Theorizing Land Cover and Land Use Change: The Peasant Economy of Amazonian Deforestation

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This article addresses deforestation processes in the Amazon basin, using regression analysis to assess the impact of household structure and economic circumstances on land use decisions made by colonist farmers in the forest frontiers of Brazil. Unlike many previous regression-based studies, the methodology implemented analyzes behavior at the level of the individual property, using both survey data and information derived from the classification of remotely sensed imagery. The regressions correct for endogenous relationships between key variables and spatial autocorrelation, as necessary. Variables used in the analysis are specified, in part, by a theoretical development integrating the Chayanovian concept of the peasant household with spatial considerations stemming from von Thünen. Results from the empirical model indicate that demographic characteristics of households, as well as market factors, affect deforestation in the Amazon basin associated with colonists. Therefore, statistical results from studies that do not include household-scale information may be subject to error. From a policy perspective, the results suggest that environmental policies in the Amazon based on market incentives to small farmers may not be as effective as hoped, given the importance of household factors in catalyzing the demand for land. The article concludes by noting that household decisions regarding land use and deforestation are not independent of broader social circumstances, and that a full understanding of Amazonian deforestation will require insight into why poor families find it necessary to settle the frontier in the first place. *Key Words: Amazon; deforestation; peasant economy.*

Loss of the Amazon forest has been attracting the scientific community's attention over the past few decades, due to possible impacts on the carbon cycle and species diversity. A wide-ranging debate on what drives this process has pointed to a number of causes, including government policies, logging, mining, agricultural development, and increased rates of migration (Fearnside 1985; Browder 1988; Mahar 1989; Serrão and Homma 1993; Serrão, Nepstad, and Walker 1996; and McCracken et al. 1999). Despite this research, knowledge about the agents who actually manage and transform the land remains incomplete. Thus, the primary goal of the article is to understand the land cover impacts of an important agent in the Amazonian landscape, the colonist household whose livelihood strategy focuses mainly on farming.

In addressing the land cover impacts of colonists, the article contributes to an emerging literature on the interactions between rural households and the environment, particularly in tropical forest frontiers (Zimmerer 2004). By focusing on this specific agent, we overlook important elements of the Amazonian deforestation story such as the role of loggers, the political economy of development, and so on (Hecht 1985; Smith et al. 1995; Nepstad et al. 2004).[1] We also direct our attention away from forest dwellers who derive their livelihoods from a mix of activities based on diverse natural resources (Coomes, Barham, and Takasaki 2004). Nevertheless, the study adds to the growing, survey-based research addressing endogenous land cover changes in Amazonia arising from smallholders, or "peasant" farmers, whose rural population reaches into the millions (e.g., Browder 1994; Jones et al. 1995; Pichón 1997; Godoy, Jacobson, and Wilkie 1998; Marquette 1998; McCracken et al. 1999; Coomes, Grimard, and Burt 2000; Pan et al. 2004).

The article addresses colonist deforestation through an application of regression analysis. Statistical research on land cover and land use change (LCLUC), and tropical deforestation in particular, often posits a behavioral model at the level of the individual household, or agricultural enterprise. Be this as it may, regression models are almost always implemented either at aggregate scales, in which the data used are for jurisdictional units (e.g., Reis and Guzmán 1994; Andersen 1996; Pfaff 1999; Andersen et al. 2002; Chomitz and Thomas

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2003), or at disaggregate scales, in which observations are typically on very small parts of larger management units (e.g., Nelson and Hellerstein 1997; Mertens and Lambin 2000; Nelson, Harris, and Stone 2001). As a consequence, the actual land cover behaviors of the agents in question are not directly addressed. Indeed, analysts often undertake macroscale or microscale analyses because agent-specific information is unavailable. This article overcomes the mismatch of behavioral model and data observation by presenting statistical analyses using information for households, as opposed to geographic aggregates or disaggregates. Such mismatches can lead to biased results through variable omission (Walker, Perz, et al. 2002).

The information used is generated by a geographic information system (GIS) linking household survey data and classified satellite images. Such a combination of field-based study with remote sensing provides a powerful methodology deployed with increasing frequency to investigate processes of environmental change (Liverman et al. 1998; Walsh and Crews-Meyer 2002; Fox et al. 2003; Boucek and Moran 2004; Gutman et al. 2004; Entwisle and Stern 2005). In addition to linking satellite and survey data, our analytical approach pays particular attention to statistical issues affecting regression-based land cover change studies, including endogenous relations between key variables and spatial autocorrelation.

Concerning endogeneity, deforestation could result from the use of credit by farming households (e.g., Ozório de Almeida and Campari 1995). In Brazil as in many Latin American countries (e.g., Colombia, Ecuador, Peru), land clearance may be necessary to stake a claim and obtain title, often required in credit applications as collateral (Hecht and Cockburn 1990; Rudel and Horowitz 1993; Mahar and Schneider 1994; Simmons, Walker, and Wood 2002; Alegrett 2003). In such a situation, causality runs in two directions. As for spatial autocorrelation, there is abundant evidence that farmers make contagious decisions inspired by actions taken by their neighbors (e.g., Casetti and Semple 1969), which could lead in the present context to spatial relationships in deforestation decisions (Walker and Solecki 1999). The presence of such relationships leads to erroneous results if conventional approaches to regression analysis are undertaken (Anselin and Rey 1991).

The article is organized as follows. We start by considering previous research on Amazonian colonization and LCLUC. These two literatures represent the seminal roots of the approach we take, and to position the analysis we broach both of them, if briefly. After this, we provide an account of "peasant" farming and the so-called household economy model, in which economic behavior is highly conditioned by attributes of the family including labor endowment, subsistence requirements, and attitudes toward risk (Chayanov 1925; Nakajima 1969; Singh, Squire, and Strauss 1986; Ellis 1993). This leads to the statement of a theoretical model, based on the household economy formulation and adapted to the dynamic institutional environment of the frontier. In particular, we account for the asset value of land, which accumulates as the frontier matures, thereby providing strong incentives for claiming land (Margulis 2003; Arima, Barreto, and Brito 2005). With the theoretical frame, we then specify and estimate a set of statistical models addressing links between household structure and deforestation. We conclude by considering implications of the findings for both research and policy.

Previous Empirical Research

Our research concept emerges from the intertwining of two strands of work, one addressing colonization and peasant livelihoods, mainly in the Amazon basin, and the other, LCLUC. In essence, we adapt the discussion of peasant livelihoods, during the process of colonization, to the simplifications of regression analysis, as applied in LCLUC modeling. We discuss each of these after considering the "peasant" as a conceptual category, in order to clarify our object of study. In much economic research, the peasant is a land-owning, or at least a landholding, family farmer, barring explicit consideration of work addressing land tenure relations that draws important distinctions between renters, owners, sharecroppers, and so on (e.g., Cheung 1969). Typically, the peasant depends on household resources, and sustains only sporadic attachments to markets for productive factors (capital, labor), inputs, and outputs (Ellis 1993). The concept of a peasant economy as implemented in this article, and in particular the seminal contribution by the Russian economist Chayanov, is discussed below. At this point, suffice it to say that for the purposes of the regression analysis, we equate this abstract peasant—who derives his or her livelihood from farming and not a multiplicity of income-generating activities—with a specific agent of land cover change in the Amazon basin, the *colonist* farmer.

In fact, the Amazonian colonist also requires careful identification. Brazilian agricultural researchers and other commentators refer to the *camponês*, a Portuguese word that translates roughly as "peasant." This is a social category covering the rural poor, both landed and landless, who derive livelihoods from agriculture, extractive activities, and even wage labor. Such individuals may be market-oriented or not, or more likely some combination, and they defy reduction to conventional developmentalist descriptors such as *autarkic* or *market-integrated* (see McSweeney 2004a). The *camponês*, in turn, can be further specified in a number of ways, but for our purposes the distinction between *sitiantes*, *posseiros*, and *colonos* is useful because it applies to the study region (Ianni 1978). All three may be regarded as migrants to Amazonia and therefore distinct from indigenous peoples despite complex histories of racial mixing. The *sitiante* and *posseiro* are individuals who have occupied land with little legal concern, practicing usufruct rights and subsistence agriculture in areas of primary forest, far from roads or centers of commerce. Such individuals have typically been long residents in the region, descendents of Brazilians from other parts of the country attracted to Amazonia by early resource booms. By way of contrast, *colonos*, or colonists, are the relatively new arrivals who began coming with the infrastructure investments of the military regime in the 1970s that opened the frontier to settlement. These individuals seek title to land and ultimately plant commercial crops that can be transported to market, although they often start out engaged in subsistence production, and maintain food production for household consumption even with market successes. Our article and research focus on colonist farmers because they constitute the largest component of rural population in the Amazon basin. By virtue of their agricultural practices, they also account for a considerable amount of the region's deforestation, although this varies both spatially and temporally and recently has been overshadowed by the clearings of large holders (Walker, Moran, and Anselin 2000; Alves 2002).

Colonization Studies in the Amazon Basin

The present study builds on a long history of colonization research in the Amazon, which tends to organize into (1) political economic commentary on the likely social welfare impacts of Amazonian development (e.g., Foweraker 1981; Sawyer 1984; Schmink and Wood 1984, 1992) and (2) descriptions of the experiences of households who have migrated to forest areas (e.g., Moran 1975; Lisansky 1988, 1990). The later focus is particularly germane to the present study, which addresses precisely such households. Although work on colonists to the Amazon region began early (Moran 1975, 1981; Lisansky 1988; Lena 1991), systematic environmental themes focusing on land use do not emerge until the 1990s, with growing concern about loss of the Amazonian forest.

Household research responding to this concern has been conducted mainly in Brazil, Peru, and Ecuador.[2] Although a variety of approaches have been undertaken in this regard, much of the work is survey-based, and has attempted to explain links between land use and land cover and household attributes, as well as traditional market factors such as transportation costs. This research has shown that demographic characteristics such as family or kin group size (Rudel and Horowitz 1993; Pichón 1997; Coomes, Grimard, and Burt 2000; Coomes 2004), number of male workers (Sydenstricker Neto and Vosti 1993; Walker, Perz, et al. 2002; Pan and Bilsborrow 2005), and internal household dependency (Walker, Perz, et al. 2002) impact crop choices, the amount of land clearance, or both. Other attributes play roles too, such as level of household wealth (Alston, Libecap, and Schneider 1993; Jones et al. 1995; Murphy, Bilsborrow, and Pichón 1997; Pichón 1997; Alston, Libecap, and Muller 2000; Walker, Perz, et al. 2002), length of family residence on the holding (Pichón 1997; Walker et al. 2002a), and access to markets, or transportation costs (Jones et al. 1995; Ozório de Almeida and Campari 1995; Pichón 1997; McCracken et al. 1999; Walker, Moran, and Anselin 2000; Walker, Perz, et al. 2002; Pan et al. 2004). Thus, the evidence from these various field-based studies suggests that household demography and productive assets influence smallholder deforestation, as does market accessibility (Brondízio et al. 2002; Walker 2003; Pan and Bilsborrow 2005).

Deforestation Research

Since the seminal contribution by geographers Allen and Barnes (1985), a great deal of research has addressed the issue of tropical deforestation, both in the Amazon and worldwide, and it would be impossible to provide a complete review (see Kaimowitz and Angelsen 1998; Lambin, Geist, and Lepers 2003; Gutman et al. 2004). Therefore, we consider the early work in broad outline to establish the context of current analyses focusing on so-called *spatially explicit models* using highly disaggregated data, often derived from remote sensing applications (Walker 2004). Such models are used with increasing frequency by the LCLUC community, because the models allow for relatively easy collection of accurate land cover data (via satellite) and because they enable an analyst to perform spatial projections, if so desired. Such projections provide information of potential use to landscape ecologists that is not possible with more aggregate models.

Initial efforts at deforestation analysis attempted to explain forest loss at aggregate scale, estimating deforestation occurring over some time period, Y, as a function of socioeconomic and physical variables, X, or $Y = f(X)$. Data were obtained for jurisdictional units using government censuses on forest expanse and socioeconomic indicators (Allen and Barnes 1985; Rudel 1989; Barbier 2001). Geographers, sociologists, and ecologists stated the first aggregate models of deforestation, but formal specifications based on behavioral theory did not appear until economists addressed the issue and conceptualized the deforestation process as the expression of profit maximization. When the farmer maximizes profits, he or she demands factors of production including land, labor, and capital; it is this demand for land, a "derived demand," that economists originally interpreted as the incentive driving deforestation (Panayotou and Sungsuwan 1994; Reis and Guzmán 1994).

Many current statistical analyses of deforestation, stemming from a seminal geographic contribution by Ludeke, Maggion, and Reid (1990), reflect rapid advances in computational technology, and GIS and remotely sensed data to generate analysis samples (e.g., Chomitz and Gray 1996; Nelson and Hellerstein 1997; Mertens and Lambin 1997, 2000; Nelson, Harris, and Stone 2001; Pan and Bilsborrow 2005). The spatially explicit model considers land cover change at the level of the individual pixel, as observed from a remote sensing platform, and no longer depends on the aggregate information provided by government agencies, as was necessary in the early statistical work. Although profit maximization still provides the formal theoretical context for many applications, the decision unit involves individual parcels of land, and discrete switches between land cover categories based on the ranking of alternative land uses. For example, Bockstael (1996), Chomitz and Gray (1996), and Nelson and Hellerstein (1997) all provide similar statements in this regard, in which the probability of deforesting a parcel of land j is given as

$$\mathrm{Prob}(D) = \mathrm{prob}(V_{jDt} + \varepsilon_{jDt} > V_{jUt} + \varepsilon_{jUt}),$$

where V is the "systematic" component of net profit (or rent) for deforesting some parcel (D) or leaving it in an undeveloped (U) state at time t, and ε is a random variable. The parcel is deforested if rents so generated exceed those that would arise from the land left in an undeveloped state. Appropriate specification of the error term transforms this into a logit model that can be estimated using the method of maximum likelihood (Maddala 1983).

Rent (and profit) maximization constitutes the behavioral foundation for most spatially explicit models, although many applications have been undertaken without formal statements (e.g., Ludeke, Maggion, and Reid 1990; Wear and Bolstad 1998; Mertens and Lambin 1997, 2000; and Geoghegan et al. 2001). This is clearly defendable under a bid rent paradigm when property rights are well-established and the economic environment is mostly free from uncertainty (Alonso 1964). However, the institutional environment of frontier areas, where deforestation occurs, may not be conducive to the market-driven behavior we associate with agricultural agents in developed economies. In the absence of product markets, profit maximization is hardly an option, and the concept of rent is inapplicable. In addition, such settings are likely to be associated with poorly defined property rights, which can significantly impact agricultural decision making (Mueller et al. 1994; Alston, Libecap, and Mueller 2000). Reduced levels of investment given short time horizons and inability to use land as collateral in securing loans have strong potential effects on the pattern of land use. Another possible response by smallholders to insecure land tenure is risk-averse behavior, which is borne out by empirical observation in Brazil (Dillon and Scandizzo 1978; Homma et al. 1996; Faminow et al. 1999), and at least one theoretical framework has been advanced for the deforestation case in Amazonia, linking farming system switches (from sustainable forest extraction to ranching) to increases in the uncertainty of forest income due to the twin threats of fire and land invasion (Homma et al. 1996).

Because the present study addresses deforestation associated with colonist farming, it is sensitive to circumstances that distinguish them and their decision making from other agricultural enterprises, particularly commercial farms and ranchers. Thus, the behavioral model we posit is different from the profit-maximizing conceptualization that generally underlies regression-based studies of tropical deforestation (e.g., Panayotou and Sungsuwan 1994; Reis and Guzmán 1994; Bockstael 1996; Chomitz and Gray 1996; Nelson and Hellerstein 1997). The operational aspect of the statistical analysis is different, too. In particular, we draw inspiration from Amazonian colonization studies, using household surveys to create an estimation database defined on decision-making units, not on geographic aggregates (e.g., states, counties) or disaggregates (e.g., satellite pixels). The approach we take follows McCracken et al. (1999) and Walker, Moran, and Anselin (2000), both of whom linked remote sensing with survey-based data in regression analyses of deforestation in the Brazilian Amazon (also see Fox et al. 2003; Pan et al. 2004; and others).[3]

Conceptual Framework

Theoretical Foundations

As indicated, the Russian economist Chayanov is central to our formulation of the peasant economy and land use behavior in the present application (Chayanov 1925; Thorner, Kerblay, and Smith 1986). Chayanov, who studied Russian agriculture after the October revolution of 1917, argued that household farm decisions could largely be explained by reference to family subsistence requirements and labor power. Under an assumption of easy access to land and limited possibilities for market exchanges, especially labor, Chayanov deduced that farm size reflected family size, not the degree of capitalization or class position of the family. Resident workers brought productive power to the household, and young children and elderly individuals increased its internal *dependency* by adding mouths to feed, which Chayanov argued motivated the group's willingness to endure heightened work-related "drudgery," the price of meeting household subsistence requirements.

Chayanov demonstrates this empirically by showing that the consumption burden imposed by dependents (nonworkers) intensifies a family's degree of *self-exploitation*, measured by increased work hours (Chayanov 1925, 78). In a two-good world of leisure and subsistence, this gives rise to an increasing marginal utility of food, and a decreasing marginal utility of leisure, the "subjective wage rate." In the language of microeconomics, a household's "preferences" shift in favor of more agricultural production (Nakajima 1969; Ellis 1993). As the household's balance of workers and dependents evolves over time in response to *life cycle* dynamics, its welfare, or utility, function also changes. Since Chayanov assumes off-farm work is not available to the peasant farmer, all economic activity concentrates on farm production (Chayanov 1925, 61). In the absence of technological change, increased dependency, as well as increased household labor power, lead to increments in the amount of "sown" land. In the Chayanovian household, consumption and production decisions are therefore *nonseparable*, and the consumption demands of the family are directly linked to the amount of land and labor needed for subsistence production.

The theory of the peasant economy, as restricted to studies of household farming, has evolved since the Russian revolution and has been adapted to other geographic and institutional settings (Nakajima 1969; Singh, Squire, and Strauss 1986). A prime development has been the creation of models of household agricultural decision making in which markets exist for inputs (including labor) and outputs, leading to *separable* decisions between consumption and production (Singh, Squire, and Strauss 1986). Determining the extent to which peasant households conform to separable or nonseparable behavior has been an important issue in development economics (e.g., Benjamin 1992; Carter and Yao 2002). The present application departs from such applications, typically directed at labor surplus situations under land scarcity, to consider forest frontiers where land is freely abundant and labor scarce, a situation more in line with the original setting in which Chayanov developed his approach (see Maertens, Zeller, and Birner 2006).[4]

The dynamic quality of the Chayanovian model, together with its focus on the importance of household labor, has already inspired adaptation to the case of Amazonian deforestation, the subject of the present article. In particular, Walker and Homma (1996), Pichón (1997), McCracken et al. (1999), Perz (2001), Brondizio et al. (2002), Walker, Perz, et al. (2002), Walker (2003), Moran, Brondizio, and VanWey (2005), and Pan and Bilsborrow (2005) have called attention to the importance of family labor, to the impact of dependency, and to links between a household's demographic life cycle and deforestation (CAT 1992).

As the above-mentioned authors have described, the household's agricultural economy shifts from subsistence to market production, beginning with the arrival of a young family on a forested parcel of land on the frontier, beyond the extensive margin of agriculture. Given initially low levels of capital and little farm experience, the family first depends on shifting cultivation and annual crops. This continues while the children are young and household dependency is high. With time, the children age and their parents acquire agricultural experience, which mitigates risk aversion. With new family workers, the household is now positioned to invest, through deferred consumption, in a farming system of greater commercial potential, typically a ranch, a perennials plantation, or some combination. Thus agricultural activities evolve in concert with the development of the household, and with a government's continuing effort to open the frontier through infrastructure investment.[5] The implication is that household-level demographic and economic processes, as articulated by Chayanov and his interpreters, provide a microscale explanation of tropical deforestation.

Here we address this process of change in household production and structure, and implications for deforestation. In so doing, we add an overlooked theme to the life-cycle narrative, namely the importance of asset accumulation in land to colonist families, many of whom move to the frontier mainly to occupy properties they will one day be able to sell once a land market emerges. Frontier settlement, and the land cover change that results, is one of the only ways available to poor families to accumulate wealth. Much Amazonian deforestation presently associated with the expansion of pastures is explained by the perception that land values are rising (Margulis 2003; Arima, Barreto, and Brito 2005).

Framing the Regression Analysis

The statistical model presented in this article adopts elements of the peasant economy in seeking to identify factors affecting deforestation processes at property level. We focus on the link between characteristics describing household structure (e.g., family labor power and dependent consumption) and the level of a family's economic activity, taken to manifest itself in the amount of land used for agriculture, Chayanov's "sown" land. Amazonian colonists who arrive on the frontier and occupy forested parcels need to create "sown" land, which we take to be the objective of the deforestation process. Hence, the demographic and market variables that explain the demand for agricultural land are the same ones that explain the magnitude of deforestation.

Our study extends the household economy model—developed to investigate the agricultural decision making of poor farm households in developing countries—to the case of deforestation in forest frontiers (Singh, Squire, and Strauss 1986). To this end, we posit a two-phase process of farm creation, whereby deforestation in phase one creates agricultural land for commercial production, or sale, in phase two (Holden, Pagiola, and Angelsen 1998; Walker 2003). We assume pure subsistence and market detachment in the early years of the farm (nonseparability), followed by commercial production with a household economy open to markets for products, labor, and land (separability). Families clear primary forest with the expectation that frontier development and maturation will bring markets and expanded opportunities for economic activity, including the sale of their holdings (Binswanger and McIntire 1987; Rudel and Horowitz 1993; DeShazo and DeShazo 1995; Margulis 2003; Arima, Barreto, and Brito 2005). Colonists, even in remote areas, often have some degree of market engagement, however slight and erratic (Ellis 1993). Nevertheless, to facilitate the exposition, we follow Walker's (2003) approach and assume pure subsistence in the beginning, followed by the similarly extreme case of complete market integration. It is important to note that we assume a "unitary household" with a well-defined and stable set of family objectives. This masks internal power relations and inequities, which are neglected in the interest of focusing on the household demand for land (see Zimmerer 2004).

In the model to be presented, the switch from autarkic production to a market environment is assumed to be an outgrowth of a farm's evolution and does not result from a contemporaneous decision based on an evaluation of market-based transactions costs (Goetz 1992; Key, Sadoulet, and de Janvry 2000; Vance and Geoghegan 2004). This is consistent with the empirical setting, in which smallholders typically focus on food production in their early years and later they either sell out and move, or shift their efforts to commercially-oriented systems (Walker, Perz, et al. 2002; Walker 2003). Therefore, we do not consider the decision to sell, buy, or remain detached from the market as a function of transactions costs (Key, Sadoulet, and de Janvry 2000). Instead, market participation is assumed during the second period, in which prices exist for goods and land.[6] These prices, in turn, are linked to transportation costs and distance, via von Thünen's rent concept (Omamo 1998; Fujita, Krugman, and Venables 1999; Key, Sadoulet, and de Janvry 2000).[7] Specifically, as a farm's distance to the market increases, or as its market accessibility decreases, transportation costs increase. This lowers output prices as it increases input prices, thereby reducing the market value of land (Nelson and Hellerstein 1997). Accessibility is a key operational concept in the literature on LCLUC (Geist and Lambin 2002).

Following Walker (1999, 2003), the objective of the household is the optimization of utility over the long run, with yearly agricultural activity. Given the emergence of market opportunities as the frontier matures, the family seeks to maximize

$$\sum_{t=0}^{\mu-1} \beta^t U(l,s) + \sum_{t=\mu}^{\infty} \beta^t U(\$) \tag{1}$$

subject to the household labor constraint, where the Us are utility functions, s is subsistence production, l is leisure, \$ is cash income, β is a discount factor, and μ is the time at which the system switches from subsistence to market-oriented activities. Note that in the second phase, utility is a function only of financial gain, indicating a complete focus on market rewards.

The formulation in (1) reflects a land creation process in the early years, when deforestation occurs in a series of deforestation events (Caldas et al. 2003). The total amount of land cleared becomes available for commercial production in subsequent years, or it can be sold. Thus, deforestation runs its course in the initial period,

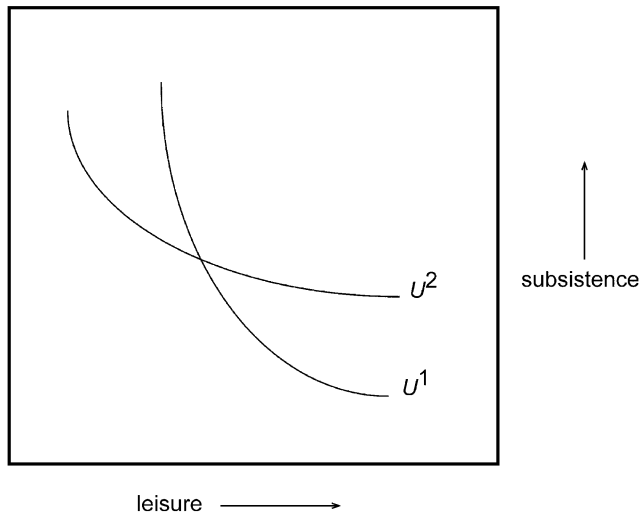

Figure 1. Effect of increased dependency on utility function.

which is consistent with empirical observations on land clearing by single families (Homma et al. 1993; Walker 2003). With sufficient time, deforestation on individual properties may continue as ownership exchanges hands or as colonist children begin families of their own and undertake additional clearing. Thus, the present model may be taken to reflect midrun deforestation processes occurring within generations and not across them (Perz and Walker 2002).

A parameter c may be added to the utility function, $U = U(c,\ l,\ s)$, to account for Chayanovian household dependency. With increasing household dependency (and higher values of c), the marginal utility of subsistence increases as that of leisure decreases, and the household becomes increasingly willing to intensify its agricultural efforts, enduring Chayanov's so-called drudgery of work (Figure 1). Theoretically, the utility function changes from U_1 to U_2; the implication in practical terms is that a household is willing to give up more leisure for the same amount of food.

To facilitate the exposition for the purposes of analysis, consolidate objective function (1) into two periods reflecting multiyear phases of farm activity. Let utility be achieved in the first period by leisure and subsistence consumption, and in the second period strictly by income, represented by the asset value of the land cleared. The asset value of land, or its sale price, in the absence of speculation or other market distortions, is the capitalized value of the rent, or net yearly revenue divided by the interest rate (Fujita 1989). The land price, per unit land, reflects the net income stream, or rent, associated with the production value of the unit.

Let period one, agricultural production, all of which is consumed, be a function of the amount of land cleared, or $A = k(L–l)$, where A is sown land, k is capital, L is household labor endowment, and l is leisure. Then subsistence consumption is $s = aA$, where a is a coefficient (Walker 1999). By the second period, the deforestation process has run its course, and the value of the land asset is $pk\ [L–l]$, where p is the expected price of land (with an implicit time discount). Assume that the amount of land can be freely chosen given the frontier setting, in which case only family labor power constrains the deforestation process.[8] Also assume that intensification arising from substitution of inputs or labor for land does not occur during the deforestation phase; such substitutions are unnecessary when land is abundant (White et al. 2001). In a Chayanovian sense, family labor exertions do *intensify* with increasing household dependency, but this leads to additional deforestation, and an increasing use of land. Given the cost of capital, r, the objective of the household is now to maximize, through choices of leisure and subsistence,

$$U[c, l, s] + pA - rk \tag{2}$$

subject to

$$\begin{aligned} s &= aA \\ A &= k(L - l) \\ l &\leq L \end{aligned}$$

Implicitly assumed is that the timing of the switch to the market system is exogenous, given the well-defined nature of the time periods. Walker (2003) suggests that colonists have strong expectations about when they will be able to sell their goods (or land), given the pace of development in vicinity of their farms. On this basis, they make early decisions about the amount of land that needs to be cleared for future market-oriented production. Of course, the future may not live up to expectations, but the land clearance decisions have already been made. With land prices expected to increase (which reflects increasing expected farm-gate prices stemming from improved accessibility), the asset value of land increases, affecting the amount of deforestation in the combined problem, as shown in Figure 2.

The x-axis in Figure 2 depicts the amount of sown (or deforested) land, A, which increases from left to right with family labor expenditures. Because land creation requires labor, the amount of household leisure increases from right to left. The maximum amount of deforestation occurs when the entire family labor endowment is absorbed by the labor process, yielding a quantity of sown land of $A^{**} = kL$, on the far right of the figure. The subsistence generated when no leisure is consumed, and all family labor power (L) is expended to deforest and farm, is s^{**}, shown on the y-axis, also to the right. This

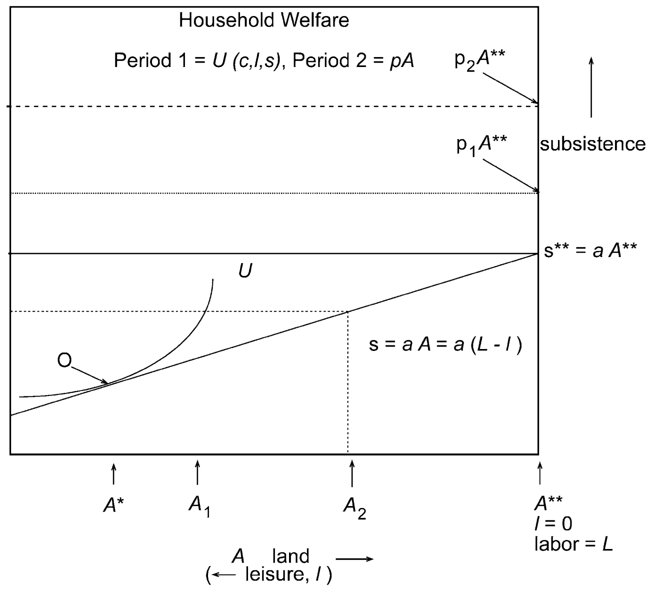

Figure 2. Finding the deforestation magnitude, A.

axis also depicts the asset value of land, which is simply a multiplicative function of A and land price. If all family labor power is expended in period one (i.e., leisure, $l = 0$), the asset value of the land is p_1A^{**} under expected land price p_1. If the family has stronger expectations, the same amount of land is cleared given that family labor is constrained by its endowment, L. Nevertheless, its utility is greater given that same amount of land has more value (p_2A^{**}).

If the family paid no attention to asset value, it would maximize strictly according to first-period utility, and achieve point O, consuming both subsistence production and leisure. Note that in Figure 2 the utility "indifference" curve is oriented toward the upper left quadrant, which reflects the fact that one of the consumed goods, namely "leisure," increases from right to left, and not from left to right (Ellis 1993). Because the family does consider the asset value of land, it chooses less leisure and more land (and subsistence), represented by point A_1, under expected price p_1. If the price expectation is stronger (p_2), less leisure is consumed and even more land created (A_2).

The Statistical Model

In operational terms, our approach attempts to estimate an equation for the derived demand for land at farm level, or the shifts in the A values of Figure 2, in response to variations in household structure, distance from the market, and so on. Thus, the statistical work is implicitly in the tradition of Allen and Barnes (1985), as elaborated by the derived demand theory of Panayotou and Sungsuwan (1994) and Reis and Guzmán (1994), although the regressions are estimated for actual decision-making units, namely farm properties. We do not address disaggregated parcels of land, as in the spatially explicit model.

The theoretical model suggests a number of relationships between deforestation, to be regarded statistically as the dependent variable, and a set of independent variables reflecting household characteristics. Specifically, the model suggests that deforestation increases with the number of family workers, the degree of household dependency, and household wealth (reflecting household capital), and it decreases with distance from the market, which lowers farm-gate prices and therefore land prices.[9] In the statistical examination of these effects, we include variables that have been hypothesized to influence the degree of deforestation but are not explicitly observable in the theoretical model, such as quality of the resource base (Pichón 1997), use of credit (Ozório de Almeida and Campari 1995; Godoy et al. 1997), use of off-farm labor (Pichón 1997; Walker, Perz, et al. 2002; Pan and Billsborrow 2005), and human capital acquisition (age of household head, length of residence: Alston, Libecap, and Schneider 1993; Godoy et al. 1997; Pichón 1997; Godoy, Jacobson, and Wilkie 1998). We have no a priori expectations about the impact of the resource base or of human capital acquisition on magnitudes of deforestation.[10] Credit should represent another component of capital, and therefore increase deforestation; similarly, *hired* labor should increase deforestation by adding to the labor pool.

Sample Construction and Variable Definition

The data used in the empirical analysis comprise information reflecting household characteristics taken from a household survey, and a deforestation measure derived from the classification of satellite images. The survey of farm households addressed the activities of small producers in Uruará county (1996 population: 37,395), which is located in the eastern part of the Amazon basin in the Brazilian State, Pará (Figure 3). The Transamazon Highway (BR-230) passes through the town of Uruará, where a settlement frontier opened in the 1970s with road building. We chose Uruará county in central Pará for pragmatic reasons, as it is a frontier location with primary forest and large numbers of accessible smallholders. Although we initially intended to conduct the survey in the south of Pará, the 1996 massacre at Eldorado de Carajás in which nineteen land reform activists died convinced us to search for a secure location. Although central Pará has become increasingly

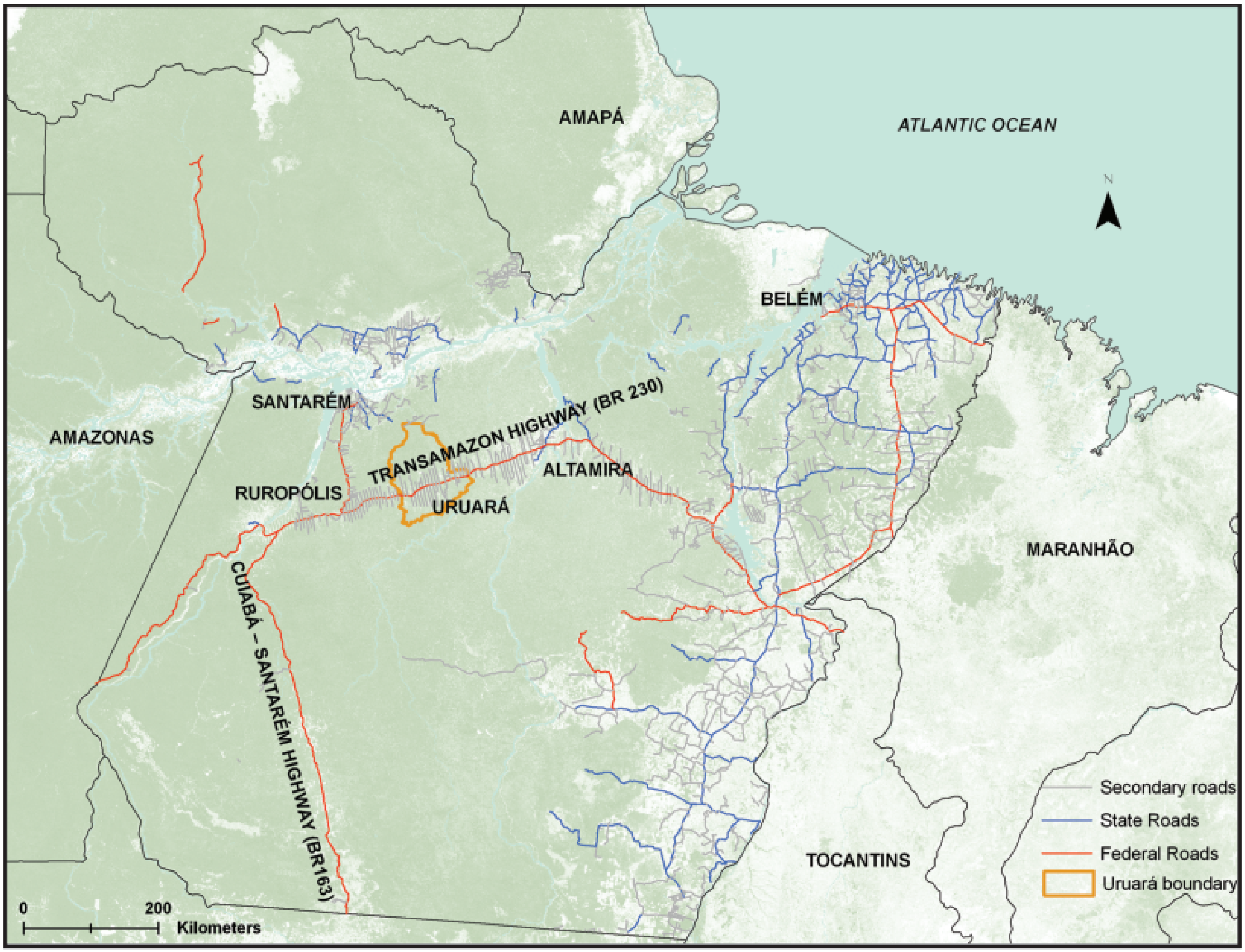

Figure 3. Uruará study site in the Brazilian State, Pará.

violent, the Transamazon Highway west of Marabá was relatively peaceful in 1996.

Three teams of fieldworkers administered a twenty-page instrument during the month of July 1996, obtaining information on household demography (including family size, age composition, and migration behavior), durable goods possession, farming system components, and agricultural technology. The difficulties of field data collection complicated formal efforts at geospatial sample design (Griffith 2005). Moreover, random sampling by distance (every *n*th kilometer) and household count (every *n*th farmstead) proved impractical. Counting houses was problematic due to proprietor absence, and structures were sometimes hidden from view along the road. The same may be said for distance sampling, since residences were not always apparent at a specified sampling stop. In addition, the remoteness of household locations made time a serious constraint on data acquisition. For reasons such as these, the analysis sample was collected opportunistically; in essence we conducted interviews with people we could find, building geographic representation by daily updates of the survey geography using regional maps. We obtained a widely dispersed sample across the county, although time constraints and the desire to build sample size led to local clusters, as can be observed in Figure 4. Evidently, the sample possesses both systematic and random spatial components, given the desire for representation on the many settlement roads, and the randomness of opportunity once sampling occurred on them. Such a sample possesses desirable statistical properties (Griffith 2005).

Farmsteads absent of proprietors or knowledgeable individuals and farmsteads difficult to access were omitted from the sample. In this context, given the degree of land ownership in the region, an absent proprietor is not an absentee landlord but typically someone who is traveling for reasons related to farming activity or family business. Therefore, there is no systemic differ-

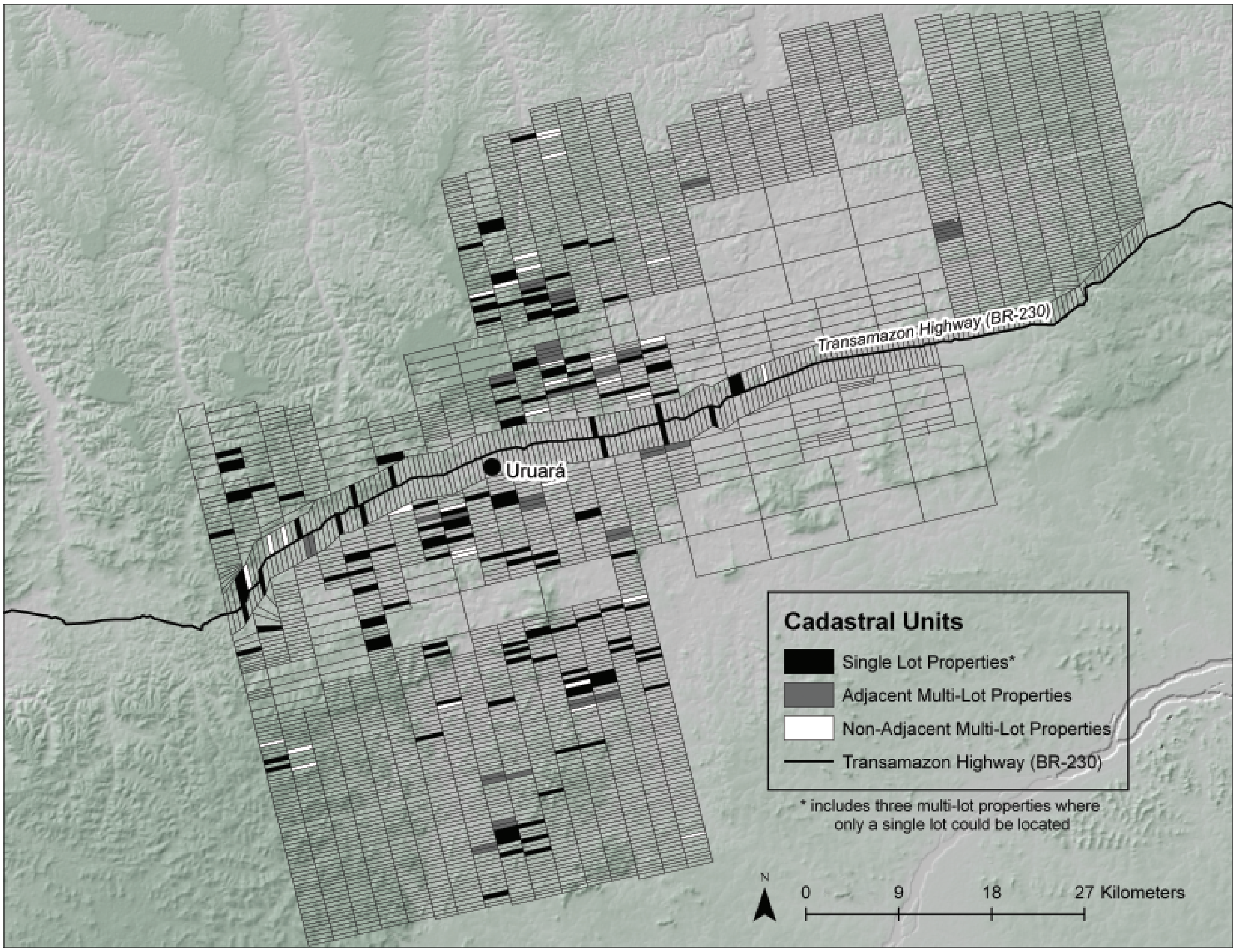

Figure 4. INCRA cadastral unit map.

ence between the sample and households excluded due to "absence" along dimensions of wealth that might exist by virtue of differentials between owners and renters. Properties deemed difficult to access are those located far out on settlement roads, many kilometers off the Transamazon Highway. Such properties were simply hard to get to, and significant sampling effort would have generated very few observations. The settlement populations, whether near or remote location, are similar in that all are colonists from outside the region. Indigenous peoples, although resident in the area, live in two settlements along a river about 100 km to the south and can only be reached by boat. They were not included in the study.

Uruará's settlement geometry, initially designed by the Institute for Colonization and Agrarian Reform (INCRA), consists of mostly 100-ha lots (400 × 2,500 m, and 500 × 2,000 m), running north and south of the Transamazon Highway; these show on Figure 4 as a fine network of small, narrow rectangles. Other large parcels, so-called *glebas* ranging up to 3,000 ha, can also be seen, although colonization in this area focused on smallholders who were granted individual 100-ha lots upon their arrival. The survey effort focused on such smallholding colonists, and the observational unit in the analysis to follow is the *property*, an economic entity containing one or more lots. Altogether, data were collected for 261 properties, consisting of 347 lots. Of these 261 properties, we retained 132 (169 lots) for data analysis purposes. Observable in Figure 4, they are mostly single-lot properties, although some degree of aggregation exists (Table 1).

Several factors restricted the sample size ultimately used in the analysis. For some properties, we could not obtain adequate satellite imagery. In other cases, colonists had settled in areas not yet demarcated, and were unable to report the identifying lot numbers we used to find locations on the INCRA map. Finally, we eliminated

Table 1. Frequency of Lot Holdings

No. of lots per property	Frequency	Percentage
1	107	81.06
2	18	13.64
3	3	2.27
4	3	2.27
5	1	0.76
Total	132	100.00

properties that raised doubts about the equivalence of sown land and deforestation (see below).

The empirical analysis used data from the questionnaire and from satellite image analysis. The household surveys yielded the independent variables indicated by the theoretical development, including distance from the main highway (BR-230), which serves as a proxy for market access (i.e., farm-gate and land prices), household dependency (the number of individuals not engaged in farm work, namely children, women, and elderly individuals), and family household structure, given by counts of individuals in age-gender cohorts.[11] Capital available to a family was proxied by household wealth, defined as a categorical variable on the basis of durable goods in the household's possession upon arrival on the property.[12] Other variables used in the analysis are the amount of hired labor employed (in person-days, or *diárias*), age of the household head in years, access and use of agricultural credit for farm activities, length of time (in years) the household has been living on the property, and measures of resource quality (soil type and availability of water).[13] We measured soils at property level by overlaying a digital soils map (EMBRAPA 2001) on the cadastral map, and using categories based on EMBRAPA classifications (Table 2). For water features, we used a digital map showing all streams in the county.

Table 2. Soil types found on the sample properties

	Soil type				
	1	2	3	4	Total area
Area (ha)	16148.27	1883.64	2805.23	1716.42	22553.56
Mean area (ha)	96.12	11.21	16.70	10.22	
Proportion	0.72	0.08	0.12	0.08	100

Soil Type 1: High potential, ranching. Mostly latisols, with good structure, but nutrient poor (EMBRAPA 2001).

Soil Type 2: High potential, crop agriculture. Eutrophic soils; saturation of bases > 50 percent (EMBRAPA 2001).

Soil Type 3: Medium potential, ranching. Mostly latisols, with good structure, but nutrient poor and hilly (EMBRAPA 2001).

Soil Type 4: Low potential. Gravelly soils with minimal A horizon (EMBRAPA 2001).

General characteristics of the overall sample are consistent with the peasant economy of Chayanov, as can be seen in Table 3(Ellis 1993; Walker 2003). Families consume the majority of their rice (60 percent), corn (78 percent), and beans (70 percent), and tend to hire little off-farm labor (29 person-days per year). Average household size is 7.5 individuals, and there are 2.85 children and 0.17 elderly individuals. It is important to note that we are taking the household to be the sum of individuals living on the property, which sometimes includes more than one family (mean = 1.31). As a rule, these represent extended families who share in the labor process, if not in food preparation and household arrangements. The household head, 47 years old on average, has 2.03 years of schooling. More than half of the properties have had access to credit (52 percent), even though they arrived on their properties with very few durable goods in their possession (the omitted dummy variable category in Table 4: 73 percent for the full sample). The properties are located an appreciable distance for the main highway, BR-230 (18 km), and typically consist of one or more 100-ha lots.[14] For the overall sample, the average property possesses 133 ha; fragmentation of holdings is largely unobserved, although this has begun to change (Aldrich et al. 2006).

The farming systems of the sample households are highly diversified across annuals crops (rice, beans, and corn), perennials (coffee, cocoa, and pepper), and cattle. Pasture is the dominant consumer of land, and averages about 23 ha per property, as is common for Amazonian colonists (see Walker 2003). In general the sample possesses properties comparable to others in both the county (Table 3, panel B) and the region (IBGE 1996a; Jonas da Veiga, Tourrand, and Quanz 1996; Walker et al. 1997; Balanza 2005). Representativeness can be gauged by comparing the questionnaire and census data (Table 3, panel B), where it can be observed that the sample colonists produce somewhat more output than the mean for census properties possessing between 100 and 200 ha. We speculate that production differences are attributable to a distance bias introduced by not obtaining large numbers of remote observations. Certain of the settlement roads extend very far from the main highway, and require hours of travel time to transit (Arima, Barreto, and Brito 2005). We designed the project to build an adequate database for statistical inference, an objective that would have been unobtainable, given time and budget constraints, had we sampled regularly out to a 100 km from the Transamazon Highway. Although we have no way of testing it, we speculate, and ultimately assume, that the agricultural behavior of our sample properties are reflective of smallholders in the

Table 3. Descriptive characteristics of households

A. Household characteristics	Full sample ($N = 261$) mean	Analysis sample ($N = 132$) mean
Age of household head (yrs)	47.23 (13.04)	49.19 (13.14)
Length of land occupation (yrs)	12.05 (6.78)	13.78 (6.95)
Day labor[a]	28.86 (38.15)	30.92 (39.34)
Distance from Transamazon highway (km)	17.71 (14.44)	13.29 (11.39)
Number of people on property	7.50 (7.77)	7.54 (4.88)
Number of families on property	1.31 (.64)	1.34 (.61)
Education of household head (yrs)	2.03 (2.17)	2.06 (2.11)
No. of men	2.35 (1.63)	2.44 (1.59)
No. of women	1.75 (1.22)	1.84 (1.19)
No. of children	2.85 (2.74)	3.06 (2.892)
No. of elderly	0.17 (0.49)	0.19 (0.57)
Dependents[b]	4.77 (3.63)	5.13 (3.87)
Credit by property[c] (%)	51.76 (47.0)	68.93 (46.0)
Consumption characteristics (%)		
Rice consumed	60.04 (35.32)	59.77 (34.82)
Beans consumed	69.61 (36.97)	68.98 (36.97)
Corn consumed	77.73 (34.21)	80.02 (32.89)

B. Farm system characteristics	Full sample system	Analysis sample system	Census (smallholders)
Rice production (kg)	2407.14 (2503.12)	2232.39 (2177.97)	2157
Beans production (kg)	253.70 (450.57)	237.69 (478.23)	157
Corn production (kg)	1601.89 (2199.30)	1601.51 (2355.31)	1321
Cocoa production (kg)	553.98 (1787.33)	697.20 (2249.11)	433
Pepper production (kg)	532.15 (951.47)	726.84 (1152.20)	426
Coffee production (kg)	319.64 (1149.34)	367.01 (1493.71)	278
Pastures (ha)	22.50 (15.38)	25.22 (15.06)	23
No. of cattle	17.52 (23.24)	22.32 (24.17)	12
Mean property size (ha)	133 (83.57)	128 (75.18)	129[d]

Note: Standard deviations are in parentheses.
[a]The amount of day labor paid the preceding year (person-days).
[b]Dependents: children + elderly + women.
[c]The survey asked if the property had ever received agricultural credit.
[d]The census data include large properties.

county. The nature of colonization, in particular, ensures that size of land holdings shows significant regularity, outside of those interests that occupy *glebas*. In addition, the farming systems of the sample and the county, although differing in production magnitudes, are diversified across the same component crops (i.e, annuals, perennials, and cattle). They are basically the same size demographically, and gross land covers (primary forest, secondary forest, pasture, and land in crops, secondary forest) are very similar.[15]

The dependent variable, deforestation magnitude (number of hectares) on individual properties, was measured using satellite images, as follows. First, land parcel information was acquired from INCRA in the form of a paper map without a projection (a spherical geographic coordinate system) in the South American 1969 datum. The map was digitized in Environmental Science Research Institute's (ESRI) ArcInfo 8.1 using a digitizing table, and the digital cadastral data were georeferenced and projected to match the Universal Transverse Mercator projection (Zone 22 South, World Geodetic System 1984 datum) of Landsat imagery (Landsat.org 2004).

Landsat TM images for path 226/row 62 and path 227/row 62, covering most of the survey area, were then georeferenced and co-registered with the cadastral map, and an unsupervised algorithm was used to classify land cover into categories including forest, regrowth, deforested land, clouds, and water. A GIS overlay function joined the digital cadastral map with the classified images, which enabled the generation of land cover magnitudes for the *lots*. These data were then outputted to files readable by statistical software, and the cover and survey data were combined for analysis. Cloud cover restricted our land cover data to 1997, although the surveys were completed in 1996.

Table 4. Household wealth characteristics upon arrival

	Analysis (%)	
Wealth categories upon arrival	Full sample ($N = 261$)	Analysis sample ($N = 132$)
Category 1 [omitted category]	73.18	75.00
Category 2 [wealth (1) = 1]	14.18	12.24
Category 3 [wealth (2) = 1]	5.75	5.20
Category 4 [wealth (3) = 1]	6.89	7.56
Total	100.00	100.00

Notes: Wealth was defined on specific durable goods possession as queried in the survey:
Category 1: household possesses none of the surveyed goods.
Category 2: household possesses stove or chainsaw.
Category 3: household meets category 2, plus refrigerator, or generator, or television, or satellite dish, or motorcycle.
Category 4: household meets category 3, plus car or tractor.
The dummy variables used in regression (see Table 5) are given in brackets, as defined by the categories; the omitted dummy for the regression analysis comprises the poorest group of farmers.

The amount of deforestation was taken as the sum of lands classified as cleared land and regrowth. This presents conceptual issues, given regrowth can indicate abandoned land, in which case deforested land (cleared land plus regrowth) will not be equivalent to the amount needed for agriculture (Chayanov's *sown* land), as assumed in the theoretical statement. Since much of the regrowth probably forms part of the agricultural system as a form of so-called dirty pasture, this does not present a large problem (Perz and Walker 2002).[16] Nevertheless, respondents in 1996 may not be the original landowners, who could have needed more land for their own agricultural activities. In such a situation, some of the regrowth measured in the satellite images would represent true abandonment. We have corrected for this potential problem by limiting the analysis subsample to only those 1996 owners who reported that the amount of deforestation on their properties *upon arrival* was less than that measured by the satellite images. Deforestation magnitudes for multilot properties were calculated by summing over all the *lots* associated with the individual properties.

For methodological reasons, we chose to implement our regression models using deforestation measured from satellite images. It would have proved intractable to measure by remote sensing the deforestation from year of arrival to 1996, given the many different arrival times of the colonists. Our precautions in sample composition do not eliminate the possibility that the 1996 owners have in fact abandoned land, in which case regrowth is not a component of the farming system, as with dirty pasture or land under shifting cultivation. Given the relatively young ages of the households, this is not likely to present a significant problem (McCracken et al. 1999; Perz and Walker 2002). The regression database ultimately provided 132 observations because of the restrictions described, and also because some properties did not report location and had to be omitted for lack of deforestation data. This subsample is similar to the full sample in its demographic and agronomic characteristics, as can be observed in Table 3. As is shown in a subsequent section, Spatial Issues, spatial autocorrelation is present in the data, which raises a potential issue of effective geographic sample size in undertaking inference (Griffith 2005). Be this as it may, we are not aware of a literature addressing the determination of effective sample size for regression analysis in the presence of spatial autocorrelation. In any event, we would hesitate to reduce our sample given its relative smallness, and we are satisfied that using some subset of our 132 observations will not improve results. Since we already have these observations in hand, we cannot benefit ex post from a sample design that might have indicated we could have gotten by with fewer observations.

Estimating the Regression

The regression model considered is given in conventional form as

$$y_j = \mathbf{x}_j\beta + \varepsilon_j, \tag{3}$$

where y_j measures deforestation (in hectares) occurring on property j; $\mathbf{x}_j$ contains observations on a set of independent variables; β is the related set of parameters; and ε_j is a random disturbance. We approach estimation aware that (i) certain of the independent variables may by endogenous to deforestation and (ii) spatial relations may affect the dependent variables, as well as the error term. Ultimately, we estimated Equation (3) using ordinary least squares, or OLS (columns 1 and 2; Table 5), and maximum likelihood for spatial regression (columns 5 and 6; Table 5).

Endogeneity Issues. Relationships between deforestation, credit, and land-titling—not considered by the theoretical model—are complex, and not immediately obvious.[17] Although the use of credit augments the productive potential of the household and should therefore induce deforestation, it is also the case that the extent of deforestation will influence the demand for credit. As for land title, many have suggested that possession promotes resource conservation, which could imply a reduction in the degree of deforestation, although empirical verification of such an effect has proved elusive (Walker, Wood, et al. 2002). For the Brazilian case, causality is likely to

Table 5. Regression results for deforestation

	Ordinary least squares		Instrumental Variables (IV)		Spatial Model (SM)	
Variable	(1) ($n = 132$)	(2) ($n = 132$)	(1) ($n = 132$)	(2) ($n = 132$)	(1) ($n = 120$)	(2) ($n = 120$)
Age of household head (yrs)	– 0.0047	– 0.121	– 0.004	– 0.126	0.145	– 0.001
	(0.164)	(0.190)	(0.180)	(0.214)	(0.185)	(0.214)
Length of land occupation (yrs)	0.029	0.033	0.035	0.019	– 0.002	0.013
	(0.394)	(0.410)	(0.390)	(0.386)	(0.372)	(0.367)
Day labor[a]	– 0.016	– 0.023	– 0.016	– 0.024	– 0.006	– 0.017
	(0.063)	(0.062)	(0.056)	(0.055)	(0.058)	(0.057)
Distance to Transamazon highway (km)	– 1.048***	– 0.983***	– 1.052***	– .975***	– 0.714***	– 0.672**
	(0.212)	(0.212)	(0.248)	(0.248)	(0.267)	(0.264)
Dependents	– 0.106		– .099		– 0.225	
	(0.590)		(.633)		(0.613)	
No. of men	3.607**	3.055*	3.594**	3.089*	3.160**	2.692[b]
	(1.692)	(1.779)	(1.669)	(1.746)	(1.715)	(1.808)
No. of women		3.911		3.911*		3.547
		(2.816)		(2.262)		(2.285)
No. of children		– 1.224		– 1.250		– 1.395*
		(0.964)		(.874)		(0.852)
No. of elderly		3.163		3.252		4.402
		(3.668)		(4.445)		(4.425)
Wealth (1)[c]	7.033	7.763	7.052	7.721	6.355	7.189
	(7.867)	(7.639)	(6.718)	(6.643)	(6.932)	(6.866)
Wealth (2)	30.138***	30.425***	30.235***	30.217***	34.427***	35.957***
	(11.145)	(10.813)	(9.417)	(9.288)	(10.626)	(10.541)
Wealth (3)	20.547**	22.945*	20.557**	22.967***	17.849**	20.877**
	(12.258)	(12.036)	(8.332)	(8.417)	(8.065)	(8.154)
Soil type 1[d]	12.643*	11.645*	12.589	11.747	8.291	7.099
	(6.444)	(6.637)	(9.224)	(9.109)	(8.999)	(8.898)
Soil type 2	15.628	13.441	15.567	13.516	8.099	5.473
	(10.665)	(10.730)	(11.992)	(12.016)	(11.711	(11.830)
Soil type 3	7.606	7.138	7.538	7.270	– 1.630	– 2.151
	(9.335)	(9.215)	(11.187)	(11.040)	(11.191)	(11.047)
Water[e]	6.120	4.742	6.167	4.609	7.103*	5.468
	(4.385)	(4.630)	(4.471)	(4.642)	(4.432)	(4.515)
Credit[f]	12.677**	12.911***	11.611	15.225	11.194**	11.612**
	(4.904)	(4.700)	(17.635)	(17.738)	(4.820)	(4.756)
Intercept	27.367***	30.638***	28.014	29.371*	– 0.911	5.590
	(9.662)	(11.485)	(17.937)	(18.129)	(18.067)	(18.708)
ρ					0.449**	0.424**
					(0.189)	(0.186)
	AIC = 852.10	AIC = 852.41	AIC = 852.16	AIC = 852.69	AIC = 1024	AIC = 1024.96
	$R^2 = .47$	$R^2 = .48$	Sq.Corr = .47	Sq.Corr = .48	$R^2 = .48$	$R^2 = .50$

Notes: Robust standard errors are in parentheses below the coefficients. Two-tailed probabilities. AIC = Akaike Information Criterion.

IV (1) and (2) are two-stage estimators; title to land is used as an instrumental variable for credit. The same credit equation was used in both IV (1) and (2). The title coefficient is 0.88 with a significance level of 0.001.

Spatial (1) and (2): spatial lag model; credit variable used in IV (1) and IV (2) estimations. Breuch-Pagan tests do not allow rejection of homoskedastic error hypotheses in either regression.

[a]Paid non-family labor used the year before the survey, in men per day.

[b]One-tailed probability value is 0.068.

[c]The wealth dummy variables (1)–(3) are defined in Table 4. Category 2 = wealth 1; Category 3 = wealth 2; Category 4 = wealth 3, and the omitted dummy is Category 1.

[d]Soil class 4, the low potential category, is omitted because variables are defined as percentages, which sum to 1 for individual properties. Including all four variables would introduce a linear dependency, thereby rendering estimation impossible.

[e]Water is a binary variable with value 1 if a stream flows within 500 m of the front of the lot (facing the settlement road), and 0 otherwise. Multilot properties were measured for the lot of residence, typically the first one occupied.

[f]Dummy variables that measure the household access to agricultural credit. For how access to credit was determined, refer to the main text and to Note 13.

***significant at 1 percent; **significant at 5 percent; *significant at 10 percent.

work in reverse, because the productive use clause of the Brazilian constitution encourages land clearance in staking a claim (Simmons 2002, 2004; Simmons, Walker, and Wood 2002). Indeed, colonists in the Brazilian Amazon refer specifically to a *marcação*, an area deliberately cleared to show an intention to occupy.

When title is awarded after a property has been occupied, and after a demonstration of productive use, typically through deforestation, it can hardly be argued that title has an impact one way or the other on land clearance, at least in the short run. The implication is that credit is endogenous to deforestation, since land title must often be posted as collateral (Mueller et al. 1994).[18] Thus, we modify Equation (3) to

$$y_j = \mathbf{x}_j\beta + \delta z_j + \varepsilon_j,$$

where y_j and ε_j are as before. Now, however, $\mathbf{x}_j$, with its coefficient vector β, contains only the purely exogenous independent variables, and z is an endogenous dummy variable for use of credit. This binary variable, in turn, is modeled as the outcome of a latent variable z_j^*, assumed to be a function of exogenous variables $\mathbf{w}_j$, at least one of which is distinct from those in $\mathbf{x}_j$:

$$z_j^* = \mathbf{w}_j\gamma + u_j$$

$$z_j = \begin{cases} 1, & \text{if} \quad z_j^* > 0 \\ 0, & \text{otherwise} \end{cases}$$

Here, γ is a coefficient vector and u_j is the error term. In the present application, we take $\mathbf{w}$ to contain only one variable, the so-called instrument, title, which does not enter $\mathbf{x}_j$ under any circumstances (Table 5). To estimate this formulation, we implement a two-stage approach, fitting a probit model for credit first, with title as an instrument, then generating the fitted probability values for credit (and the hazard function, or the normal density over the cumulative density) to use as an independent variable in the OLS deforestation model. The variance matrix in the second stage is corrected for estimation in the first stage (Maddala 1983; Greene 2000).

Spatial Issues

In addition to the endogeneity issue, we hypothesize that spatial autocorrelation presents estimation problems because unobserved variables have generated deforestation contagions through their impact on agricultural decision making. For the Amazonian case, a farmer's use of fire is highly likely to affect his or her neighbor's choice of cropping system, which has implications for the amount of deforestation observed on individual properties. In a fire-prone environment, farmers opt for pasture as opposed to perennials, and they clear more land than they would have otherwise given the land requirements of grazing (Simmons 2004). In addition, the fungus *vassoura de bruxa*, (*Crinipellis perniciosa*), which has wiped out many cocoa plantations in Uruará county, diffuses from sites of infestation. As with fire, *vassoura de bruxa* can unleash deforestation contagions as farmers switch from cocoa to ranching to avoid the fungus. The effect as described is presently occurring in Bahia State, Brazil's premier cocoa producing region. Similar contagions may be associated with *fusarium*, another fungus that devastated Amazonian pepper crops in the 1990s.

Spatial autocorrelation in a regression framework typically manifests in two ways. Error terms can be correlated among themselves, which gives rise to so-called nuisance autocorrelation and coefficients that are not *efficient*, in the statistical sense (Anselin and Rey 1991). Alternatively, the dependent variable can be autocorrelated, in which case the problem is referred to as substantive autocorrelation. When this form of the problem is present, OLS regression coefficients are biased. The different forms of spatial autocorrelation call for different statistical procedures.

To address spatial autocorrelation, we consider OLS estimation of Equation (3), examining residuals for possible problems in this regard (Anselin and Rey 1991).[19] To do this, we first create contiguity matrices for establishing which farm properties are to be regarded as neighbors (i.e., contiguous), and which are not. Following Walker, Moran, and Anselin (2000), we define contiguity as the state of being within some distance of some property. Thus, property A is contiguous to property B (and vice versa), if the distance between these two properties (measured from their centroids), is less than some predetermined distance. In an analysis of violence in the Brazilian Amazon, Simmons (2004) defined contiguity based on adjacency. This makes sense when the analysis objects (in her case, counties) are collectively exhaustive of the sample space. For farm properties, this is not the case, as we did not visit every property on the grid. Hence, certain of the sampled properties are isolated, which makes an adjacency definition of contiguity problematic (see Figure 4), since a contiguity matrix with a row of zero entries is singular, and cannot be used in analysis. The actual matrices used in analysis are created in two steps. First, for some arbitrary row for some arbitrary property, the neighbors identified are entered as a value 1 (all other entries are 0). The row is then *normalized* by dividing the 1s in the row by the number of 1s in the row.

We examine OLS residuals using different contiguity matrices, based on different distances, because we have

Table 6. Spatial autocorrelation diagnostics

	Value	Probability
15,000 m		
Moran's I	5.453	0.0000
Lagrange multiplier (error)	.959	0.32
Lagrange multiplier (lag)	1.79	0.18
20,000 m		
Moran's I	4.057	0.0000
Lagrange multiplier (error)	.005	0.941
Lagrange multiplier (lag)	3.170	0.075
30,000 m		
Moran's I	2.681	0.0073
Lagrange multiplier (error)	2.125	0.144
Lagrange multiplier (lag)	1.340	0.246
40,000 m		
Moran's I	1.723	0.0849
Lagrange multiplier (error)	0.391	0.531
Lagrange multiplier (lag)	0.641	0.423

Note: These are the Robust Lagrangian statistics. The Moran's I statistic is always greater than the expected value, indicating positive spatial autocorrelation.

no a priori reason to believe spatial autocorrelation will manifest under any particular distance. The presence of multilot properties presents difficulties, since the individual lots comprising the property may be nonadjacent. We have addressed this problem by limiting the analysis sample for the spatial models to only single lot properties and to multilot properties whose lots are all adjacent ($n = 120$). For such multilot properties, we use the mean values of the coordinates of the centroids for the lots constituting the property.

Table 6 presents the diagnostics necessary for gauging the presence of spatial autocorrelation problems. These are generated by examining the OLS (1) residuals, using the instrumented value of credit (see Table 5). The diagnostics begin with a contiguity matrix using a distance of 15,000 m to define property neighborhoods; this is incremented up to 40,000 m, and diagnostics are generated for each case. The initial distance of 15,000 m was chosen because measurement of all pairwise distances among the properties indicated the most isolated to be 12,716 m from its closest neighbor. It was thus necessary to use distances no less than this in order to avoid a singularity in the contiguity matrix.

The table presents Moran's I statistic and Robust Lagrangian Multipliers for both errors and lags in the dependent variables. Moran's I shows that positive spatial autocorrelation is present among the residuals, with statistically significant values for neighborhoods defined on 15,000 m, 20,000 m, and 30,000 m. The only Lagrangian Multiplier approaching significance is for lags in the dependent variable, with a 20,000 m neighborhood. Thus, the diagnostics are suggestive of substantive spatial autocorrelation, which implies that the estimated coefficients for the OLS models could be biased. To correct for this we redefine Equation (3) as a spatial lag model:

$$y_j = \rho \mathbf{c}_j Y + \mathbf{x}_j \beta + \mu_j,$$

where y_j, $\mathbf{x}_j$, and β are as before. Now, $\mathbf{c}_j$ is the jth row of the contiguity matrix $\mathbf{C}$, ρ is an autoregressive spatial coefficient; and μ_j captures random error. Y is a vector with observations on the dependent variable, y_j, for all j, $j = 1, \ldots, n$. The spatial lag model may be solved by the method of maximum likelihood, which we implement using a contiguity matrix defined on 20,000 m (Walker, Moran, and Anselin 2000).

Results and Discussion

Table 5 gives statistical results for the three models, using two different representations of household structure. In estimation 1 for each model, total men and dependents describe it, whereas for model 2, household structure is disaggregated by age cohorts, with a gender breakout for working age individuals.[20] In general, the models perform well, with R^2 and square correlation values all close to 0.50. Of particular note are the robust findings for two of the main theoretical variables. Household labor (the number of men) performs consistently across the various estimation procedures, leading to an additional 3 ha of deforestation per additional male worker in the family. Distance of the property from the Transamazon Highway, the land value proxy variable, maintains higher levels of significance in every specification and procedure. Each additional kilometer from the Transamazon Highway reduces deforestation from between 0.7 to 1 ha. Other strongly performing variables include household capital endowment, proxied by wealth, which exhibits a considerable impact on deforestation. The dummy variables associated with wealth categories 2 and 3 indicate that these households have between 20 and 30 ha more deforestation than the poor families in the sample. The credit variable is statistically significant in the OLS and the spatial regressions, indicating that farms that have had credit show about 12 ha more deforestation than those that have not. When endogeneity is treated by the two-stage approach, however, the credit variable loses its significance, although the coefficient value remains high.

The number of dependents in the family, a variable in specification 1, is statistically insignificant across the models, suggesting that household labor endowment and not subsistence requirements are more important in explaining the amount of deforested land at property level. We hesitate to draw a strong conclusion in this regard, given the definition of dependents in the model, the negativity of the coefficients, and results with more fully elaborated household structures as given in specification 2. Here, for OLS, the two-stage approach, and spatial regression, the number of women and elderly individuals show positive—if (mostly) insignificant—coefficients, similar in magnitude to those associated with adult male workers. Statistical insignificance for the results could be an artifact of relatively small sample size. The coefficients for number of children are also statistically insignificant, but negative.[21]

Results for quality of the resource base are suggestive. Soil type 1 shows a positive impact on deforestation, although one that is not always statistically significant. A similar effect is observed for the availability of water on individual properties. Other variables in the regressions, including age of household head, length of occupation, and day labor, show inconsistent results that are statistically insignificant and of low magnitude.[22]

The intercept term is of interest given its sharp reduction in value in the spatial regressions. Note first that the spatial autoregressive term, ρ, is positive and highly significant, indicating the presence of positive spatial autocorrelation in the dependent variable, *deforestation*. Regarding the intercepts, they are very large, positive, and statistically significant in the OLS models, reaching 30 ha with a fully disaggregated specification of household structure. Thus, despite a relatively high R^2 (and low Akaike Information Criterion [AIC]) and good performance by several variables, it would appear that the OLS analysis leaves a considerable amount of deforestation unexplained, as the expectation is that the amount of sown land is determined by the variables used in estimation reflecting household structure, land value, and so on. Such large intercept terms have been observed before, and interpreted as the amount of land cleared for nonagronomic reasons (Walker, Moran, and Anselin 2000). As is often discussed in the Amazonian case, these include land speculation and the desire to stake one's claim under Brazil's productive use stipulation (Simmons, Walker, and Wood 2002). The spatial models appear to dispel this notion, however, as the intercept terms fall precipitously to between –1 and 5 ha, and they do not approach significance. Evidently, high intercept values in the OLS and two-stage results are an artifact of the presence of spatial autocorrelation.

Conclusions

The main objective of this research was to develop a peasant economy perspective on deforestation in tropical forest frontiers, and to apply it in a study of colonist households living in the Brazilian Amazon along or near the Transamazon Highway. A secondary objective was to advance a methodology integrating household surveys and remotely sensed data. Considering the secondary objective first, the study successfully implemented a regression analysis of land use behavior using a combination of remotely sensed and survey-based data, thereby adding to the growing body of household-scale approaches addressing the human dimensions of environmental change (Zimmerer 2004). In so doing, we corrected for possible problems associated with endogeneity and spatial autocorrelation. Sample sizes were sufficient to generate statistical power for testing, although statistically insignificant results in some cases might still be attributable to the number of observations. As for the first objective, to investigate the deforestation associated with colonist farmers in an Amazonian frontier, the results possess theoretical consequence, demonstrate that deforestation is a spatially autocorrelated process, and may have policy relevance. We now consider each of these points in turn.

The statistical findings point to the importance of household structure and expected land values (reflecting market access) on deforestation. In this regard, we draw two conclusions. First, household labor endowment is the most important demographic variable in the deforestation process. The insignificance of dependents suggests that the Chayanovian intensification effect brought about by increased subsistence requirements has no effect on deforestation, the opposite of what was expected. In fact, dependency may work in reverse, particularly with additional children who could act as a distraction in the allocation of family labor to farm production. Our conclusion is that the effect of dependency on the deforestation process, as described by proponents of the life cycle, is overstated, and dominated by the availability or lack of household labor. Nor does use of hired labor appear to have any bearing on the matter, although the availability of physical capital (i.e., durable goods) does raise the amount of deforestation. Although others have found a positive relationship between hired labor and deforestation and agricultural activity more generally (Pichón 1997; Walker, Moran, and Anselin 2000; Pan et al. 2004), our findings probably reflect the fact that hired labor is not an important factor of production among the households in our sample (Table 3). This is consistent with the Chayanovian assumptions on which our analysis is based (Maertens, Zeller, and Birner 2006).

Other results are of interest as well. We find the life-cycle variable, age of the household head, to show no impact on the magnitude of deforestation, in agreement with previous research (Walker, Perz, et al. 2002). Our finding that length of residence is statistically insignificant has also been observed (Alston, Libecap, and Schneider 1993; Ozório de Almeida and Campari 1995). It is important to note that the household labor variable is likely to be correlated with age of the household head, and to some degree with length of residence. The significance of household labor, and not the time-based variables, shows that deforestation is not an autonomous process, but instead is linked to household structure.

Our second conclusion is that the simultaneous significance of household and market variables illustrates the duality of the peasant household, reliant as it is on family resources but hopeful of market success (Turner and Brush 1987; Walker 2003). Deforestation arises on colonist farms pursuant to economic objectives and household constraints. Of key importance is the role played by distance in the results, the most robust variable in all the specifications, which is consistent with findings from much research on LCLUC conducted at the household scale (Alston, Libecap, and Schneider 1993; Pichón 1997; McCracken et al. 1999; Walker, Perz, et al. 2002; Pan et al. 2004). We have taken distance in our theoretical statement to represent the asset value of land, understood to reflect its production potential. As an expected value, it can clearly include a speculation premium if the landowner views the future through rose-tinted glasses, although current research shows the agricultural potential of Amazonian locations to be greater than originally thought.[23] In any event, the findings show that such expected values do conform to theoretical expectations in that they are organized in space according to a Thunian principle of market access. As has been pointed out, the value of land appears to play a role in the land use decisions of smallholders in the Amazon Basin (Margulis 2003; Arima, Barreto, and Brito 2005).

The statistical analyses provide additional insights into land cover change processes in the region beyond the theoretical expectations of the model. One of these is that deforestation is contagious, given the presence of *substantive* spatial autocorrelation affecting the dependent variable (Table 6). Based on field observation, we suspect that pasture fires are the primary culprit. When a colonist plants pasture, which requires periodic burning, he or she affects the agricultural decisions of neighbors. This is because the logical response is to follow suit given that pastures are fire-adapted. Besides the spatial autocorrelation result, weak evidence emerges on the importance of the resource base to the deforestation process. Soils that are good for pasture (soil type 1) tend to increase deforestation, as would be expected given the land-extensive nature of pasture-based systems. The same may be said for the presence of water, necessary to the maintenance of cattle stocks.

Of prime interest to the policy debate about promoting sustainable development is the role of credit, the provision of which is important to any agricultural development program. The results are mixed in this regard. Although the OLS model yields a strong and statistically significant effect, the two-stage results are insignificant. Since the coefficients nevertheless remain large and positive even with the two-stage correction, we hesitate to strongly reject the null hypothesis of *no effect* suggested by these results. The sample size, although reasonable, is simply not large enough to draw a definitive conclusion, given the controversial nature of the issue and the fact that others have found that credit promotes deforestation (e.g., Ozório de Almeida and Campari 1995).

Migration to rural areas in the Amazon has declined in recent years, but no one is declaring an end to deforestation, and alarms continue to sound about the loss of the Amazon rainforest (Perz 2000; Laurance et al. 2001). Individual colonist households still deforest at high rates, and the aggregate numbers have shown little sign of trending, reaching 26,000 km^2 in 2004 (INPE 2004). The statistical results presented in this article suggest that, in addition to the economy, demographic factors affect the land use decisions of colonists. Thus, a substantial component of Amazonian deforestation may not be very responsive to the usual policy levers, based as they are on the presumption that agricultural behavior is driven by profit maximization and conditions in the marketplace. With government plans for continued road building and infrastructure investment in the region (de Cassia 1997; Nepstad et al. 2001; Andersen et al. 2002; Laurance et al. 2004), it becomes all the more important to understand the land use logic of peasant households in the colonization frontiers of Amazonia.

Although this article has provided insight into factors affecting household-level decisions and land use, it must be reemphasized that this is only part of the story. Of particular importance are the underlying factors that bring colonists to the Amazon forests in the first place (Pichón and Bilsborrow 1999; Geist and Lambin 2002). They do not arrive by accident, and typically are responding to social and economic circumstances beyond their control, such as a life of poverty or a lack of opportunity in other parts of the country. Our story, focusing on microscale dynamics, is in large part determined by macroscale forces creating the push factors that lead to migration to the frontier in the first place (Barbieri, Bilsborrow, and Pan 2005). Thus, we are not blaming the victim, but simply describing a final result in a long chain of action and reaction, stemming from the power centers of decision making in the national economy and government (Gray and Moseley 2005). A full account of the peasant economy of Amazonian deforestation must ultimately comprehend the political economy of development, or lack thereof, which sets the stage for frontier occupation, and the environmental consequences that are of such concern to the world community.

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Notes

1. Indeed, loggers and colonists engage in mutually beneficial interactions with immediate implications for forest cover (Walker 2003). Aggregate and disaggregated approaches may avoid this because their dependent variable is indifferent to deforestation associated with different types of agents such as loggers, miners, and so on. But they cannot attribute the amount of deforestation to the individual types.
2. We by no means wish to suggest that research on household livelihoods, land use, and agriculture in forest frontiers of the Amazon basin and elsewhere is limited to the three countries indicated. Land cover change in Bolivia has been studied (Godoy, Jacobson, and Wilkie 1998; Mertens et al. 2004; Hecht 2005), where colonization processes have a long history (Stearman 1984). In addition, land use and livelihoods of both "peasant" and indigenous peoples have received considerable attention in Honduras (Godoy, Groff, and O'Neill 1988; Stonich 1993; McSweeney 2004a, 2004b).
3. The McCracken effort was largely descriptive and the socioeconomic variables implemented in their regression models were not theoretically derived (McCracken et al. 1999, 1316). On the other hand, sample size severely constrained the Walker study ($n = 32$).
4. Markets for inputs, labor, and land certainly existed in nineteenth- and early twentieth-century Russia. Nevertheless, Chayanov abstracted from the empirical setting to focus on the case of autarkic households, at least with respect to labor markets. Although nonseparability can arise from weaker conditions than a completely nonexistent labor market (Benjamin 1992), our treatment abstracts from such complexities to focus on the household demand for land, rather than labor. In fact, it is common in forest frontiers for households to be detached from labor markets, but engaged in product markets (Maertens, Zeller, and Birner 2006).
5. In other words, the decline in transportation costs over time allows a switch from nonseparable to separable production (Lopez 1984, 1986).
6. The assumption, then, is that although product markets exist, those for labor are imperfect. This is consistent with such frontier settings (Maertens, Zeller, and Birner 2006).
7. Transportation costs affecting farm-gate prices can be interpreted as transactions costs (Omamo 1998; Key, Sadoulet, and de Janvry 2000).
8. This is equivalent to an open access situation (*terra devoluta*), where land is free for the taking. In colonization areas, boundaries are demarcated, but the land grants typically exceed the amount of land that can be cleared in the short to midrun.
9. These results are derived in a technical appendix available from the authors upon request.
10. Good soils could encourage agricultural intensification and reduced deforestation, although they might also increase deforestation given enhanced profit potential, as Pichón (1997) observed. Similarly, human capital might include acquisition of environmental knowledge and values, at the same time that enhanced farming ability could lead to more clearing.
11. Distance to the Transamazon Highway is used because transportation price structures are mostly defined on this distance, at least within the vicinity of Uruará. Travel on BR-230 is easy; travel on the settlement roads is difficult. Uruará is the commercial market for the goods, if not the population of final consumption. Dependency is defined as number of nonworkers. Chayanov's variable (the number of dependents divided by the number of workers) confounds the number of dependents with the active workforce. Our definition yields a pure consumption effect, to the extent nonworkers do not contribute to farm labor.
12. We defined our wealth variable based on possession of durable goods. Because we did not have their prices, we did not create a single monetary value (Junming 1997; Morris, Carlleto, and Hoddinott 2000). Rather than impose a weighting scheme, we chose categories that could be used to define dummy variables (Weil 1989; Menon, Ruel, and Morris 2000). Wealth is correlated with durable goods possession (Morris, Carlleto, and Hoddinott 2000). The four wealth categories are given in Table 4. The poorest households (category 1) possess none of the durable goods listed. Category 2 households possess either a stove or a chainsaw, and nothing else, and category 3 households possess a stove or a chainsaw, plus either (i) some good depending on electricity generation or (ii) a motorcycle. The wealthiest households (category 4) have what category 3 households own, but also possess either a car or a tractor. In essence, our categorization here elaborates the two categories used in Walker, Perz, et al. (2002).
13. Credit is a binary variable indicating whether the property currently has or has ever had bank credit for agriculture. Colonists were queried in the survey for a yes/no response,

and how the credit was used. At some time, 52.2 percent of the households had had agricultural credit. Of these households, 16 percent reported using it strictly for pasture, 4.1 percent strictly for annuals crops, and 2.3 percent strictly for perennials. The remainder used their loans for combinations of these three basic crop groups.

14. Distance for a single-lot property is simply the distance from the lot to the Transamazon, BR-230 (cf. Note 11). For multilot holdings, distance is from the lot of residence, typically the first lot occupied by the colonist.
15. The 1996 Brazilian population count (IBGE 1996a) and 1995/96 Brazilian agricultural census (IBGE 1996b) allow for comparisons to assess sampling bias. The Uruará sample had a mean household size of 7.5; the 1996 population count figure for the municipality of Uruará was only 5.6, but it is not clear from census documentation whether families beyond the first were counted. If we exclude people outside the first family, household size in the Uruará sample is also 5.6. The 1995/96 agricultural census indicated the following land use allocation in Uruará: 65 percent in primary forest, 5.6 percent under cropland, 23 percent under pasture, and 5.9 percent under secondary growth. This is very similar to the sample (see Perz 2004).
16. The term "pasture" as used by colonists does not reflect our common understanding. In particular, colonists broadcast grass seeds onto deforested land, which they abandon until they can stock it with cattle. Any regrowth seeded with grass is subsequently referred to as "pasto sujo" (dirty pasture), and comprises part of the farming system, even if it shows up on satellite imagery as "regrowth." For this reason we calculate our dependent variable by summing cleared land and other lands not forested, which we call regrowth, for lack of a better term. In the region, truly fallowed land has two names, *capoeira*, which may possibly be used again in the long-term, and *terra abandonada*, which is land that has been abandoned for some reason (too wet, too rocky, etc.). Self-reported magnitudes in the sample for these two categories are 1.73 and 0.20 ha, respectively, amounts that are small compared to average deforestation on the properties, which is 49 ha (Perz and Walker 2002).
17. Household wealth might also be regarded as endogenous to deforestation, since increased clearance should yield more production and greater potential for market success. To overcome a possible endogeneity issue, we use wealth *endowment*, or the productive assets in the possession of the colonists when they arrived on the property, and not in the year of the survey, 1996.
18. Other assets could be posted, but land may be the only possession of sufficient value. Evidently, the Fundo Constitucional do Norte (FNO) program in Brazil, which provides credit to smallholders, did not require much in the way of collateral.
19. For models using discrete dependent variables defined on pixel states, researchers have been stymied in this regard because theoretically valid approaches to resolving the problem—namely, through implementing *spatial* regression—have been unavailable until recently (Lesage 2000). Thus, modelers have typically resorted to ad hoc solutions, such as defining new independent variables based on spatial "lags" of the dependent variable (Nelson and Hellerstein 1997; Wear and Bolstad 1998; Nelson, Harris, and Stone 2001).
20. Although women clearly work on the farm, there is a distinct gendered division of labor, and men undertake most of the land clearing and crop tending. The men and women cohorts are for individuals aged 15–64. Children are younger, and the elderly are older (Table 5).
21. We experimented with a third demographic specification, aggregating total men, total women, and the elderly, and leaving children as a separate variable. This model yielded similar results. The aggregated labor force variable was positive (3.4) and significant ($\alpha = 0.005$), and the children "dependents" variable was negative (−1.2) and insignificant ($\alpha = 0.178$).
22. Some of the households (36 percent) obtain off-farm income via external activities (e.g., business in town, wages), retirement funds (Brazil's *Funrural* program), or remittances. We experimented with a binary dummy variable defined on whether a household had access to off-farm income. OLS regression did not change the significant variables of Table 5 or their magnitudes in a meaningful way.
23. Arima, Barreto, and Brito (2005) show for example that cattle ranching in the Amazon is more profitable than in the choice locations in the southern part of the country.

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