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LAND USE AND LAND COVER CHANGE IN FOREST FRONTIERS: THE ROLE OF HOUSEHOLD LIFE CYCLES

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Tropical deforestation remains a critical issue given its present rate and a widespread consensus regarding its implications for the global carbon cycle and biodiversity. Nowhere is the problem more pronounced than in the Amazon basin, home to the world's largest intact, tropical forest. This article addresses land cover change processes at household level in the Amazon basin, and to this end adapts a concept of domestic life cycle to the current institutional environment of tropical frontiers. In particular, it poses a risk minimization model that integrates demography with market-based factors such as transportation costs and accessibility. In essence, the article merges the theory of Chayanov with the household economy framework, in which markets exist for inputs (including labor), outputs, and capital. The risk model is specified and estimated, using survey data for 261 small producers along the Transamazon Highway in the eastern sector of the Brazilian Amazon.

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Tropical deforestation remains a critical issue given its present rate, and there is widespread consensus regarding its implications for the global carbon cycle and biodiversity. Nowhere is the problem more pronounced than in the Amazon basin, home to the world's largest intact, tropical forest. In the Brazilian portion of the basin, rates of yearly forest loss have ranged between 10,000 and 20,000 km^2 over the past several decades (Skole and Tucker 1994). Nor is there any indication that the loss is abating, as might be hoped given the historic trends of forest recovery experienced by many temperate countries (Walker 1993; Grainger 1995; Mather and Needle 1998; Rudel 1998; Rudel and Zichal 2000). Continued land cover change could substantially reduce the extent of the Amazonian forest in the near future, converting very large tracts to agricultural activity.[1]

Indeed, forest loss in Brazil should come as no surprise, given the political economy of the development process in that country and its spatial articulation. During the 1970s, Brazil's military government pursued frontier expansion as part of its approach to national development (Mahar 1979). Among other things, the regime encouraged substantial investment in highway infrastructure to facilitate directed colonization programs for small farmers (Smith 1982). The government's hope was that colonization would reduce pressure for agrarian reform in more densely settled parts of Brazil and would satisfy the national security objective of securing the northern borders. Whether the policies achieved their objectives remains a subject of debate. There is little disagreement, however, that the road-building program expanded the land area under production, pushing the frontier farther north. The new roads rendered vast tracts of land accessible, raising land values and encouraging agricultural production among migrant smallholders (Ozório de Almeida 1992).

This study addresses land use and land cover change in the Brazilian basin, taking as given that aggregate phenomena and circumstances originally opened the region to human impact. We address the land cover change processes at the household level occurring in the aftermath of a migration decision, or what may be referred to as the endogenous processes of change engendered by the broader scale factors affecting interregional migration and capital flows. To this end, we adapt a concept of the household life cycle to the current institutional environment of tropical frontiers. In particular, we pose a risk minimization model that incorporates demographic factors at the household level with the more conventional market-based factors, such as transportation costs and accessibility.

It has been suggested that the life cycle may partly explain the evolution of the landscape, given that land managers and their families, like everyone else, experience an ever-changing set of needs, capabilities, and objectives, all of which affect their economic decision making. Consequently, one goal of this study is to fully elaborate the concept, or what will be referred to as the life cycle hypothesis (LCH), within the context of land use. A second goal is to develop a behavioral context and model that integrates household and market-based factors. We focus our attention on settlement frontiers and their occupants, typically poor farmers engaged in a struggle for survival. Such agents are considered a major factor in global environmental change and are widely implicated in the process of tropical deforestation. Our study examines the degree to which household-level processes are drivers of land use and land cover change in the tropical forest biome. Our particular interest involves the relative importance of exogenous economic conditions and the internal functioning of the family.

This article is organized as follows. We first consider an early contribution on microscale land use by Chayanov (Thorner, Kerblay, and Smith 1986), whose relevance is constrained by the social and institutional conditions found in the forest frontiers of today. We extend the Chayanovian framework beyond its focus on household demography and allow for the impact of economic conditions on farm evolution and land use. In essence, we merge the theory of Chayanov with the household economy model in which markets exist for inputs (including labor), outputs, and capital. After the theoretical development, we present and discuss relevant empirical work addressing household-level land use in the application region, Amazonia. We follow this discussion with results from a survey-based, statistical assessment of the link between household demography, economic conditions, and land use for 261 small producers along the Transamazon Highway in the eastern sector of the Brazilian Amazon. A discussion of policy implications concludes the study.

The Life Cycle and Land

Theoretical Foundations

Much of the theoretical foundation for specifying the importance of life cycle effects on agricultural land use was laid by the Russian agricultural economist Chayanov, who studied peasant farming practices in that country after the 1917 revolution (Thorner, Kerblay, and Smith 1986). Chayanov serves as a useful point of departure in the present context because the Russian revolution freed substantial tracts of land, creating conditions of land abundance similar to contemporary agricultural frontiers in Amazonia and elsewhere. Chayanov observed that peasant households held farms of different sizes with varying levels of surplus production, and he explained this in terms of household structure, distinguishing households by life cycle stage, described by the labor-consumer balance (cf. dependents).[2] In particular, well-endowed households with many family workers were observed to possess larger holdings than those constrained by labor power. Chayanov also considered the household's response to scarcity, noting that an increased level of dependency in a household (i.e., a low labor-to-consumer ratio) disposed it to greater manual exertion, a lowered preference for so-called leisure, and self- exploitation.

Although Chayanov's theory provides a demographic basis for the differentiation of households into property-size classes—and therefore magnitudes of land clearance and distribution associated with family structure—it has several shortcomings that complicate direct application to contemporary Amazonia (see, e.g., Harrison 1975, 1977, 1979; Hunt 1979; Shanin 1986). Chayanov assumed that labor markets do not exist, so the family can neither hire workers nor sell its own labor power to off-farm employers. And although Chayanov observed markets for products and capital in the Russian countryside, in his theoretical formulations, he assumed a highly constrained production system based entirely on family labor, taken as a fixed factor, with little opportunity for expansion through reinvestment or borrowing. These conditions are not always upheld in the Amazon region, which has a well-articulated system of cities connected to the world economy (Browder and Godfrey 1997). Nevertheless, there are very remote areas with individuals living near or at subsistence. Our sample of smallholders shows considerable variation in market attachment, largely a function of location in the system of colonization roads, or *travessões*. Some are completely profit oriented, with little family labor or consumption of farm-produced goods. Others consume all they produce and use only family workers. Of the sample, 49 percent used no off-farm labor in the year preceding the survey; this is comparable to Chayanov's observation that 90 percent of Russian peasants were detached from labor markets.[3]

For the development that follows, it is convenient to provide a framing context, to which end we synthesize the stylized presentations for the Brazilian Amazon given by Centro Agro-Ambiental do Tocantins (CAT 1992), Walker and Homma (1996), and McCracken, Brondizio, et al. (1999). All three draw on intuitive notions of life cycle whereby family life is perceived as a series of stages following one another in an evolutionary track that has implications for farm production. The stages are determined mainly by the age of the household head, the amount of available family labor, the number of dependent consumers, and the use of hired labor and off-farm income.

Generally, the scenario starts with migration of a young family to a plot of land beyond the extensive margin of agriculture. With time, the household head ages and, through experience and experimentation, is able to improve his or her farming practices. Concurrently, the number of dependent children rises, imposing a consumption burden on the household's active workforce. The children ultimately add their productive power to the sum total of household workers, which allows for farm expansion and the extension of existing activities into new endeavors. As the life cycle winds down with aging of the household head, activities may contract or continue in robust fashion should adult children remain in place and build on the family's patrimony. An important expectation driving the initial migration is that the extensive margin will pass, thereby incorporating the farm into a settled agricultural region with markets for inputs, products, and capital.

The Impact of Markets and Household Preferences

These stylized treatments (CAT 1992; Walker and Homma 1996; McCracken, Brondizio, et al. 1999) are largely descriptive and do not provide a theoretical statement capable of statistical assessment. To this task we now turn. We begin by asserting the existence of two institutional states relative to the market, and we assume that a pure life cycle effect will be manifest under autarchy, in the complete absence of markets for labor, inputs, and products (Nakajima 1969). The existence of markets occasions the functional breakdown between attributes of the family and farm system. Although the market may be necessary to the demise of life cycle phenomena in this context, it is not sufficient. Note that the CAT (1992), Walker and Homma (1996), and McCracken, Brondizio, et al. (1999) elaborate the experience of colonists in the Brazilian Amazon who occupy land in advance of the frontier. These colonists experience the arrival of the highway system with all that it brings, including markets for labor, outputs, and capital. Thus, the process of colonization in Amazonia brackets the institutional setting vis-à-vis markets.

At least two market-related mechanisms can break apart the autarchic apparatus of the household and its production system. First, the family may respond to the advent of opportunities in markets for labor. Off-farm job opportunities often provide wages that can be used to mechanize production, effectively substituting capital for labor. Indeed, we note from fieldwork a systematic trend in the interaction between the household and external labor markets. When labor is scarce, as in the early and late stages of the life cycle, families may hire workers to set up or maintain the farm, invest early in future activities, or simply continue production for one more year. Alternatively, with abundant labor, as during the middle stages of the life cycle, household members may hire out to supplement or smooth income or accumulate the saving necessary for investment.[4] Besides this labor market effect, a prime source of funds for farm improvement comes with the sale of commercial crops and extractive products. Amazonia has been subject to a number of commodity booms that have enriched some residents, if only for short periods. Although the region as of yet has not developed an agricultural base capable of generating widespread well-being, there is evidence of modest wealth accumulation that has come with strong prices for pepper and cocoa (e.g., Walker et al. 1994).[5]

Household consumption demands also play a key role in farm decisions. These demands reflect the values placed on the goods and services consumed by household members, or its welfare function. In tropical frontiers, welfare is likely to depend on a highly restricted set of items, given low incomes and lack of access to markets for consumer goods. In theoretical accounts, the choice set is often restricted to food and so-called leisure (Ellis 1993). Through the course of the life cycle, the welfare function of the family presumably changes as its needs evolve, which, under autarchy, necessarily affects the farm system and its attributes. For example, the same number of workers must till more land to feed a larger family whose members include dependent children or elderly individuals who have passed their prime. Such an effect is traceable to changes in the household's welfare function, particularly to a changing valuation of the trade-off between time spent on agricultural pursuits and time "consumed" as leisure. With a growing consumption burden, the household's capacity for self-exploitation through increased work efforts also grows.

Thus, we can identify two loci of family attributes affecting farm decisions and, consequently, attributes of the farm system. These include the household's array of productive factors and the welfare function that embodies trade-offs between leisure and subsistence experienced across the family. In empirical work, the welfare function effect is captured, to a certain extent, by the concept of dependency, typically taken as some indicator of consumptive demands vis-à-vis productive resources (similar to the ratio that Chayanov posited of consumers to workers). The household factors encompass the traditional attribute, family workforce, but also include the wealth, human capital, and financial capability of the family. It is important to draw a distinction between the household head's life experience, a function of age, and the site-specific experience and learning that come with residential duration (Moran 1989). Both contribute to the family's stock of human capital, as does formal education.

Age is also linked to attitudes about risk and investment. As Modigliani and Brumberg (1954) argued long ago, individuals invest early to ensure an income stream for later years. For the case of small producers in a settlement frontier, early investments may be problematic due to high dependency and a limited workforce, which disposes the decision maker to high discount rates and risk aversion. The initial phase of the farm system may then be focused on reliable and fast-producing cultivars such as rice, corn, and beans. Only later, as children age and enter the household labor force, do discount rates relax and does risk aversion soften its restraint on farm planning. Investments are then more likely to be undertaken in activities yielding real financial gains such as cattle ranching or the creation of perennials plantations.

The Farming System

In early formulations of the household economy, the farm system is a highly stylized production function yielding only one product, food. This allows for the classical formulation of the consumption problem as a trade-off between leisure and consumption (of food), in the absence of markets for labor, output, and consumer goods (Thorner, Kerblay, and Smith 1986; Nakajima 1969; Ellis 1993). Household production in later formulations permits a full range of market interactions but still posits a single product (Singh, Squire, and Strauss 1986). Be this as it may, farm systems are often highly diversified, particularly those of small producers, the subject of this discussion (Serrão and Homma 1993).[6]

Anthropologists have argued that indigenous agriculturists diversify crop selections to mimic the natural environment, thereby increasing ecological resilience of the farm system and protecting it from herbivorous pests. Others have suggested that system components such as cattle may serve other economic functions beyond mere consumption. As a store of easily transferable value, for example, cattle represent a form of liquidity in environments with weak lending institutions. The production of more than one crop requires a formulation of joint production, and crops would presumably be selected on some basis of complementary food requirements (Walker 1999) or portfolio diversification.

Portfolio theory refers to investment and the diversification of risk over uncertain economic returns (Hirshleifer 1970). Although the choice of any crop represents investment of a kind, some yield high-certainty outcomes in the short run, while others are riskier over long planning horizons, but with a much greater potential for economic gain. We refer to the former type as income crops and to the latter as investment crops; these categories are analogous to the terms *subsistence* and *commercial crops* but carry the specific distinctions of capital theory (Walker and Homma 1996). Diversification over income crops reflects efforts at nutritional complementarity and safeguards in the face of a risky pest environment (Walker 1999). Investment crops may themselves be diversified, as when various types of perennials are planted, but farms with mixes of income and investment crops, particularly those that show switching from income crops to investment crops, are of special interest in the present context and setting.

Walker and Homma (1996) documented region-scale switches in farm systems focused on rice production to ones with large components of perennials, pasture, and cattle along the Transamazon Highway between the early 1970s and 1993.[7] Although their analysis did not track individual farms but instead was based on two different surveys, they explained the phenomenon in terms of processes observed by CAT (1992) in the south of Pará. In particular, households age; in so doing, maturation of the family workforce enables farm evolution from annuals production to ranching.

We are now in a position to provide a narrative statement summarizing endogenous land cover change factors at the household level, based on the LCH. In particular, as colonist smallholders begin their families and start farming, they meet subsistence needs with limited economic resources since youthful children are strictly consumers. Dependency, risk aversion, and high discount rates create strong incentives to achieve food security through annual crops. As the children age and expand the family labor force and as the household head acquires experience, production constraints are relaxed, discount rates are lowered, and risk aversion is mitigated. The stage is set for investment in commercial crops, typically perennials and cattle.[8] The evolution in crop selection thus described points to important farm system attributes beyond simple measures such as scale of production, size of holding, or area deforested. Indeed, the selections themselves constitute an attribute linked, presumably, to the life cycle. The implication is that perennial plantations and ranches will reflect later stages in the joined destiny of the farm and the people who work it.[9]

To summarize for the Amazonian case, the LCH suggests a link between life cycle stage and crop selections, particularly the relative distribution between income and investment crops. Regarding the factors of production (excepting labor), the size of the holding (i.e., the area of land worked) is a critical characteristic in traditional agriculture, although with more modern systems, the role of capital equipment becomes increasingly important. Nevertheless, life cycle stage will be linked both to farm area and the degree of mechanization under conditions of land abundance.[10]

Other factors, of course, influence and complicate the articulation of life cycle impacts on farming system choice. Economic resources, generally, such as available capital, clearly influence farm decisions. Those arriving on a parcel of land endowed with prior savings can be expected to follow a different developmental track than those who must accumulate along the way, building their resource base. In addition, we have argued that people migrate to frontiers with an expectation that the extensive margin will advance beyond their farm locations. This is tantamount to an expectation that transportation and market accessibility costs will be reduced over the long run. A switch to a commercial system may have as much to do with the arrival of a road, or its improvement, as with the endogenous factors we have elaborated. A model of land use in settlement frontiers must be capable of addressing both sets of factors.

EMPIRICAL CONSIDERATIONS

Empirical research in the Amazon addressing relationships between household structure, the external economy, and farm systems is limited. The work that has been done focuses mainly on deforestation and does not fully operationalize the meaning of *life cycle stage* or *farm system*, two key concepts addressed by this study. Nevertheless, we argue that an explication of the farm system provides insight into deforestation processes via the proximate causation framework, which asserts that what drives deforestation—namely, the demand for land (Reis and Guzman 1994; Panayotou and Sungsuwan 1994)—must itself be explained by reference to the decision maker (Turner, Meyer, and Skole 1994; Walker, Moran, and Anselin 2000). Table 1 presents an overview on household studies of land use in frontiers and other remote areas of the neotropics in the Americas. For each source, the table presents a land use outcome and the analytical approach implemented (empirical models or other statistics) to explain it. The variables of greatest interest involve continuous measures of forest cover, the extent of deforested land, and the area under annuals, perennials, or pasture. While some outcome measures use categorizations that capture differences between farm system types (e.g., Pichón 1996; Marquette 1998), these tend to emphasize the quantity of area cleared rather than the portfolio of activities. The profile of components of farm systems is thus not fully taken into account, although some analysts (e.g., Pichón 1997a) have called for more holistic appraisals.

Table 2 summarizes the explanatory variables and their performance for the multivariate models of Table 1; a number of these variables are reflective of internal household factors. Age of household head upon arrival and at time of interview is given in columns 10 and 11, respectively, while duration of residence appears in column 6. Specifications of total household members and male and female adults

TABLE 1. Operational Definitions of Land Use/Investment Outcomes in Preexisting Empirical Household-Level Analyses in the Amazon and the Neotropical Americas

Source	*Analytic Approach*	*Land Use Outcome*
Alston, Libecap, and Schneider (1993, 35-38)	Logit model	Investment in hybrid seed, pesticides, fertilizers, or corral
	Tobit model	Percentage land area under annuals
	Tobit model	Percentage land area under perennials
	Tobit model	Percentage land area under pasture
Alston, Libecap, and Schneider (1996, 23, 29)	Tobit model	Percentage land area under crops or pasture
Fearnside (1986, 100-13)	Simulation	Percentage land area deforested
Godoy, O'Neill, et al. (1997, 982)	Tobit model	Hectares of old-growth forest
Godoy, Wilkie, and Franks (1997, 877)	Probit model	Probability of cutting old-growth forest
Godoy, Jacobson, et al. (1998, 166, 168)	Tobit model	Hectares of primary forest cut
Godoy, Franks, and Claudio (1998, 360)	Probit model	Probability of using chemical fertilizers or insecticides
Godoy, Groff, and O'Neill (1998, 661)	Tobit, ordinary least squares (OLS), and probit models	Hectares of old-growth forest cut
Godoy, Jacobson, and Wilkie (1998, 58-59)	Tobit model	Hectares of primary forest cut
	Tobit model	Hectares of secondary forest cut
Jones et al. (1995)	3SLS model	Production functions for quantity of beef, milk, cocoa, rice, and beans
	OLS, SUR model	Income per adult
	OLS, SUR model	Equipment per adult
	OLS, SUR model	Cattle per adult
	OLS, SUR model	Land per adult
	3 simultaneous equations	Time on lot
		Location
		Diversification (of on-farm income sources)
		(with burning practices variables)
	3SLS model	Forest clearing per year
		Stock of cleared land
		Productivity per hectare
		Cattle productivity per hectare
Marquette (1998, 584-87)	Cross-tabulations, means analyses	Land use categorization:
		Low-cleared area (LCA)
		Medium-cleared area (MCA)
		High-cleared area-pasture (HCA)
McCracken, Siqueira, et al. (1999)	Graph	Hectares deforested
	Graph	Hectares in secondary succession
Murphy, Bilsborrow, and Pichón (1997, 45-47)	OLS model	Total income
	OLS model	Total assets (durable goods, housing, livestock)

(continued)

TABLE 1. Continued

Source	*Analytic Approach*	*Land Use Outcome*
Ozório de Almeida (1992, 282-306)	OLS model	Total value of farm investment
	OLS model	Total value of durable goods
	OLS model	Total value of agricultural receipts received
Ozório de Almeida and Campari (1995, 176)	OLS model	Total hectares deforested since arrival
	OLS model	Hectares deforested in 1991
Pichón (1996, 421)	Cluster analysis	Land use categorization by primary land cover: Forest, Perennials, Pasture, Diversified
Pichón (1997a, 77-86)	Cross-tabulations, mean analyses	Land use shares in the following: perennials, annuals, pasture, forest Spending on the following: technological inputs, hired labor
Pichón (1997b, 721)	Tobit model	Percentage land area under perennials
	Tobit model	Percentage land area under annuals or perennials
	Tobit model	Percentage land area under pasture
	Tobit model	Percentage land area in forest
Rudel and Horowitz (1993, 113-31)	OLS model	Percentage land area in forest
Sydenstricker and Vosti (1993, 21-27)	OLS model	Area deforested
	Correlations	Area planted
Thapa, Bilsborrow, and Murphy (1996, 1323)	Logit model	Whether respondent is involved in planting or harvesting
	OLS model	Person-months of female labor for planting/harvesting

Note: 3SLS = three-stage least squares; OLS = ordinary least squares; SUR = seemingly unrelated regressions.

appear in columns 14, 15, and 16. Column 17 indicates the number of children, and columns 18 and 19 are for hired workers and off-farm labor. Models that consider any aspect of life cycle mostly include just the total number of household members (e.g., Alston, Libecap, and Schneider 1993; Godoy, O'Neill, et al. 1997; Godoy, Wilkie, and Franks 1997; Godoy, Groff, and O'Neill 1998; Godoy, Jacobson, and Wilkie 1998). Few models include the head's age, but many consider duration of residence, which amounts to an incomplete specification of the "location" of a household along its life cycle. Models that specifically deal with adults tend to leave them aggregated, with no differentiation by gender or age.

(text continues on p. 183)

TABLE 2. Explanatory Variables Used in Models of Land Use/Investment Outcomes in Preexisting Empirical Household-Level Analyses in the Amazon and the Neotropical Americas

	Explanatory Variables																			
Source	Area 1	Dist 2	Soil 3	Sreg 4	Wlth 5	Time 6	Titl 7	Cred 8	Asst 9	Age1 10	Age2 11	Ed 12	FExp 13	Fam 14	Male 15	Fem 16	Kids 17	Hire 18	Off 19	Inc 20
Alston, Libecap, and Schneider (1993)																				
Investment (Table 3)		–**			+ns	+**	+**				+ns	+*		+*						
Percentage area annuals (Table 4)		–ns		+**	–*	–ns	–ns				+ns	–**		–ns						
Percentage area perennials (Table 4)		–*		+ns	–**	+ns	+ns				–ns	+ns		–ns						
Percentage area pasture (Table 4)		+ns		–**	+**	+ns	+ns				–ns	+**		+ns						
Alston, Libecap, and Schneider (1996)																				
Percentage area crops or pasture (Table 2)					+**	–ns	+**				+ns	–ns								
Godoy, O'Neill, et al. (1997)																				
Hectares of old-growth forest (Table 5)					–ns	–ns		–ns			+ns	–ns		–ns					–*	
Godoy, Wilkie, and Franks (1997)																				
Probability of cutting old-growth forest (Table 3):																				
Mojeno						+ns						–ns		–ns						+ns
Yurucare						+*						+ns		+*						+ns
Chimane						+ns						–**		+ns						+ns

(continued)

TABLE 2. Continued

	Explanatory Variables																			
Source	*Area* 1	*Dist* 2	*Soil* 3	*Sreg* 4	*Wlth* 5	*Time* 6	*Titl* 7	*Cred* 8	*Asst* 9	*Age1* 10	*Age2* 11	*Ed* 12	*FExp* 13	*Fam* 14	*Male* 15	*Fem* 16	*Kids* 17	*Hire* 18	*Off* 19	*Inc* 20
Godoy, Jacobson, et al. (1998)																				
Hectares of primary forest cut (Table 3)	–*ns*	–*ns*				+**					–**	–*			–**	+*ns*	+*ns*			
Godoy, Franks, and Claudio (1998)																				
Probability of using fertilizers or pesticides (Table III)		–**										–*ns*			+*					+*ns*
Godoy, Groff, and O'Neill (1998)																				
Hectares of old-growth forest cut (Table VI, probit)						+**					+*ns*	–*ns*		–*ns*					–*ns*	+**
Godoy, Jacobson, and Wilkie (1998)																				
Hectares of primary forest cut (Table 2)					+*ns*						–*ns*	–**		+*ns*						
Hectares of secondary forest cut (Table 2)					+*ns*						+*ns*	–*ns*		–*ns*						
Jones et al. (1995)																				
Beef production (Table 1)					+*				+*ns*											
Milk production (Table 1)					+*ns*	–*ns*			+*ns*											

Coffee production (Table 1)					+ns	+*			+*											
Cocoa production (Table 1)		–ns			+ns															
Rice production (Table 1)					–ns															
Bean production (Table 1)					+**								+ns							
Income per adult (Table 2, Mod. 1, OLS)	+**		–*		–ns				+ns		+ns						–ns			
Income per adult (Table 2, Mod. 3, SUR)			–*						+ns		–ns						–*			
Cleared hectares per year (Table 3)		+*																		
Total cleared hectares (Table 3)	+ns					+ns														
Murphy, Bilsborrow, and Pichón (1997)																				
Total income (Table 10)	+**	–**	+**			+**		–ns	+**			+*	+**		+ns	+ns			+**	
Wealth value (Table 10)	+**	–**	+ns			+**		–**	+ns			+ns	+**		+ns	+**			+**	
Ozório de Almeida (1992)																				
Income (Table 60)				+**	+ns	+ns	+ns				+ns		+ns							
Investment (Table 61)				–ns	+ns	–ns	+**				–ns		–ns							+**
Assets (Table 62)				–ns	+**	+**	+**				–ns		–ns							

(continued)

TABLE 2 Continued

	Explanatory Variables																			
Source	*Area* *1*	*Dist* *2*	*Soil* *3*	*Sreg* *4*	*Wlth* *5*	*Time* *6*	*Titl* *7*	*Cred* *8*	*Asst* *9*	*Age1* *10*	*Age2* *11*	*Ed* *12*	*FExp* *13*	*Fam* *14*	*Male* *15*	*Fem* *16*	*Kids* *17*	*Hire* *18*	*Off* *19*	*Inc* *20*
Ozório de Almeida and Campari (1995)																				
Hectares deforested since arrival (Table D3)	+*ns*	+*			+*ns*	+*ns*	–*ns*	+*			–*ns*		+*ns*							+**
Hectares deforested in 1991 (Table D7)	+*ns*	+*ns*			+*ns*	+*ns*	+*ns*	+**			+*ns*		+*ns*							+**
Pichón (1997b)																				
Percentage land in annuals (Table 2)	–*	–*ns*	+**		+*ns*	–*ns*	–**		+*ns*			+**		+**			–*ns*	+**	+*ns*	
Percentage land in perennials (Table 2)	–**	–**	+**		+*ns*	+*ns*	–**		+*ns*			+*ns*		+**			+**	+**	+**	
Percentage land in pasture (Table 2)	+*	–*ns*	+*ns*		+**	+**	–*ns*		–*ns*			+**		+*ns*			+*	+*ns*	–**	
Percentage land in forest (Table 2)	+**	+**	–**		–**	–**	+**		+*ns*			–**		–**			–**	–**	+**	
Rudel and Horowitz (1993)																				
Percentage land deforested	–*							+*ns*						+*						
Sydenstricker Neto and Vosti (1993)																				
Hectares deforested															+**	+*		+*ns*		

Note: While exact definitions may vary somewhat, in general, the explanatory variables (by column) refer to the following: (1) property size, (2) market distance, (3) soil quality, (4) previous region of residence (South/Southeastern as opposed to Northeastern Brazil), (5) initial wealth, (6) duration of residence, (7) title, (8) credit, (9) technical assistance, (10) age of head on arrival, (11) age of household head, (12) head's education, (13) head's previous farm experience, (14) family size, (15) adult males, (16) adult females, (17) children, (18) hired labor, (19) off-farm income, and (20) total income. + = positive or direct effect; – = negative or inverse effect. OLS = ordinary least squares; SUR = seemingly unrelated regressions; *ns* = not significant.
$^{*}p < .10$. $^{**}p < .05$.

Table 2 shows that estimation has often not attained complete specification of factors affecting farm decisions. Alston and coworkers (Alston, Libecap, and Schneider 1993) and Jones et al. (1995) have tended to omit variables that indicate dependency, while Godoy et al., in a number of studies (Godoy, O'Neill, et al. 1997; Godoy, Wilkie, and Franks 1997; Godoy, Groff, and O'Neill 1998; Godoy, Franks, and Claudio 1998; Godoy, Jacobson, et al. 1998; Godoy, Jacobson, and Wilkie 1998), include either wealth or market accessibility, but not both. Pichón (1997b) offers the most complete suite of independent variables covering market access, wealth, family workforce, age of household head, and dependency. The statistical work has usually treated farm system components by estimating equations for each, violating assumptions of error independence. An exception is Jones et al. (1995), who allow error dependency in a farm-level analysis of system components in an application of seemingly unrelated regression.

In general, the work to date has neglected explicit reference to household life cycle and has failed to specify a full suite of relevant variables. It has also tended to emphasize the extent of land allocated to crops or pasture and not the decision to implement particular farm systems. The analysis that follows attempts to address both of these shortcomings by refining the list of explanatory variables and by considering the role they play in determining what kind of a farm system is likely to be observed under a given set of conditions. Indeed, the theoretical discussion indicates links between farm systems, economic conditions (i.e., the presence of markets), and demographic attributes of the family, although specification remains somewhat unformed on all counts.

Statistical Analysis

Specification

The challenge to model specification is twofold—namely, to describe a farm behavior reflecting the empirical setting and to define a dependent variable consistent with the behavioral description. Much of behavioral modeling in this context has addressed tropical deforestation, assuming profit maximization by well-informed agents (Pfaff 1999). The demand for land is derived on the basis of factor prices, particularly for land and labor (Reis and Guzman 1994; Panayotou and Sungsuwan 1994). Unfortunately, the notion of prices may be problematic, given that markets are poorly defined in colonization frontiers. Wage rates may be nonexistent, and land understood as a factor of production does not exist, in which case a price concept is inapplicable. The process of deforestation actually creates the land factor, used subsequently in agricultural production.

Given that the process of deforestation itself is nonremunerative and undertaken in the interest of future economic rewards, it is best regarded as a decision to invest, not to maximize profits in a static setting. The households engaged in these activities do not fit Chayanov's category of the capitalist farm and therefore engage in labor-leisure trade-offs. Moreover, the environment in which they operate is filled with uncertainty. This is to say that their decision making does not maximize an objective function based purely on net economic gains, due to the drudgery of labor and the high risks of farming. Such households are better viewed as optimizing their welfare functions through the minimization of risk (Dillon and Scandizzo 1978).

As has been argued, the primary decision taken by the smallholder involves the choice of farming system, made on the basis of the household's internal demands for survival and subsistence and on objective circumstances such as farm location and ambient conditions in the economic environment. The farming system description we implement is based on the notion of joint production, and we take the relative mix of outputs to be reflective of farm type. This is in accord with field typologies based on such mixes, particularly between annual crops, perennials, and pasture (Nair 1991; Serrão and Homma 1993). We measure the relative mix in our sample by first converting outputs of annuals (rice, corn, and beans), perennials (cocoa, pepper, and coffee), and cattle herds to monetary units using price data and then determining the relative amount of revenue accounted for by the respective component. Such an approach is similar to that of Bonnal et al. (1993) in assessing life cycle phenomena for small producers in Minas Gerais, Brazil, for a recent period. Bastos da Veiga (1996), Walker et al. (1997), and Pichón et al. (1999) have used clustering techniques to identify smallholder system types. None of these studies attempts to explain the existence of the identified systems inferentially.[11]

The estimation model is based on random utility theory, which predicts choices on the basis of comparisons of the utility associated with distinct alternatives—in this case, the farm systems available to the smallholders. The seminal applications of random utility theory posit alternative-specific utility functions, U_i, and estimate coefficients using data on variables observed for both selected and rejected alternatives (see Ben-Akiva and Lerman 1985; Bockstael 1996). Typically, $U_i = V_i + \varepsilon_i$, where V_i is the systematic component of utility and ε_i is the error term. Alternative i is selected if and only if $U_i > U_j$, so the probability of selecting i from a set of k alternatives, $i \in (1, 2, \ldots, k)$, is

$$\text{Prob (alternative } i) = \text{Prob } (V_i + \varepsilon_i > V_j + \varepsilon_j) = \text{Prob } (\varepsilon < \mathbf{V}), \text{ for all } j \neq i,$$

where $\varepsilon = \varepsilon_j - \varepsilon_i$ and $\mathbf{V} = V_i - V_j$. If the individual error terms are identically and independently distributed as Gumbel (or Type I extreme value), then the difference is logistically distributed and the probability model is logistic (Ben-Akiva and Lerman 1985).

Estimation requires specification of the V_i function for individual alternatives, and for discrete choice models with information on the complete choice set, V_i is often taken as $\beta' X_i$, where X_i captures alternative specific attributes. Such a function is problematic in the situation when only the chosen alternative is observed and there is no information available on other choices. Considering the linear form, $V_i = \beta_i' X_i$, a $\mathbf{V}$ function is specified as $\mathbf{V} = \beta_i' X_i - \beta_j' X_j$. If X is taken to be the same across all alternatives, as would be the case for household attributes in the present application setting, then $\mathbf{V} = (\beta_i' - \beta_j')X$, and at least one pair of β values in each pair of vectors must differ in order that the systematic components be distinct. If all β vectors are the same, then the systematic components do not vary, and distinguishing between alternatives cannot be accomplished.

For example, in farming households, the size of the family workforce clearly affects any choice of system and necessarily remains constant across the alternatives the household considers in making its decision. The same point holds for any other variables collected at the household level. If there is no good a priori reason for uniquely associating a particular variable with one of the alternatives, then it is conservative to assume $X_i = X_j = X$ for all pairs, i,j, which also excludes any alternative specific "dummy" variables.[12] Thus, the existence of distinct systematic components in the random utility function depends on variation among the β vectors. Such variation may be justified by an appeal to common sense, given it is reasonable to expect that certain variables will be of greater or lesser importance to the choice of particular systems. But the task remains to provide a behavioral argument justifying the existence of the fixed component.

We resort to a constructive approach based on the asserted behavior of risk minimization involving the utility of farm income, or $U(I)$, where I is farm income, a random variable possessing a density function. I is best interpreted as net imputed income since some households produce only food crops that they completely consume. The utility function can be parameterized in household variables in compelling ways, as can the system-dependent density function of income, thereby enabling the construction of the alternative specific "utility" functions necessary for estimation.

Consider the income, I, associated with a system specialized in cattle production (cs). Let this income be stochastic and possess a density function, $f_{cs}(Z;I)$, where Z is a vector reflecting both site and household attributes. This is the convention that accounts for differences in economic outcomes across the available alternatives since the density functions vary for system types, even with identical Z vectors. For example, labor is relatively unimportant in ranching activities but critical to perennials plantations. External but site-specific conditions may also affect the density function, such as distance from a graded or paved road and soil quality.

The utility of farm income, in turn, is dependent on factors other than income, or $U = U(Z;I)$. In particular, household attributes such as age of household head and degree of dependency are very likely to influence attitudes toward risk. Such utility functions are difficult to observe, but they possess a measurable "certainty equivalent" (CE), defined for the cattle specialization as the following (DeGroot 1970; Ellis 1993):

$$U(CE_{cs}) = \int U(Z;I)\, f_{cs}(Z;I)dI,$$

or

$$CE_{cs} = U^{-1}[\int U(Z;I)\, f_{cs}(Z;I)dI],$$

where U^{-1} is the inverse of the function, U. The utility associated with the farming system may now be defined with a fixed component defined by the certainty equivalent (CE_{cs}) and a random part (ε_{cs}) accounting for any stochastic influences on the experience of utility. Hence,

$$U(cs) = CE_{cs} + \varepsilon_{cs},$$

and the empirical model may be stated directly. In particular, the event $Y = i$ that farming system i is selected occurs if and only if $U(i) > U(j)$, $\forall\, j \neq i$. The probability that this occurs is

$$P(Y = i) = P[U(i) > U(j)]. \tag{1}$$

This may be estimated once the form of the fixed component is specified. We have no a priori grounds for the function in question and therefore adopt the linear convention, $CE_i = \beta_i' X$. An implication is that we do not observe coefficients for an omitted category, and the coefficient values actually estimated are differences, $\beta(i) = \beta_i - \beta_0$, where β_0 is associated with the omitted category. Be this as it may, the estimated coefficients still yield measures of the relative risk between choosing some alternative and the one selected for omission in the estimation, provided the probabilities are taken to be logistic (see Hosmer and Lemeshow 1989).

APPLICATION

The model implicit in equation 1 is estimated through an application of multinomial logistic regression, using data on 261 smallholders collected in 1996 near the town of Uruará, in the Brazilian state of Pará. Uruará was created in the early 1970s as part of the Transamazon colonization project to resettle landless peasants from the Brazilian Northeast (Instituto de Desenvolvimento do Estado do Pará [IDESP] 1990). At that time, the Brazilian government distributed lots of 100 hectares to "first-wave" colonists, who began clearing forest and cultivating mainly annual crops. Since then, spontaneous colonization has continued, with migration from all parts of Brazil, making this region in central Pará one of the most populated and dynamic frontier areas in the Amazon basin. Uruará is an appropriate site for addressing the LCH because it has a history of settlement that, by 1996, included longtime as well as recent arrivals and because farms in the area exhibit considerable diversity in their agricultural activities.

The 1996 fieldwork was accomplished by a nine-member research team, which administered a survey questionnaire covering household attributes and land use. The sample of 261 farm households represents 12 percent of all rural establishments in Uruará at the time (Instituto Brasileira de Geografia e Estatística [IBGE] 1998). These households together owned 347 lots, indicating a modest degree of

TABLE 3. Sample Characteristics: Averages (*n* = 261)

Household	
Family size	7.12
Number of children	2.85
Age of household head	47
Years of schooling (household head)	2.02
Percentage of rice production consumed	60
Percentage of bean production consumed	70
Person-days of hired labor	70
Farm system	
Rice production (kg)	3,000
Beans production (kg)	284
Corn production (kg)	1,936
Cocoa production (kg)	816
Pepper production (kg)	658
Coffee production (kg)	394
Number of cattle	24

property aggregation. Systematic sample collection proved intractable because many farmsteads were not visible from the road. Moreover, residents were often absent upon stopping. Consequently, the team sampled on the basis of "first opportunity" and employed a cadastral map from the Brazilian Amazon's regional agricultural agency, EMBRAPA/CPATU, to ensure that the sample was not clustered spatially. Table 3 gives aggregate statistics on households and farming systems for the entire sample. These data reflect systems with a high diversity in crop selections that are very similar to those described by other research from the same general region in central Pará (Bastos da Veiga et al. 1996; Walker et al. 1997).

To implement the model, we apply a clustering procedure to three-dimensional vectors reflecting contributions from annuals, perennials, and cattle to overall gross revenue. To identify the appropriate number of clusters, we use the approach of Milligan and Cooper (1985), who considered the maximum values of the pseudo F-statistic and the cubic clustering criterion. The upper half of Table 4 presents these statistics for nine clusterings of the data. Seven clusters yield high values of the relevant statistics while maintaining adequate numbers of observations for estimation purposes. Although ten clusters show even higher values for the statistics, some clusters possess very few observations. The systems identified are quite consistent with clusters based on independent samples collected in Uruará (Bastos da Veiga 1996) and farther to the east, toward the town of Altamira (Walker et al. 1997).

The lower half of Table 4 gives percentage averages for the clusters broken down by revenue components. The data indicate specialization into cattle, perennials, and annuals, as well as diversified systems that typically have one relatively large component. Thus, we observe systems based on annuals with nontrivial amounts of perennial production (annuals with perennials) and also with cattle (annuals with

TABLE 4. Cluster Analysis of Land Use to Identify Distinct Farm System Types, Uruará, Pará, 1996

Cluster Analysis Results

Number of Clusters	*Pseudo* F	*Cubic Clustering Criterion*
2	208.76	7.976
3	337.37	17.237
4	454.59	29.210
5	405.76	26.400
6	455.16	29.640
7	485.54	31.462
8	444.23	29.494
9	475.48	31.323
10	490.40	32.224

Distribution and Characteristics of Clusters

Number	*Annuals*	*Perennials*	*Cattle*	*Land Value (Reais)*	*Revenue (Reais)*	*Farm System Type*
11	.044	0	.955	48,272	1,433	Cattle specialization
20	.070	.892	.037	73,947	8,922	Perennial specialization
74	.616	.293	.089	27,109	6,888	Annuals with perennials
16	.680	.022	.296	22,250	2,608	Annuals with cattle
39	.328	.583	.088	32,444	6,841	Perennials with annuals
11	.051	.604	.344	45,545	5,375	Perennials with cattle
75	.935	.035	.028	11,534	4,227	Annuals specialization

Note: Prices used are as follows: .70 reais per kg rice, .75 reais per kg beans, .30 reais per kg corn, .85 reais per kg cocoa, 1.12 reais per kg coffee, and 1.40 reais per kg black pepper. Prices are producer prices for 1996, provided by EMATER, state of Pará (except for black pepper, which is 1995). Cattle revenue component assumes young bull weight of 200 kg (dressed), a 20 percent off-take rate for herds, and a price of .55 reais per kg carcass. Browder (1994) reports very low off-take rates for Amazonia and Brazil as a whole. Mattos and Uhl (1994) calculate profits for a midsize ranch (554 hectares), assuming off-take rates of 21 percent (including calves) and 28 percent (excluding calves). For small herds with little or no sales, off-take may be taken to reflect herd growth, or capital accumulation, in which case the calculation of "off-take" represents a form of savings.

cattle). Two perennial-based systems are found as well: perennials with annuals and perennials with cattle. It is important to note that these definitions are derived from relative magnitudes and may conceal large components, in absolute terms. The perennials with cattle system actually has more cattle (mean = 99) than the specialized cattle system (mean = 59).

The identification of seven systems complicates interpretation, and consequently we aggregate them into discernible categories. We take cattle specialization, perennial specialization, and perennials with cattle to constitute high-value

TABLE 5. Key Variables by Farm System Type

System	*Distance*[a]	*Time*[b]	*Dependency*[c]	*Men*[d]	*Women*[e]	*Age*[f]
Subsistence (annuals specialization)	25.9	8.5	.46	1.86	1.44	45.8
High value						
Cattle	12.6	11.5	.43	1.18	.91	46.2
Perennials	11.9	12.9	.31	2.52	1.78	48.3
Perennials with cattle	5.2	11.3	.40	3.00	2.27	42.4
Mid-value						
Annuals with perennials	14.2	13.1	.37	2.81	2.17	49.3
Annuals with cattle	14.5	13.0	.32	2.37	1.56	49.4
Perennials with annuals	12.3	14.4	.28	2.57	1.86	48.6

a. Distance in kilometers from the main axis of the Transamazon Highway.
b. Years since acquisition until 1996, the year of the survey.
c. Calculated as sum of young children (age fourteen and younger) and elderly individuals (age sixty-six and older) divided by total number of occupants of property.
d. Total number of men ages fifteen to sixty-five, inclusively.
e. Total number of women ages fifteen to sixty-five, inclusively.
f. Age of household head.

systems, while mid-value systems comprise annuals with perennials, annuals with cattle, and perennials with annuals. Lower land values in general are associated with systems focusing some attention on annuals production, and particularly the annuals specialization.

Table 5 gives descriptive data for a number of key variables, organized by the aggregated categories. The data show a very strong relationship between the categories and distance from the main highway. The high-value systems are uniformly closer than those of lower value, which in turn are much closer than those at subsistence. The household variables also show discernible patterns, mainly consistent with the LCH. Subsistence farms are newer and show higher dependency than the higher value ones. They also tend to have less agricultural labor in the family, as indicated by the number of men.

The LCH suggests switching between systems as a function of life cycle stage but does not elaborate the number of stages or the types of systems to be found at any given point. In the interest of parsimony, we consider a two-period model involving an early stage focused on subsistence (annuals specialization) and a later stage in which diversification has occurred, with some incorporation of investment crops. Consequently, all the systems excepting annuals specialization may be regarded as a variation of some second, or later stage, system. In principle, multinomial regression allows for comparison between any combination of dependent variable outcomes, or *farm systems* in our application. However, our focus is on comparisons between the later stage systems and annuals specialization, which functions in the estimation as the omitted category (see Hosmer and Lemeshow 1989).

Table 6 gives results from the multinomial regression using a dependent variable with seven categories.[13] These estimates are for log odds ratios that can be exponentiated to give measures of relative risk (Hosmer and Lemeshow 1989). Chi-square statistics and significance probabilities are also reported, which may be interpreted as two-tail probabilities given the definition of chi-square. The ordering of the results follows that of Table 5, with annuals specialization serving as the omitted category. Under the LCH, the annuals category would be representative of an early stage in the life cycle process. Of course, external economic conditions can be expected to play a role in shaping the likelihood that some arbitrary farm household is focusing its main efforts on food crops.

We first consider as a group the "later stage" systems with appreciable accumulation, indicated by land values. These are cattle specialization, perennials with cattle, and perennial specialization systems, all showing substantial allocation to investment crops. For these, regression results appear weaker than might be expected from the descriptive statistics. Variables reflecting life cycle stage, such as dependency, age of household head, duration of residence, and size of household workforce, show either weak or ambiguous effects. The availability of household labor does promote the perennials with cattle system but is also associated with the reduced likelihood of the cattle specialization. This contradicts the reasoning of the theoretical argument, although it agrees with key informants who point to the low labor requirements of ranching. Cordeiro de Santana et al. (1997) report low labor productivity for ranching in Amazonia, presumably reflecting its labor inputs. The duration of residence does affect the likelihood of a perennials specialization outcome but reveals little impact on the cattle specialization or the perennials with cattle system. Nevertheless, the coefficient is positive in all three cases.

A strong discriminator between annuals specialization and the high-value systems is distance, highly significant for the cattle specialization and the perennials with cattle systems, the latter of which has more cattle on average than its specialized counterpart. The sign of the coefficient indicates that these systems are found closer to the main highway, where market access is greater.[14]

Distance is also important for the lower value systems, although the magnitude of the effect is considerably less than observed for their higher value counterparts. The annuals with perennials, annuals with cattle, and perennials with annuals systems tend to be located closer to the main highway, but not so close as the specialized or perennials with cattle systems. With respect to the life cycle hypothesis, and in contrast to the high-value systems, LCH variables indicating duration of residence and dependency function strongly for the mid-value systems. The longer a farm has been active in the region and the lower its internal dependency, the greater the likelihood of diversification. The initial capital endowment of the family, proxied by wealth, generally does not provide much explanation and presents a perverse, suggestive relationship for the perennials with cattle system.

Implementing seven categories inhibited use of important variables such as titling status and might be one reason for weak results, given that some of the

TABLE 6. Multinomial Logit Analysis of Farm System Types

Explanatory Variable	*Cattle Specialization*		*Perennials Specialization*		*Perennials with Cattle*		*Annuals with Perennials*		*Annuals with Cattle*		*Perennials with Annuals*	
Distance to highway (km)	–0.1334	(.0056)	–0.0390	(.1556)	–0.2344	(.0028)	–0.0354	(.0173)	–0.0443	(.1108)	–0.0530	(.0128)
Day labor (hired)	0.00930	(.0185)	0.0100	(.0102)	0.00936	(.0539)	0.00566	(.1171)	0.00901	(.0273)	0.00766	(.0506)
Family workers (men)	–1.0083	(.0716)	0.3269	(.1695)	0.5283	(.1072)	0.3216	(.0426)	0.1965	(.4246)	0.1291	(.4999)
External income[a]	1.5011	(.1106)	0.4992	(.5257)	1.7213	(.2012)	–0.4029	(.4768)	1.0007	(.1963)	–0.6015	(.3974)
Initial wealth[b]	0.4700	(.6318)	–0.4860	(.5309)	–2.3884	(.0970)	–0.4563	(.3494)	–0.9249	(.2849)	0.8369	(.1361)
Years since acquisition[c]	0.0320	(.6896)	0.1292	(.0291)	0.0124	(.8575)	0.0909	(.0136)	0.0880	(.1172)	0.1491	(.0010)
Age of household head	0.1022	(.6294)	–0.00009	(.9996)	0.0575	(.8008)	0.0303	(.7797)	0.0901	(.5977)	–0.0337	(.7900)
Age (squared)	–0.0008	(.6940)	–0.00013	(.9364)	–0.00141	(.5727)	–0.00031	(.7754)	–0.00117	(.4911)	0.00011	(.9315)
Years of school	0.2379	(.2849)	0.2396	(.1304)	0.4450	(.0346)	0.1597	(.1506)	–0.1635	(.4026)	0.0529	(.7028)
Dependency[d]	–1.5545	(.4127)	–0.8478	(.5552)	0.6988	(.7887)	–0.8109	(.3612)	–2.4185	(.0692)	–3.3921	(.0025)
Origin[e]	3.0397	(.0108)	1.1377	(.0973)	1.2130	(.1970)	0.4956	(.2864)	1.4911	(.0306)	–0.4086	(.5035)

Note: Regression coefficients are presented, with significance levels in parentheses. Model yields $\rho^2 = .296$, where $\rho^2 = 1 - \zeta(b)/\zeta(c)$. ζ is the likelihood associated with the estimated coefficient vector, b, and the constant, c, respectively (see Ben-Akiva and Lerman 1985).

a. Dummy variable equal to 1 if more than 50 percent of income comes from off-farm; 0 otherwise.

b. Dummy variable equal to 1 if, on arrival, household possesses a gas stove, chainsaw, TV, refrigerator, generator (electricity), satellite dish, motorcycle, tractor, or car. The variable is 0 otherwise. Weil (1989) defines wealth based on possession of sets of manufactured goods.

c. Years since acquisition until 1996, the year of the survey.

d. Young children and elderly individuals divided by size of family.

e. Dummy variable equal to 1 if born in Minas Gerais, Espirito Santo, Rio de Janeiro (state), São Paulo (state), Paraná, Santa Catarina, Rio Grande do Sul, Mato Grosso do Sul, Goais, and the Federal District; zero otherwise.

TABLE 7. Logistic Regression on Aggregated Categories

	Omitted Category: Subsistence				*Omitted Category: Mid-Value*	
Explanatory Variable	*High-Value System*		*Mid-Value System*		*High-Value System*	
Distance to highway (km)	–0.0807	(.0006)	–0.0417	(.0018)	–0.0369	(.0970)
Day labor (hired)	0.00951	(.0070)	0.00650	(.0400)	0.00323	(.1425)
Family workers (men)	0.0998	(.6186)	0.2463	(.0889)	–0.1266	(.4298)
External income[a]	0.8117	(.1769)	–0.1909	(.7065)	1.0901	(.0325)
Initial wealth[b]	–0.2095	(.7153)	–0.1322	(.7594)	–0.2142	(.6764)
Age of household head	–0.0158	(.9009)	0.0143	(.8836)	–0.0413	(.6943)
Age (squared)	–0.00003	(.9829)	–0.0002	(.8379)	0.000277	(.7946)
Years of school	0.3125	(.0121)	0.0959	(.3431)	0.2380	(.0218)
Dependency[c]	0.4949	(.6643)	–1.733	(.0315)	1.5392	(.1343)
Title[d]	4.0427	(.0065)	3.7513	(.0005)	0.0342	(.9792)

Note: Regression coefficients are presented, with significance levels in parentheses. Three-outcome model yields $\rho^2 = .294$, where $\rho^2 = 1\ \ \zeta(b)/\zeta(c)$. ζ is the likelihood associated with the estimated coefficient vector, *b*, and the constant, *c*, respectively (see Ben-Akiva and Lerman 1985). The two-outcome model yields $\rho^2 = .176$.

a. Dummy variable equal to 1 if more than 50 percent of income comes from off-farm; zero otherwise.

b. Dummy variable equal to 1 if, on arrival, household possesses a gas stove, chainsaw, TV, refrigerator, generator (electricity), satellite dish, motorcycle, tractor, or car. The variable is 0 otherwise. Weil (1989) defines wealth based on possession of sets of manufactured goods.

c. Young children and elderly individuals, divided by size of family.

d. Title refers to both definitive and provisional title. For multiple-lot properties, title status is given for lot of primary residence, where the interview took place.

categories possessed small numbers of farms. Consequently, we collapsed the seven categories into the three of Table 5 and redid the analysis. Table 7 shows results for a three-category estimation in the left panel, taking subsistence as the omitted category, and for a two-category estimation in the right panel, taking the mid-value systems as the omitted category. As can be observed, the list of independent variables varies from Table 6. We have chosen to model an instrument for title using time and origin in a logistic regression describing land title status; time and origin do not then appear in the multinomial logit. Land title and tenure security are probably jointly dependent with the type of farm system as defined here. The same may be said for use of day labor, but we are restricted in our selection of exogenous variables, and previous research has argued the importance of hired workers (Walker, Moran, and Anselin 2000).

These results bring into clearer focus the impact of household attributes and market access on farm system selection. Distance to the main highway discriminates both the high- and mid-value systems from the subsistence system (left panel) and is highly suggestive as a discriminator between the high- and mid-value systems (right panel). The impact of the variable is consistent with expectations that property values tend to increase with market access. Prime life cycle variables—

family workforce and dependency—are both important in explaining the likelihood of a mid-value system, while level of educational attainment discriminates high- from mid-value systems. The age variables show no impact in either estimation, while external income appears important in differentiating the high- from mid-value farms. Initial wealth provides no explanatory value whatsoever for either estimation.

Discussion and Conclusions

The results display the importance of household structure and market accessibility in explaining the observance of smallholder systems. The distance factor appears most robust across the specifications. Other studies have considered the role of highways and nearness to markets in explaining deforestation. Chomitz and Gray (1996) take deforestation and road location to be jointly determined, given that roads may be built in areas of good agricultural potential. By way of contrast, Wear and Bolstad (1998) argue that land use and land cover are jointly determined and that accessibility affects land use, which, through proximate causation, determines land cover. Our approach follows this general line of reasoning, as location on a colonization highway is exogenous to the farming system. The road exists prior to the migration decision.

The proximate causation effect on land cover for the present case is illustrated in Table 8. These data replicate the spatial pattern of tropical deforestation that occurs along settlement crossroads radiating from a larger arterial highway, the so-called "fishbone pattern." This pattern, plainly visible on satellite images, is due to the excessive pasture requirements demanded by cattle under low-input ranching and shows a triangle associated with individual crossroads, whose base along the main highway tapers to a point beyond which primary forest remains intact (Walker, Moran, and Anselin 2000). Note that the average herd of the perennials with cattle system (ninety-nine) is greater than the cattle specialization (fifty-nine).

The role of distance presumably bears some relationship to the transport costs associated with the movement of commodities along difficult-of-access crossroads, where most of the properties are located. That pasture-based systems appear sensitive to such costs raises a question. Some have argued that cattle are desirable in part because they can "transport" themselves, in which case we would not expect accessibility to play much of a role in the location of ranches. Nevertheless, we do observe a systematic disposition of pasture toward more accessible locations in settlement frontiers throughout Amazonia. Although capable of self-transport, cattle are also moved by truck, which considerably reduces time and labor costs to ranchers.[15]

The household variables do play notable, if less pervasive, roles in determining the likelihood of observing a particular system. The title instrument and hired labor are important in discriminating both high- and mid-value farms from the subsistence

TABLE 8. Proximate Causation by System

System	*Cattle*	*Pasture (hectares)*	*Percentage Cattle*	*Average Distance (kilometers)*	*Total Clearance (hectares)*[a]
Perennials with cattle (11)	99	64	.344	5.2	69.5
Cattle specialization (11)	59	44	.955	12.6	45.04
Annuals with cattle (16)	30	34	.296	14.5	46.10
Perennials with annuals (39)	28	31	.088	12.3	44.00
Annuals with perennials (74)	24	32	.089	14.2	30.89
Perennials specialization (20)	16	22	.037	11.9	38.03
Subsistence (75)	6	20	.028	25.9	29.89

a. Clearance calculated from area in farm system components, taken as the sum of land in pasture, rice, corn, cocoa, pepper, and coffee. Beans are intercropped with corn, so area is included in corn area. Perennials area calculated on the basis of average tree spacing, which in the region is 3m × 3m for cocoa and coffee and 2m × 2m for pepper.

group, while internal dependency and family labor differentiate the mid-value systems from subsistence farmers in a fashion consistent with the LHC. In addition, both external income and educational attainment discriminate the high- from the mid-value farms. It is of some interest to note that neither age nor initial capital stock have appeared to play roles in the system state as of 1996, which is mainly a function of location, dependency, available labor, external resources, and the human capital associated with educational attainment. Walker, Moran, and Anselin (2000) showed similar results for available labor, age, and initial capital stock in explaining household-level magnitudes of deforestation among small-holders in the same general region.

We draw two conclusions from the analysis. First, the results suggest that models of land cover change omitting data collected at the household level may be misspecified. Although distance factors, easily measurable by GIS software, are very important to the process, elements of household structure, accessible mainly through survey work, also play substantial roles. The second conclusion relates to the concept of farm evolution as a dynamic process. In the sample, both dependency and total stock of family workers are functions of time, as can be shown through regression analysis. As time passes, dependency diminishes and the family workforce grows, paving the way for the system switches predicted by the LCH. Thus, the life cycle process, working together with standard economic factors, accounts for the distribution of farming systems in the frontier.

There is, however, an aspect of the family process completely missed by our analysis—namely, the intergenerational aspects of family succession and extension. These appear to play roles in advancing the agricultural frontier and have yet to be conceptualized or studied. In the Uruará study area, the fishbone pattern has been considerably extended beyond its original 6 kilometer extent. Key informant interviews suggest that demands for new land and the capital to open it arise in part from a complex web of familial relations among the colonists themselves. A considerable policy implication is that endogenous forces emanating from families are unleashed once a region is settled, and it may not be possible to turn the conservation clock as far back as one would like through top-down interventions, such as reduced expenditures on highway construction or improvement. The structure and function of households, then, continue to be an important subject for field researchers and policy makers concerned about land use and land cover change in tropical forests.

NOTES

1. Brazilian President Cardoso recently announced the opening of 60,000 km^2 of land along highway BR-174 out of Manaus to create a farming area "so colossal that it would double the nation's agricultural production" (de Cassia 1997).

2. Chayanov defined a ratio of consumers to workers, noting that through the course of the life cycle, it rose first with childbearing, then fell as the children aged and began to work.

3. Thirty-six percent did not use off-farm labor and did not receive much off-farm income, if any. The income question on the survey identified those whose off-farm income was less than 50 percent of total farm income.

4. However, as Pichón et al. (1999) note, the opposite has been observed in the Ecuadorian Amazon, where young households with limited labor may seek jobs during the off-season, while those with more adults may hire labor to increase production.

5. These mechanisms may be regarded as endogenous in that they emanate from the internal workings of the household. Market-related factors can also be exogenous, however, as with so-called "capitalist penetration," which occurs only in the presence of market-based, profit opportunities.

6. Smith et al. (1996) observed, for a sample of 132 small producers, 108 agroforestry configurations in a total of 136 polycultural fields. Walker (1999) reproduced data for Peru and Brazil, indicating considerable diversity in crop choices.

7. It is often said that rice is planted with the initial cutting of virgin forest, given good early yields from forest soils. This explanation of the early phasing of rice is inherently agronomic and adds nothing to our economic argument.

8. Average slaughter age in Amazonia is four years. Cocoa trees take about four years to produce, and pepper and coffee are similarly delayed. The empirical setting would seem to add an initial phase to the Modigliani conceptualization. Families need first to achieve circumstances that will enable them to invest in the future.

9. Nor is there any guarantee that the maturing farm system will be more land demanding than the early, income-based phase, in which case the size of holding, or at least that part actively worked, could actually diminish. This is not likely to be the case, however, when land is freely available as in settlement frontiers, and the conversion to cattle ranching from the production of rice, corn, and beans clearly represents a significantly expanding use of land on individual properties.

10. This latter point suggests that Chayanov and Lenin, or perhaps their ideological interpreters, were laboring under a false dichotomy. The old debate would have us believe that small producers only farm under the most primitive conditions and that capital is exclusively owned by corporate interests. Research in several of the region's colonization frontiers has shown both growth in the average size of holdings and a modest accumulation of both consumer durables and capital equipment, occurring over a period of one to two decades.

11. Bonnal et al. (1993) state a life cycle progression between the systems identified, but they do not separate the farm system from household attributes in their proposed series of "stages" and therefore cannot pursue an inferential argument.

12. For farming system choice, it is difficult to conceive of an alternative specific coefficient, unlike the classical case of auto versus mass transit choice (Lisco 1967; Cambridge Systematics 1976).

13. Analysis was done at the level of the property, an economic unit, and not the lot, a physical unit of approximately 100 hectares. Although the initial colonization prescribed one 100-hectare lot per family, some farm consolidation has occurred (see Walker, Moran, and Anselin 2000). The possession of multiple lots presents econometric issues with respect to certain variables. Although most variables implemented in the analysis are property-level variables reflecting characteristics of the family, two are not. The distance measure reflects the distance of "lot number 1" from the main highway. The first lot is where the interview took place. It is typically the lot of residence, the first lot acquired, and, presumably, the lot of greatest significance to the household.

14. To obtain a relative risk interpretation, note that the average distance from the Transamazon Highway for this group is about 5 kilometers, while for the subsistence group focused on annuals production, it is 26 kilometers. Exponentiating the log odds ratio for the perennials with cattle outcome, after multiplying by ten and assuming a 5-kilometer start point for measuring distance, we observe that the relative "risk" of observing such a system 10 kilometers further from the Transamazon Highway is about 10 percent of the starting point value. If we assume that the frequency of the perennials with annuals systems is high near the highway (say, 50 percent for illustrative purposes), then this declines to about 5 percent at 15 kilometers.

15. There is a truck specifically designed for the transport of cattle, called a *carreta*. In the summer of 1999, we observed a *comitivo*, or cattle drive, along the Transamazon Highway in the State of Pará. The herd had 930 head of cattle and had been traveling three months from the western part of the Pará. Another month was anticipated before arriving in Altamira. Twenty animals had died in transit. A labor crew of five accompanied the herd, including three *vaqueiros* (cowboys), a cook, and a *gerente*, or boss.

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