtailing expansion of cultivation. Accordingly, market failures that limit agricultural expansion below the privately optimal level could result in a second-best outcome in which land allocation is optimal from a community perspective, even if no cooperative management strategy exists.

Comparative statics for this case are qualitatively the same as under cooperative management (Table 1). One exception is the number of farms downstream of farm i; since farms do not internalize the value of the hydrological services they provide, M_i has no effect on land allocation.

These results suggest several testable hypotheses about land management in private tenure shifting cultivation systems. If farmers deviate from private income-maximization, are there institutional, socioeconomic, or other factors that help explain this decision? Do community enforcement mechanisms encourage farmers to internalize the value of the fallow externalities they provide to farmers downstream? Or are market failures responsible for potential deviations from individual profit-maximization? After discussing the study region and data, I return to these questions.

Study Region and Data

The Bragantina is a collection of 14 municipalities situated east of Belém, the state capital of Pará. The region has a century-long history of agricultural settlement and is relatively integrated into regional markets through railways and roads. Shifting cultivation remains the principal means of livelihood despite agronomic evidence that converting fallow to cultivated land and replacing the lost soil nutrients with chemical fertilizer could increase farm profits (Toniolo and Uhl 1995). Virtually all virgin forest in the region has been cleared for several decades, but secondary vegetation covers approximately 75 percent of total land area (Kato et al. 1999).

Data were collected as part of the SHIFT (Studies on Human Impact on Forests and Floodplains in the Tropics) project, an initiative to study livelihoods and ecosystem dynamics in Brazil. Three municipalities were selected to capture regional variation in distance to commercial centers, agricultural intensification, and agroecology. In late 2002, 271 households in 22 villages were randomly chosen and surveyed about their land use, cropping practices, sources of income, and other socioeconomic attributes.

Most of the sampled households are considered smallholders by Brazilian standards, with median landholdings of 25 hectares. While family labor and manual land-clearing and cultivation predominate, hired labor and mechanized equipment are also used for labor-intensive tasks like land preparation, weeding, and harvesting. The humid tropical climate supports rainfed cultivation, receiving rainfall of 2,400–2,700 mm annually. A typical one-to-two-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 consumed at home or sold to regional markets. Since the mid-twentieth century, smallholders have branched into perennials like black pepper, passion fruit, and oranges, as well as cattle production. Many farms also harvest non-timber forest products from their fallow plots.

Fallow in the study area is composed of a mosaic of vegetation in various stages of regrowth, from grasses and shrubs to closed-canopy tree cover. Typical fallow lengths of four to eight years result in tree cover reaching heights of three to ten meters. Forest fallow in Bragantina exhibits many similarities with virgin forest, providing similar levels of nutrient accumulation and below-ground carbon storage, though less above-ground carbon storage and tree species diversity (Sommer, Denich, and Vlek 2000, Holscher et al. 1997, Kato et al. 1999, Tucker, Brondizio, and Moran 1998).

Farmer-reported fallow area data are used to measure on-farm fallow and to estimate forest fallow upstream of each farm. As an alterative measure of upstream forest fallow, I use MODIS Vegetation Continuous Fields (VCF) GIS data. The VCF data consist of 25-hectare resolution pixels created using 40-day composite satellite images from March 2001 through March 2002 (Hansen et al. 2006). Each pixel represents percent canopy cover, defined as the amount of sunlight blocked by tree canopies over five meters high.[9] The resolution is sufficiently fine to reflect land use on farms in the region, since the median farm is 25 hectares. GIS data can be used to identify secondary forest fallow in the Bragantina because virtually all tree cover in the region is fallow rather than virgin forest.

I also use GIS flow direction data from the U.S. Geological Survey (1999) to determine where farms lie along a gradient from upstream to downstream. According to a flow direction map for the region, farms cluster into 11 groups defined by a common drainage area and flow direction. Each cluster includes at least one sampled community. I assume that, within each group, each observation affects farms downstream and is affected by farms upstream. I also use 1-km resolution data from the U.S. Geological Survey (1999) on slope and flow accumulation, defined as the size of the drainage area upstream of each farm.

Table 2 presents a variety of household and farm characteristics included in the analysis. Surveyed farmers kept a large portion of their land in fallow—almost 70 percent on average. However, 14 percent did not devote any land to fallow, practicing continuous cultivation with intensive use of chemical inputs instead of shifting cultivation. While fallow area data provide only a snapshot of land management patterns over a multi-year cycle, the decision to eliminate fallow in favor of continuous cultivation represents a more permanent shift in land management that is difficult to reverse, at least in the short-to-medium term. In addition, the hypotheses derived from the theoretical model still hold whether or not the system is in a steady state.

Most of the sampled households held title to the land they farmed (65 percent). Participation in off-farm jobs ranging from day labor to petty trading to teaching was common, with households earning an average of B$980. Many households also received remittances, scholarships, means-tested old-age pensions, or consumption subsidies for purchases of gas and food, resulting in B$1,671 of income on average. Despite a well-developed road network, the average household could access transportation to markets less than once a day, and an additional survey of 25 of the study participants found that 16 percent of the subsample identified transportation problems as a primary source of income risk (Borner 2006).

Farmers in the Brazilian Amazon can access commercial credit through the FNO (Fundo Constitucional de Financiamento do Norte), a program targeting low-interest loans to smallholders since the late 1980s. In practice, complicated bureaucracy and other transaction costs often render the loans inaccessible (Andrae and Pingel 2001). PRONAF (National Program for the Strengthening of Smallholder Agriculture), a late-1990s government initiative to fund agro-industrial projects,

[9] GIS coordinates are missing for 10 farms in the sample. The survey-derived upstream fallow variable is missing for an additional 25 observations that had no upstream neighbors among the sampled farmers. Table 2 indicates that fallow area is more prevalent than canopy cover on average (covering 68 percent of upstream area versus 25 percent), which is unsurprising since canopy cover excludes vegetation under five meters tall.

Table 2. Household Characteristics (271 households)

	Mean	Std. Dev.
FALLOW MANAGEMENT VARIABLES		
Percent area under fallow	0.69	(0.33)
Allocate some land to fallow (1 = yes, 0 = no)	0.86	(0.35)
Percent area under fallow on all upstream farms within the same sub-watershed (survey data)	0.68	(0.19)
Percent area under canopy cover at least 5 meters high on upstream land within 3 kilometers (GIS data)	0.25	(0.09)
AGROECOLOGICAL CHARACTERISTICS		
Flow accumulation (kilometers squared)	18.07	(79.19)
Slope (degrees)	2.65	(2.54)
SOCIOECONOMIC CHARACTERISTICS		
Farm size (hectares)	40.73	(47.97)
Household head education (years)	3.81	(2.98)
Present working age (16–64) household members	2.99	(1.60)
Absent working-age household members	0.75	(1.39)
Present non–working-age household members	2.22	(1.72)
Absent non–working-age household members	0.08	(0.33)
Distance from household to market (kilometers)	23.10	(12.50)
Transportation frequency (1 = 1×/week, 2 = 2×/week, 3 = 3×/week, 4 = 1×/day, 5 = >1×/day)	3.86	(1.37)
Off-farm wage income (R$)[a]	979.67	(2,116.84)
Off-farm non-wage income (pensions, remittances, public assistance, scholarships) (R$)	1,670.78	(4,017.43)
Access to credit (1 = yes, 0 = no)	0.55	(0.50)
Own farmland with legal title (1 = yes, 0 = no)	0.65	(0.48)
Community association meetings per month	0.68	(0.45)
Purchased input expenditures (R$)	1,039.05	(3,445.65)
Agricultural revenue (R$)	7,435.88	(14,685.36)
PRODUCTION PRICES		
Community crop price average (R$/kg)	1.94	(0.86)
Farmer-reported forest product price average (R$/kg)	6.95	(14.18)
Community fertilizer price average (R$/kg)	0.93	(0.10)

[a] US$1 = R$2.97, 2002 average.

also offers credit to smallholders. Thirty-one percent of sampled farmers obtained bank credit during the previous decade, and an additional 24 percent reported that it would be easy or very easy to obtain a loan. Thus, small-scale farmers in the Bragantina have better access to credit than their peers in other rural areas of Latin America, in keeping with the higher level of economic development in the region.[10]

[10] A survey of six Latin American countries found credit accessible to only 8–33 percent of farmers (López and Valdéz 2000).

A related study using the same data measured the contribution of cultivated area, on-farm fallow area, upstream fallow area, and other inputs to agricultural production among surveyed households (Klemick 2011). It found that on-farm and upstream fallow were both important factors of production, confirming that fallow provides valuable ecosystem services to local agriculture, some internal to the farm and some external.

Klemick used the estimated elasticities from the farm production function to test whether farmers allocated land efficiently between cultivation and fallow either from an individual perspective or from a community perspective (i.e., considering the value of local externalities to downstream farmers). Equations (1) and (2) from the optimal control model provided the basis for these two tests, respectively. The results showed that a majority of farmers allocated too much land to fallow to maximize individual profits, but the resulting pattern of land allocation was efficient for the entire community due to positive local externalities. The average farm could have significantly increased farm profits by R$574 for every hectare of fallow cleared and put into cultivation (a 0.42 percent increase in profits for every 1 percent expansion of cultivation into fallow area). However, additional clearing would not have increased community-level profits because expanding cultivation would have reduced farm productivity downstream. These results suggest a deviation from individual profit-maximizing behavior in the study area, but they shed no light on the reasons for this pattern.

Econometric Model of Fallow Management

In this section, I consider several potential drivers of land allocation among sampled farmers in Bragantina. I estimate a model that, in its simplest form, can be written as

$$\frac{A_i - x_i}{A_i} = \beta_o + \beta_1 H_i + \beta_2 Y_i + \varepsilon_i \,. \tag{3}$$

The dependent variable represents the percent area allocated to fallow on farm *i* (retaining the notation from the optimal control model). *H* and *Y* are vectors of household socioeconomic and agroecological attributes expected to affect land allocation, while ε_i is a white noise error term.

Because fallowing is censored, with 14 percent of the sample practicing continuous cultivation without fallow, I estimate a two-part hurdle model (Wooldridge 2001). The hurdle model allows me to examine the effects of the explanatory variables on both the decision to use shifting cultivation and the amount of land allocated to fallow conditional on using shifting cultivation, rather than assuming that the variables have the same effect across the two decisions.[11] The model can be written as

$$\text{(4)} \quad D_i = \alpha_o + \alpha_1 H_i + \alpha_2 Y_i + v_i, \qquad D = \{0,1\}$$

$$\frac{A_i - x_i}{A_i} = \beta_o + \beta_1 H_i + \beta_2 Y_i + \varepsilon_i \quad \text{if } D_i = 1,$$

where *D* denotes a dummy variable indicating allocation of some land to fallow. The selection equation is estimated using a probit model, while the conditional outcome equation can be estimated by ordinary least squares.

I also estimate a spatial econometric model to account for potential interactions among fallow management patterns across the landscape. Since upstream fallow significantly improves downstream productivity in the study area (Klemick 2011), it is possible that farmers take upstream land cover into account in their fallow management decisions, as predicted by the comparative statics. I include a weighted average of upstream neighbors' fallow area as a right-hand-side variable in the fallow equation—in other words, a spatial lag in the dependent variable—to test this hypothesis. As described above, I use both the household survey data on land use and GIS data on canopy cover to construct alterative measures of upstream fallow. I use a general spatial model that also incorporates spatial autocorrelation in the error term:

[11] The Heckman selection model (Heckman 1979) would generalize the problem by allowing for correlation among the error terms of the two processes. The Heckman model is superior in theory because it corrects for selection bias, which, if present and not controlled for, can lead to inconsistent estimates of the parameters of the outcome equation. However, the lack of a valid exclusion restriction that explains the binary decision to fallow but not the extent of fallow area prevents use of the Heckman model. There are no obvious candidates for an exclusion restriction in the data set, and the theoretical model of fallowing provides little guidance in this respect.

$$(5)\quad \frac{A_i - x_i}{A_i} = \beta_o + \beta_1 H_i + \beta_2 Y_i + \rho \sum_j^{N_i} \frac{A_j - x_j}{A_j} + \varepsilon_i ,$$

where $\varepsilon_i = \lambda W \varepsilon + u_i$.

The correlation coefficient of the spatial lag is represented by ρ. The disturbance term, ε_i, has a spatially correlated component and a white noise term, u_i. A spatial autoregressive model accounts for the fact that unobserved factors may influence farmers' and their neighbors' land use decisions in similar ways, allowing for efficient estimation of the parameters. The magnitude of spatial correlation among the disturbances is represented by λ. I estimate the spatial model as a two-part hurdle model, akin to equation (4), estimating separate spatial probit and continuous regressions.

W is the spatial weighting matrix of the error term and is comprised of inverse distances between all sampled farms, reflecting correlation in unobserved factors declining with distance, such as weather shocks. Unlike *W*, the spatial weighting matrix of the lag in the dependent variable is row-normalized.[12] The uniqueness of the two spatial weighting matrices is justified conceptually, and it allows for identification of the spatial autoregressive parameters.[13] However, if spatial correlation among the disturbances follows the same pattern as the hydrological externality, then these effects cannot be disentangled without further parameter restrictions.

Estimation of the spatial lag model must address the potential endogeneity caused by omitted variables correlated with fallow allocation that vary over space. For example, if farmers hire out their labor to nearby farms, leading them to cultivate less while their neighbors intensify cultivation, a negative spatial lag in fallow could ensue. I employ an instrumental variables (IV) approach to obtain asymptotically consistent parameter estimates (Anselin 1988). Anselin suggests using spatial lags of exogenous regressors as instruments for the lagged dependent variable. I follow this approach, using the slope, farm size, and transportation frequency of upstream farms to instrument for upstream forest fallow.[14] Robalino, Pfaff, and Sanchez-Azofeifa's (2007) study of Costa Rican deforestation employed a similar approach, instrumenting for nearby land-clearing with neighbors' agroecological characteristics, although it did not define the neighborhood based on upstream-to-downstream externalities.

Explanatory Variables

Building on the conceptual model and the empirical literature on the causes of tropical deforestation, I consider a variety of socioeconomic and agroecological variables that could drive land-use decisions. One hypothesis of interest concerns whether farmers maintain excessive fallow land from an individual perspective because they deliberately internalize the local externalities their land provides to downstream farmers. Cooperative land-use patterns could occur if formal or informal community institutions allow for communication and enforcement (Ostrom 1990). The comparative statics from the conceptual model suggest that if farmers manage land to maximize community income, then farms positioned higher in the watershed (those with more downstream neighbors) will allocate more land to fallow. As a test of this hypothesis, I include watershed position, measured by the GIS flow accumulation variable, as a regressor in the fallow equation.[15] I also include the number of association meetings held per month in the community as an indicator of the level of community organization. A negative flow accumulation coefficient and a positive association meetings coefficient would suggest that community institutions are successful at inducing farmers further upstream to maintain more of their land in fallow to provide local hydrological services.

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[12] The matrix is row-normalized by dividing each element of the matrix by the number of upstream farms so that each row sums to one. Normalizing the spatial lag term by the number of sampled farms in each farm's neighborhood is important to avoid inferring that farms with more sampled neighbors have higher levels of nearby forest cover. There is no such reason to normalize *W*.

[13] Spatial lag and spatial error parameters are generally not identified without nonlinear restrictions when the two weighting matrices are the same (Anselin 1988).

[14] These three variables were jointly significant in predicting upstream survey-derived fallow area and GIS canopy cover, with Shea's partial R2 statistics of 0.62 and 0.05, respectively ($p < 0.01$ for both models).

[15] As an alternative measure of watershed position, I use GIS flow direction data to determine where farms lie along a gradient from upstream to downstream in relation to one another within each of the 11 sub-watersheds in the study area, yielding a measure of farms' relative rather than absolute positions. These results were qualitatively similar to the flow accumulation results.

I also consider the role of market imperfections. I include distance from the community market and village-level transportation frequency to capture the effects of physical market access. As one measure of access to liquidity, I construct a binary credit access variable similar to that suggested by Boucher, Barham, and Carter (2005) and Gitter and Barham (2007), using data on farmer-reported commercial credit use and ease of obtaining a loan. I consider the farmer to have access to credit if he or she either borrowed money from a cooperative or bank over 1999–2002, or did not borrow money but responded that it would be "easy" or "very easy" to get a loan. Credit access is arguably endogenous because it could depend on risk preferences, shocks, and farm technology choice, all factors subsumed in the residuals of the fallow equation. Including this variable serves at minimum as an indicator of the correlation between credit availability and land management even if I cannot draw firm conclusions about the direction of causality.[16]

I include additional variables to examine the role of labor and liquidity constraints, including off-farm wage and non-wage income normalized by total farm area. Off-farm employment could discourage cultivation by drawing labor off the farm, particularly if liquidity constraints are not binding. In fact, off-farm income could be endogenous with fallowing if labor and land-use decisions are made simultaneously, leading to an upward bias on this coefficient. Alternately, it could encourage cultivation by providing a source of income to purchase farm inputs if liquidity constraints are a concern. Non-wage income could provide capital for farm investments without drawing labor off-farm, though it might have a negligible effect on land management if it largely consists of subsidies used for household consumption. I also include four variables to capture household size and composition: the numbers of household members of working age (age 16–64) and non-working age (under 16 and over 64) living on the farm and absent from the farm, all normalized by total farm size. If labor and liquidity markets are imperfect, a smaller labor endowment could limit cultivation.

The theoretical model generally predicts that farms facing higher discount rates allocate more land to cultivation and less to fallow. Previous research has found that regions with more secure land tenure, often interpreted as a proxy for low discount rates, experience less deforestation (Angelsen and Kaimowitz 1999, Deacon 1999, Cattaneo 2001). I include a binary variable for formal land ownership in the fallow equations.

Other explanatory variables include GIS data on slope as an indicator of land quality and the log of farm size as a proxy for land constraints. While slopes are relatively flat in the study area, it is possible that minor variations could still affect fallow. Education level, represented by the household head's years of schooling, could also affect preferences or farm management ability, though the direction of the effect on fallowing is unclear.

I also include crop, forest product, and fertilizer prices to control for market conditions, which the optimal control model shows to be important determinants of land allocation. Crop and fertilizer price indices are calculated as village-level weighted averages (e.g., the price of each crop is weighted by its village-level output share), while forest product prices are weighted averages at the household level.

As an alternative to including prices and other village-level variables, I also estimate village fixed-effects logit and continuous regression models to focus on variation within communities and control for market conditions, transportation costs, agroecological variation, employment opportunities, and unobservable factors that vary between communities.

Results

Table 3 presents the results from the basic hurdle, spatial hurdle, and fixed-effects models. All equations have reasonable explanatory power, with R^2 or pseudo-R^2 statistics from 0.35 to 0.79. The spatial model is estimated using the two measures of upstream fallow discussed above. The spatial correlation coefficient is only weakly significantly different from zero in one of the spatial

[16] I also attempted to control for endogeneity by using durable household assets to instrument for credit access. I constructed an assets variable equal to the primary factor from a factor analysis of ownership of the following assets: bedroom furniture, kitchen furniture, living room furniture, refrigerator, bathroom, bicycle, car, truck, motorcycle, television, satellite dish, radio, cassette player, sewing machine, and camera. All variables loaded positively onto the factor, with loadings ranging from 0.12 to 0.74. The household assets variable is a positive and significant predictor of credit access, with a Shea's partial R2 of 0.04 ($p < 0.01$). While not an ideal instrument, durable assets should not be contemporaneously correlated with land management. The IV estimate of the credit access coefficient was negative and significant.

Table 3. Percent Landholdings Allocated to Fallow

	Probit	OLS	Spatial Probit	Spatial Regression	Spatial Probit	Spatial Regression	Fixed Effects Logit	Fixed Effects Regression
Predicted upstream percent fallow area (ρ) – survey data					-0.333 [1.191]	-0.143 [0.114]		
Predicted upstream percent canopy cover (ρ) – GIS data			0.202 [9.150]	0.46 [0.919]				
Log of farm size	0.13 [0.166]	0.051*** [0.016]	0.248 [0.192]	0.049*** [0.016]	0.246 [0.202]	0.044*** [0.016]	0.154 [0.411]	0.061*** [0.016]
Present working-age family members per hectare	-0.391 [0.328]	-0.124*** [0.045]	-0.464 [0.403]	-0.137*** [0.044]	-0.315 [0.426]	-0.098** [0.045]	-0.513 [0.659]	-0.123*** [0.045]
Absent working-age family members per hectare	0.851 [0.546]	-0.022 [0.055]	1.14** [0.765]	-0.021 [0.057]	0.947* [0.614]	0.012 [0.057]	0.324 [1.485]	3.82e-4 [0.056]
Present non–working-age family per hectare	-0.16 0.294]	-0.038 [0.065]	0.049 [0.325]	-0.014 [0.074]	0.044 [0.331]	-0.097 [0.068]	-0.47 [0.614]	-0.03 [0.066]
Absent non–working-age family per hectare	-1.355 [2.366]	1.055* [0.627]	-0.870 [3.762]	0.85 [0.622]	8.64 [8.49]	0.872 [0.648]	-2.734 [5.818]	0.874 [0.628]
Household head's schooling	0.01 [0.044]	0.004 [0.004]	0.020 [0.044]	0.006 [0.004]	0.018 [0.048]	0.006 [0.004]	0.038 [0.112]	0.005 [0.004]
Owner	1.023*** [0.264]	-0.017 [0.024]	0.778*** [0.291]	-0.01 [0.024]	0.741*** [0.230]	-0.031 [0.026]	1.987*** [0.608]	-0.038 [0.026]
Slope	0.186** [0.089]	0.001 [0.005]	0.059 [0.077]	-0.001 [0.006]	0.087 [0.076]	0.001 [0.005]	0.529* [0.306]	0.009 [0.007]
Flow accumulation	0.001 [0.002]	5.51e-5 [1.270e-4]	0.001 [0.002]	4.92e-5 [1.223e-4]	0.001 [0.002]	2.02e-5 [1.259e-4]	-0.011 [0.017]	1.13e-4 [1.307e-4]
Community association meetings per month	-1.150** [0.463]	-0.047* [0.027]	-0.371 [0.388]	-0.046* [0.027]	-0.377 [0.415]	-0.04 [0.030]		
Transportation frequency	-0.072 [0.102]	-0.014* [0.008]	-0.011 [0.113]	-0.012 [0.010]	0.016 [0.123]	-0.014 [0.009]		

cont'd.

Table 3 (cont'd.)

	Probit	OLS	Spatial Probit	Spatial Regression	Spatial Probit	Spatial Regression	Fixed Effects Logit	Fixed Effects Regression
Transportation frequency	-0.072 [0.102]	-0.014* [0.008]	-0.011 [0.113]	-0.012 [0.010]	0.016 [0.123]	-0.014 [0.009]		
Distance from local market	0.045** [0.019]	-0.001 [0.001]	0.012 [0.019]	-0.001 [0.001]	0.009 [0.015]	7.81e-5 [1.067e-3]	0.184 [0.132]	-0.001 [0.003]
Access to commercial credit	0.299 [0.263]	-0.062*** [0.022]	0.212 [0.282]	-0.056** [0.023]	0.330 [0.267]	-0.063*** [0.024]	0.347 [0.546]	-0.043* [0.023]
Wage income per hectare	-8.425e-4* [4.778e-4]	-1.461e-4** [5.645e-5]	-3.88** [2.61e-4]	-1.414e-4** [6.133e-5]	-4.51e-4** [3.10e-4]	-1.593e-4*** [5.645e-5]	-0.001 [0.001]	-1.924e-4*** [5.786e-5]
Non-wage income per hectare	1.31e-4 [1.572e-4]	-4.35e-5 [3.327e-5]	1.76e-4 [3.37e-4]	-3.25e-5 [3.293e-5]	-2.45e-4 [3.34e-4]	-3.19e-5 [3.435e-5]	3.18e-4 [5.510e-4]	-3.60e-5 [3.329e-5]
Average crop price	0.404* [0.208]	-0.013 [0.016]	0.196 [0.518]	0.012 [0.054]	0.207 [0.256]	-0.01 [0.020]		
Forest product price	-0.003 [0.007]	0.001 [0.001]	0.002 [0.013]	2.66e-4 [0.001]	1.53e-4 [0.012]	0.001 [0.001]		
Average fertilizer price	5.344*** [1.516]	-0.158 [0.122]	3.287** [1.48]	-0.169 [0.130]	3.98** [1.723]	-0.018 [0.152]		
Constant	-5.669*** [1.732]	0.965*** [0.148]	-3.676 [3.238]	0.705** [0.293]	-4.146** [1.926]	0.791*** [0.168]		0.664*** [0.101]
Spatial error correlation coefficient (λ)			0.049 [0.174]	-0.161 [0.116]	0.027 [0.177]	-0.186* [0.110]		
Community fixed effects							Included	Included
Observations	271	232	261	222	236	204	180	232
R^2 /Pseudo R^2	0.44	0.45	0.78	0.43	0.79	0.45	0.35	0.51

Notes: Standard errors are in brackets. *, **, and *** denote significance at 10 percent, 5 percent, and 1 percent. Spatial errors probit model estimated using Gibbs sampler algorithm in Matlab (LeSage and Pace 1998). All other models estimated using Stata 8.

models, indicating that unobserved factors varying with distance between farms do little to explain fallow management.[17] Nor does lagged fallow have a significant effect on land allocation using either measure, suggesting that farmers do not expand production in response to ecosystem services from upstream land cover. Village effects were jointly significant ($p = 0.015$) in the continuous fixed-effects model, and they perfectly predicted fallow outcomes for 11 villages in the logit model.[18] Results from this model are similar to those from the non–fixed-effects models, indicating that factors that vary within villages are important in explaining fallow management.

The coefficients of flow accumulation and the number of community association meetings offer a test of the hypothesis that Bragantina farmers intentionally internalize the positive hydrological externalities that flow upstream to downstream. If upstream farmers deliberately maintain higher levels of fallow to boost productivity in the community, the flow accumulation coefficient should be negative. However, the results show that watershed position, as measured by flow accumulation, has no significant effect on fallow allocation. In addition, farmers in communities with more active associations are actually *less* likely to practice shifting cultivation. These results suggest that the high levels of fallow maintained among surveyed farmers likely do not result from a strategy to manage ecosystem services using community institutions. However, because village fixed effects were significant in predicting fallow management, I cannot rule out the possibility that unobserved village institutions affect fallow, though these impacts could simply reflect variations in market and agroecological conditions.

The empirical model does demonstrate support for the hypothesis that missing markets contribute to fallow management decisions. Access to commercial credit has a negative and significant effect on the amount of land allocated to fallow for farmers who practice shifting cultivation (though not on the decision to fallow). Farmers located farther from markets and with less frequent transportation access devote more land to fallow. Off-farm wage income also has a significant negative effect on fallowing despite the potential for upward bias in the coefficient estimate, suggesting that its impact on alleviating liquidity constraints outweighs the effect of decreasing on-farm labor availability. Labor endowment is important as well. The number of present working-age members has a significant negative effect on fallow percentage, as would be expected if labor is a limiting factor. The number of absent family members (whether working- or non-working–age) positively affects fallow in some specifications, which could occur if farmers delay land-clearing in anticipation of having labor return to the farm in the future. These results are consistent with the predictions from the theoretical model that lower capital and labor endowments under liquidity constraints discourage cultivation. Perhaps surprisingly, off-farm non-wage income has no significant impact on fallowing. This result could arise because non-wage income largely consists of government subsidies directed to low-income households for consumption, which could have minimal effects on farm production decisions.

Farms facing higher fertilizer prices are more likely to devote land to fallow, which is unsurprising since fallowing and fertilizer are substitutes for soil quality improvement. In contrast to the theoretical model predictions, crop prices are positively associated with fallowing in the non-spatial, non–fixed-effects model, though otherwise crop and forest product prices have no significant effect on land allocation.

Farmers who hold legal title to their land are significantly more likely to allocate land to fallow than those who do not, confirming the predictions of the theoretical model and other empirical research that more secure land tenure leads to higher levels of forest cover. Household heads with more education also devote more land to fallow, though this relationship is not statistically significant. Consistent with previous literature, fallowing is more likely on land with steeper slopes, though this result is not significant across all models. The positive and significant effect of farm size on the percentage of fallow land indicates that larger farms cultivate less intensively.

The majority of explanatory variables included in the fallow equations have the same sign in both the binary and continuous regression equations, even if they are not all statistically significant

[17] Nor is there significant spatial correlation in the error term of either the continuous ($p = 0.13$) or binary (0.40) fallow equation when the upstream fallow land variable is excluded from the regression.

[18] Because outcomes in these 11 villages did not vary, the fixed-effects logit equation includes only 180 observations.

across both decisions. In other cases, a variable significantly affects whether to fallow in one direction but has a different (though insignificant) effect on the percent area in fallow, or vice versa. There is little guidance from the theoretical model on why this might occur, but regional agroecological factors might provide some insights. The decision whether to fallow or not represents a switch in farming regimes between a traditional fallow system and a modern continuous cultivation approach dependent on chemical inputs, which could be considered irreversible in the short-to-medium term. By contrast, the percent area under fallow is a shorter-term decision that farmers can alter from year to year in response to shifts in market conditions and household circumstances. Viewed in this context, it is plausible that farm ownership status and distance from village markets would have strong impacts on the decision to fallow or continuously cultivate but negligible effects on the percent area under fallow in a given year. However, it is still somewhat surprising that higher average fertilizer prices positively affect the fallowing decision but not the percent fallow area, and that commercial credit access increases the area under fallow but not the likelihood that a household permanently switches to continuous cultivation.

Despite these few counterintuitive results, the overall findings echo those from other studies showing the importance of land quality, tenure, and access to transportation, capital, and labor for forest management, even in a region like the Bragantina in relatively close proximity to regional markets.

Conclusions and Implications for Tropical Forest Policy

This study builds on the extensive literature on tropical deforestation by examining the land use decisions of shifting cultivators in a context where land is settled and private land tenure is prevalent. Farmers in Bragantina maintain large amounts of land in forest fallow, which provides them with important on- and off-site ecosystem services, but also comes at a cost of foregone near-term income from crop production.

Econometric results suggest that this land-management pattern likely does not arise because farmers internalize local externalities via community institutions. Rather, farmers facing transportation barriers, few capital and labor resources, and high fertilizer prices devote more land to fallow, indicating that market failures pose a barrier to agricultural intensification, even in a region that is well-connected to markets by developing country standards. Farmers who own their land also find it more advantageous to fallow.

These findings have important implications for policymakers pursuing the objectives of poverty alleviation and forest conservation in the Amazon. Like much of the previous literature on deforestation, they point to a tradeoff between economic development and forest conservation, since improved access to liquidity, inputs, and markets tends to exacerbate secondary forest loss. However, the existence of local beneficial spillovers implies that removing these barriers to agricultural intensification could have ambiguous implications for community-level income. While limiting market access does not present a viable or attractive approach to reducing deforestation, policymakers might consider whether paying farmers for forest ecosystem services rather than investing in infrastructure and market access would be a better use of resources to achieve the joint objectives of poverty alleviation and forest preservation.

Global carbon sequestration and biodiversity services provided by secondary forest could make additional forest fallow desirable from an international perspective. Schemes such as payments for ecosystem services (PES) (Wunder, Engel, and Pagiola 2008) or reduced emissions from deforestation and forest degradation could be warranted to promote increased forest cover while compensating farmers for the opportunity costs of foregone agricultural production. Indeed, Borner, Mendoza, and Vosti (2007) showed that a hypothetical PES scheme for mature secondary forests in Bragantina could raise farm income levels and forest carbon stocks under current technology.

Brazil's federal and state governments have demonstrated an interest in PES with the establishment of pilot initiatives such as Amazonas' state-level *Bolsa Floresta* ("forest grant") smallholder program and the introduction in 2007 of national legislation to legalize PES (Hall 2008). The federal *Proambiente* program has voiced similar goals, though its focus on subsidized credit and agricultural technology restrictions suggests attention to different priorities. Brazil's national forest laws have historically focused on the protection of virgin forest and overlooked secondary forest, but as PES programs gain a foothold in Brazil, it could be beneficial to both smallholders and the environment to explicitly incorporate secondary forest management as an eligible land use category, given the regional and global ecosystem services it provides.

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