Household Demography and Land Use Allocation among Small Farms in the Brazilian Amazon

Stephen G. Perz

Department of Sociology and Center for Latin American Studies
University of Florida
Gainesville, FL 32611-7330
USA[1]

Abstract

This paper presents models of land allocation among primary forest, crops, pasture and secondary forest on small farms in the Brazilian Amazon. The discussion begins with a review of theoretical arguments as to why demographic variables should influence environmental outcomes at the household level, to complement population-level arguments more commonly alleged. The paper then focuses on the case of Uruará, a frontier colony along the Transamazon highway in the Brazilian state of Pará, for an empirical analysis of land use in the Amazon frontier. Use of seemingly unrelated regression models allows efficient estimation of the effects of the explanatory variables, while accounting for the effects of correlated error terms among forest, crops, pasture and regrowth. The findings highlight the importance of household-level demographic processes for environmental change, and bear implications for future resource use and policy proposals in the Amazon as well as for research on human-environment interactions.

Keywords: *household, demography, land use, Amazon, Brazil*

Introduction

In many areas of environmental studies, there is longstanding interest in the role that demographic processes play in the alteration of biophysical systems. Over the past decade, discussions of population-environment interactions have become more salient in the demographic community (e.g., Arizpe et al. 1994; Mazur 1994; Ness et al. 1993; Pebley 1998; UN 1994). Most attention to demographic influences on the environment is pitched at a macro level, wherein aggregate population characteristics are posited to influence regional or global change (e.g., Bongaarts 1992; Cohen 1995; Davis and Bernstam 1991; Keyfitz 1991; MacKeller et al. 1998; Panayotou 1996; Perz 2002a; Preston 1996; Smil 1994). This is true in part because existing theories of environmental change that feature demographic factors tend to focus on population size, growth, or density (e.g., Jolly 1994). Two prominent examples are neo-Malthusian notions that population growth leads to resource degradation (e.g., Ehrlich and Ehrlich 1990; Green 1992; Kates 1996; Smail 1997), and theories inspired by Boserup (1965) that population-induced technological innovations might avoid or alleviate degradation (e.g., Angelsen and Kaimowitz 2001; Binswanger and Ruttan 1978; Feder et al. 1985; Turner and Brush 1987). Less common are micro level frameworks of household demography as an influence on environmental outcomes (e.g., Lutzenheiser and Hackett 1993). Micro-level models provide the valuable service of differentiating among groups within populations to better deal with questions concerning human ecology and environmental impacts of distinct subpopulations. More systematic attention to micro-level demographic factors would broaden the relevance of demography for human ecology research and environmental studies in general.

This paper focuses on land use allocation among small farms in the Amazon, featuring the role of household demographic factors.[2] Population processes occupy a central role in the "human dimensions" of land use, as articulated in the Science and Implementation Plans developed by the international land cover/land use change community (Lambin et al. 1999; Turner et al. 1995). The Amazon is a crucial case for an examination of household demographic effects on land use, given the region's extensive deforestation (e.g., Houghton et al. 2000; INPE 2001; Skole and Tucker 1993) and its many local, regional, and global environmental consequences (e.g., Fearnside 1990; Gash et al. 1996; Jordan 1986). The core argument is that the "location" of a household in its life cycle is an important determinant of land use allocation (Marquette 1998; McCracken et al. 1999; Perz 2001a; Walker and Homma 1996; Walker et al. 2002). The "location" of a household's life cycle, refers to a set of demographic characteristics of a domestic group that includes the household's duration of residence and its age composition. Households that differ in terms of these demographic characteristics occupy different "locations" along a domestic life cycle trajectory.

In the context of focusing on household demography and forest change in the Amazon, an analysis of land use allocation advances our understanding of population-environment interactions for three reasons. First, existing household level models of land use in tropical Latin America pay limited attention to demographic factors such as duration of residence or age structure. Though characterization of a household's life cycle "location" may require several indicators, many analysts use few or none (see Perz 2001a; Walker et al. 2002). Second, virtually all of the literature on land use and land cover change in the Amazon focuses on one outcome, such as analyses of deforestation. This is true of deforestation models at the regional level (e.g., Pfaff 1999; Reis and Margulis 1991; Wood and Skole 1998) and the household level (e.g., Alston et al. 1999; Godoy et al. 1997a, 1997b, 1998a, 1998b; Ozório de Almeida and Campari 1995). Such "one category" analyses, while vitally important, provide incomplete assessments of land cover/land use change dynamics. Third, the few available analyses that consider multiple land use or cover types in the Amazon focus on "primary" forests (i.e., old-growth) and land in productive use, but do not distinguish land taken out of production, or abandoned, and now regrowing into "secondary" forests, or regrowth (e.g., Jones et al. 1995; Pichón 1997; Reis and Guzmán 1994). Whereas deforestation bears negative environmental consequences and may lead to unsustainable land use, regrowth has potentially positive implications for environmental services (e.g., Brown and Lugo 1990; Gascón and Moutinho 1998; Houghton et al. 2000; Lugo and Brown 1992; Unruh 1988) and rural livelihoods (e.g., Anderson et al. 1991; Dubois 1990; Nair 1993; Redford and Padoch 1992). Land use allocation models, to be complete, must separately consider regrowth (Perz and Walker 2002).

This paper proceeds in three sections. The first section, which provides a theoretical background, has two parts: a review of the theoretical basis for considering household demographic factors in models of land use allocation, followed by a discussion of land use patterns among small farm households in the Amazon. This discussion highlights key land use outcomes and notes when they become important as households proceed through their life cycles. The second section covers data, variables, and findings and has three parts. It first introduces the study case of Uruará, a frontier colony on the Transamazon highway in the Brazilian state of Pará, and the site of a survey of family farms in 1996. Next, it reviews the explanatory and outcome variables in the analysis by presenting operational definitions, descriptive statistics, and correlations. Finally, it presents models of primary forest, cropland, pasture, and secondary growth on farm lots in the survey, using seemingly-unrelated regression equations (SURE) to obtain efficient estimates of coefficients in the presence of correlated error terms. The models show contrasting but significant effects of household life cycle variables for the four land use outcomes. These findings provide empirical evidence to support greater attention to demographic variables as influences on resource use and environmental change at the household level. The third and final section draws some conclusions and discusses the importance of household demographic change for future land use in the Amazon, policies that promote sustainable livelihoods alongside forest conservation in the region, and research on human-environment interactions in general.

Theoretical Background

Chayanov's Theory of Household Life Cycles and Land Use

The theoretical foundation of the importance of household life cycles for land use was laid by A.V. Chayanov, who studied farming practices among peasants following the 1917 Revolution in Russia (Thorner et al. 1986). Chayanov observed that peasant households contained families with different age structures, and that those households also farmed different quantities of land. He reasoned that age structures are older in households with larger numbers of economically active adults and/or smaller numbers of dependent children, both of which allow for greater allocation of labor to agriculture. This, in turn, enables cultivation of larger land areas. Chayanov extended this insight about labor availability and child dependency by noting that the age structure changes through the course of a household's life cycle. He distinguished among life cycle stages, where early on the household age structure is young (due to the presence of infants and young children), and relatively little land is farmed due to limited labor available for agriculture. As time passes, the average age increases and children become more economically active, allowing expansion of the land area cultivated. By distinguishing households in terms of their age structure, Chayanov provided a domestic life cycle explanation for differences in land area cultivated among Russian farms.[3]

Chayanov's insights are generalizable from post-revolutionary Russia to frontier areas of the Amazon because both cases exhibit agricultural production under conditions of land abundance (Pichón 1996; Thorner et al. 1986). However, Chayanovian theory makes five assumptions that hinder direct application to agriculture in tropical regions of Latin America (Ellis 1993; Netting 1993). First, it does not address complexities arising from migration of farm households to new biophysical environments. This raises questions about the impact of region of birth and duration of residence on adapting land use strategies to new circumstances (Moran 1989). Second, it assumes that agricultural input, credit, and product markets are very limited, largely precluding the possibility for generation of monetary incomes or investment in capital inputs. This is more common in the Amazon and calls for attention to the use of agricultural capital and credit as influences over land use. Third, Chayanovian theory assumes that labor markets are also limited so that farm families do not generally hire or sell labor. However, both are relatively widespread in Amazon frontier zones, which requires an account of hired labor and income from family wage work. Fourth, it assumes that land use involves a more or less homogeneous set of agricultural practices shared by all households. In the Amazon, however, some agricultural households may emphasize crop cultivation while others focus on ranching, and yet others exhibit highly diversified systems (Perz 1998; Pichón 1996; Walker et al. 2000, 2002). Fifth, Chayanovian theory focuses on productive activities and neglects fallowing practices (Walker 1999). In the Brazilian Amazon, most soils are inadequate for sustained crop cultivation (e.g., Moran et al. 2000; Nicholaides et al. 1984; Sanchez 1994), and this necessitates fallowing or risk of land degradation, abandonment, and regrowth.

Household Life Cycles and Land Use Dynamics in the Amazon

Walker and Homma (1996; see also Marquette 1998) recognize the shortcomings in the Chayanovian model and provide an adaptation of the household life cycle argument to the case of small farm families in the Brazilian Amazon. They situate farm families in a context where labor can be hired or sold, credit and capital are available, production is often destined for markets, households may diversify or specialize in their land use, and regrowth is present. The distinctions among land uses are of particular importance, as each involves different land, labor, and capital requirements, and also bears a particular set of environmental implications. The economic and environmental distinctions among land uses provide a means of linking household demographic characteristics to land cover outcomes. This linkage prompts these authors to argue that household demographic composition and change dispose farms to engage in different land uses through the course of their life cycle, and to allocate some share of their land to secondary growth.

Walker and Homma (1996, 68-73) articulate a stylized case wherein colonists migrate to the Amazon frontier as young families who establish farms by clearing plots of forest. Having spent much of their savings on the move, and often with responsibility for young children, the parents begin by cultivating annual crops, such as rice, beans, corn, and manioc. Annuals require considerable labor inputs for clearing, planting, weeding, and harvesting, but land and capital requirements are limited. Because annuals produce soon after planting, they constitute a low-risk agricultural strategy (e.g., Pichón 1996; Serrão and Homma 1993). Given the low capital requirements and low level of risk, young households or recent arrivals with limited labor and high child dependency generally plant annuals to secure a basic subsistence. However, because Amazon soil fertility declines with repeated cultivation on a given plot, households must periodically clear more forest to sustain production of annuals, implying a rise in deforestation and regrowth over time. At this stage, farm lots have little cleared land, but in labor-scarce households, weed invasions hinder productivity and make emergence of regrowth more likely, leading to plots of secondary vegetation (Maxwell 1980; Scatena et al. 1996; Thiele 1993).

As the seasons pass, farmers gain experience in Amazon agriculture, the labor of growing children makes larger contributions to the household labor pool, and farms accumulate a stock of deforested land unfit for further production of annuals. These changes — learning about locally appropriate agricultural techniques, expansion of available household labor alongside declining child dependency, and more cleared land — reduce the risk aversion of colonists. They then use the income from early harvests or proof of land claims to obtain credit, purchase capital, or hire labor and diversify into more market-oriented activities, particularly perennial crops and/or pasture for cattle.

Older households with larger labor pools often plant perennials, or tree crops, such as cocoa, coffee, coconuts, and black peppers (Marquette 1998). Perennials not only involve substantial labor inputs during planting, harvesting, and processing, but also require significant capital inputs in the purchase of seed or saplings (Pichón 1996). Older households with sufficient labor may thus plant perennials on weedy plots where tree crops can still compete, thereby shifting land out of fallow (or deforesting) and into production. Because perennials require 4-7 years of growth before the onset of production, and because they are subject to insect and fungal attacks, they pose greater economic risk to households than annuals. However, perennials often command higher prices than annuals, so the former are eminently cash crops, with production destined for local or regional markets. Perennials also offer environmental advantages because they can be planted on land formerly under annuals, as tree crops can tap nutrients deeper in the soil, and they contribute to soil remediation by providing cover and reducing erosion (e.g., Serrão and Homma 1993; Pichón 1996).

Older households with less available labor often shift land into pasture for cattle (Marquette 1998). Pasture is valuable because it indicates investment in agriculture, which raises land values (Perz 2001b). In addition, ownership of cattle constitutes a capital reserve that acts as an insurance substitute, which can be liquidated to cover unforeseen costs, such as from an illness (Pichón 1996). Smallholders cannot afford to buy many cattle due to the high capital cost and extensive land areas required. Small farm households often convert several adjoining plots previously used for cropland into pasture, and purchase a few cattle for breeding and expansion of the herd. Ranching has often been vilified as a cause of deforestation due to the large land tracts required and the unsustainability of production on many pasture grasses, which leads to weed invasions and severe land degradation (e.g., Nepstad et al. 1991; Serrão and Toledo 1990). However, the low labor requirements and the insurance function of cattle make ranching an attractive land use option among farm households in the Amazon (Tourrand et al. 1996), especially in the context of emerging urban markets for beef in the region (Faminow 1998).

McCracken et al. (1999, 1313) summarize Walker and Homma's (1996) discussion in a diagram that links life cycle stages to the extent of land allocated to different uses, including secondary growth. They distinguish between five stages of a household's life cycle, where each stage corresponds to a specific duration of residence, household age structure, and land use allocation. Stage I involves young parents with young children who are newcomers (duration of residence under 5 years), and own land largely covered in primary forest, with some clearing for cultivation of annuals. In Stage II, parents have growing children, a duration of residence around 5 years, and allocate less land to primary forest and more to annuals, young perennials, newly-formed pasture, and emergent regrowth. Stage III is characterized by older parents with teenage children, a duration of residence around 10 years, less forest decline than before, a reduced emphasis on annuals, greater attention to cattle pasture, and increasing regrowth. In Stage IV, parents are older still, children begin to reach young adulthood, duration of residence is around 15 years, forest clearing ceases, ranching and perennials predominate, and regrowth expands further. Finally, in Stage V, after 20 or more years, children may begin to leave the farm, perennials production is high, and regrowth increases yet further.

Previous discussions can be extended to consider different household and land use dynamics beyond Stage V. Two possible trajectories present themselves. The first trajectory follows that posited by McCracken et al. (1999), where outmigration of young adults occurs as they leave to establish their own farms or find urban housing and employment. Under this scenario, labor availability declines, but so does dependency and demand for subsistence production, leading to the cessation of forest clearing, a reduction in the land area under crops and pasture, and the continued expansion of land under secondary growth. However, a second trajectory is possible if grown children stay in the parental household (Perz and Walker 2002). This reflects a "generational transition" as the older generation passes control of the property to the next. This is likely if the young adult generation consists of couples with young children since the farm provides the security of an established productive enterprise for heirs. Under the "generational transition" scenario, new clearing of primary and/or secondary forests may be necessary for renewed crop cultivation and/or pasture formation as young children again expand demand for subsistence.[4]

This discussion suggests that among small farms in the Amazon, the evolution of household age structures is paralleled by the evolution of land use allocation. As households move through their life cycles, their farming experience, dependency, and labor availability change. As a result, the latitude households that have to make land use decisions also changes. Therefore, land use allocation should be different among households with age structures that indicate different "locations" along their life cycles.

Data, Methods and Findings

The Uruará Survey

The objective of this paper is to empirically assess the significance of household life cycle factors for land use allocation between primary forest, cropland, pasture, and secondary growth among small farms in the Amazon. Data for this empirical assessment are available from a recent survey of small farm households in Uruará, a colonist community situated on the Transamazon highway with a township located at Lat. 03˚42'54" S, Long. 53˚44'24" W in the Brazilian state of Pará, in the eastern Brazilian Amazon (IDESP, 1990). Map 1 shows the location of Uruará in Pará, situated in the "Legal" Amazon of Brazil. Uruará began in the early 1970s as a colonization project to resettle landless peasants from the Brazilian Northeast (IDESP 1990).[5] Colonists were given lots of 100 hectares (247 acres) and began cultivating annuals, later diversifying into perennials, and most recently moving into cattle pasture, with some reforestation. In the mid-1980s, high prices for perennial crops stimulated a second wave of in-migration, raising the municipality's population to about 25,000 by 1991, with over 11,000 being migrants since 1980 (IBGE 1996). Uruará's population has since risen further, exceeding 37,000 by 1996 (IBGE 1998a) and 45,000 by 2000 (IBGE 2001). Uruará is an appropriate site for an assessment of how life cycle factors among farm households affect land use allocation in the Amazon for three reasons: 1) this community consists almost entirely of family farms, 2) the Transamazon highway corridor exhibits substantial deforestation for crops and pasture, but also significant regrowth (e.g., Moran et al. 1994), and 3) it is situated near research sites in the Amazon where Walker and Homma (1996) and McCracken et al. (1999) gathered data in developing their theoretical frameworks.

Map 1. Study Site in Uruara, Para Legal Amazon, Brazil

In June and July 1996, a nine-member research team consisting of North American and Brazilian social and agricultural scientists administered a survey questionnaire to farm households in Uruará. The questionnaire was divided into two parts, where the first addressed household characteristics and the second concerned land use practices. Household items addressed migration history, material wealth, and the age composition of the families present. The land use component included items pertaining to reported land under forest, cropland, pasture and secondary growth. The sample includes 261 households, or 12% of all rural establishments in Uruará at the time (IBGE 1998b). These households together owned 347 lots, and the same questions were asked for each lot owned by a household. Systematic sampling proved intractable because houses on many lots were not visible from roadsides, and sampling the n^{th} house encountered was problematic because residents were frequently absent. Instead, 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 samples were not clustered spatially or selective of households by socioeconomic status.

Operationalization, Description and Correlations of Explanatory and Outcome Variables

Table 1 presents operational definitions, descriptive statistics, and correlations for the outcome and explanatory variables. Data from the Uruará survey allow construction of indicators of primary forest, cropland, pasture, and secondary growth on farm lots in the sample. Two points about the operationalization of the outcomes deserve mention. First, while it would in some ways have been more attractive to separately model annuals and perennials, given their different labor and capital inputs and the distinct farming strategies they represent, data from the Uruará survey do not allow for this distinction as it pertains to land use allocation. This does not represent a shortcoming of the questionnaire instrument per se, but illustrates the fact that annuals and perennials are often interplanted (Pichón 1996; Serrão and Homma 1993), making it impossible to separate the two for purposes of modeling land allocation.[6] Second, natural log (ln) terms are employed for the four land allocation categories. Raw values for the land uses took highly skewed distributions (values over three) that led to weaker models than those presented in this paper, and calculating percentages was unnecessary since virtually all lots were the same size (100 hectares). All four outcome variables are thus measured as the ln of hectares (ha). Antilogs of the natural log means in Table 1 show that lots had on average 53.5 ha of primary forest, 2.9 ha of cropland, 10.2 ha of pasture, and 2.0 ha of regrowth. The sizeable standard deviations for the land use outcomes indicate substantial variation among cases, which implies diverse landscapes among the lots in the sample. Correlations among the outcomes reveal systematic associations in land allocation in the farm lots surveyed. In general, it is expected that as primary forest area declines, the land area under other uses increases. This is confirmed by the negative correlation coefficients between primary forest and the other three outcomes, and the positive correlations for crops with pasture and regrowth.

Seven groups of one or more explanatory factors in Table 1 are considered: socioeconomic background, initial land cover, context of lot, institutional context, remittances and hired labor, land management practices, and life cycle location. These variables frequently appear in household models of land use and land cover in the Amazon and other neotropical forests of Latin America (Alston et al. 1999; Godoy et al. 1997a, 1997b, 1998a, 1998b; Jones et al. 1995; Ozório de Almeida and Campari 1995; Perz 2001a; Pichón 1997; Walker et al. 2002). Key to this discussion are life cycle factors (Marquette 1998; McCracken et al. 1999; Perz 2001a; Walker and Homma 1996; Walker et al. 2002). The other variables, while important, will effectively serve as controls in the models to come.

The discussion that follows highlights the reasons for including the explanatory factors in the models to follow. At this point, it is worth stating three general expectations concerning the effects of explanatory factors on the land use outcomes. First, factors that widen the decision-making latitude

Table 1. Descriptive statistics for land use outcomes and explanatory factors, farm lots, Uruará, Pará, 1996 (n=347).

	Mean	Std. Dev.	Correlation with Forest	Cropland	Pasture	Regrowth
Land Use						
Natural Log (ln) of Hectares (ha) under Primary Forest	3.98	0.92	1			
Ln ha under Cropland	1.08	1.67	-0.13 *	1		
Ln ha under Pasture	2.32	1.90	-0.20 **	0.22 **	1	
Ln ha under Secondary Growth	0.70	2.02	-0.08 +	0.14 *	-0.02	1
Socioeconomic Background						
Region of Origin (0=South or Southeast, 1=North, Northeast or Center-west)	0.33	0.48	0.00	-0.14 **	0.02	-0.04
Initial Wealth (Factor Index)	0.00	1.28	0.11 *	-0.24 **	-0.11 *	-0.08
Initial Agricultural Capital (Factor Index)	0.00	2.47	-0.02	-0.16 **	0.01	-0.11 *
Initial Land Cover						
Ln ha Deforested at Time of Acquisition	0.26	2.38	-0.07	0.04	0.11 *	0.08 +
Context of Lot						
Ordinal Lot Number (1=1st, 2=2nd...6th)	1.25	0.43	0.03	-0.37 **	-0.34 **	-0.23 **
Kilometers to Uruará Town	31.16	15.49	0.27 **	-0.33 **	-0.35 **	-0.13 *
Neighborhood Organization (0=No, 1=Yes)	0.34	0.47	0.05	-0.06	-0.01	-0.12 *
Damage by Fire Set by Neighbor (0=No, 1=Yes)	0.21	0.41	-0.17 **	0.17 **	0.22 **	0.19 **
Institutional Context						
Use of Credit (0=No, 1=Yes)	0.46	0.50	-0.12 *	0.29 **	0.42 **	0.08 *
Assistance from Extension Agency (0=No, 1=Yes)	0.16	0.37	-0.19 **	0.19 **	0.15 **	0.07
Remittances and Hired Labor						
Remittance Income from Absent Family Member (0=No, 1=Yes)	0.11	0.31	0.08	-0.07	-0.13 *	0.07
Ln Days of Labor Hired	2.25	2.24	0.03	-0.01	-0.03	-0.04
Land Management Practices						
Agricultural Inputs (Factor Index)	0.00	2.12	-0.14 *	0.26 **	0.22 **	0.06
Pasture Rotation (0=No, 1=Yes)	0.69	0.46	-0.13 *	0.29 **	0.61 **	-0.04
Life Cycle Location						
Years on Lot	10.12	6.70	-0.13 *	0.21 **	0.23 **	0.27 **
Number of Elderly (Persons age 66+)	0.15	0.46	0.02	0.10 +	0.06	0.05
Number of Adults (Persons ages 15-65)	4.33	2.65	-0.07	0.14 **	0.22 **	-0.01
Number of Adults Squared	25.76	30.65	-0.06	0.09 +	0.19 **	-0.03
Number of Children (Persons under age 15)	2.93	2.83	-0.02	0.08	-0.01	0.04
Number of Elderly * Number of Children	0.64	3.87	-0.03	0.10 +	0.05	-0.03

+ p < .15, * p < .05, ** p < .01

of households should serve to reduce the allocation of land to primary forest cover and increase cropland, pasture, and secondary growth. This reflects the expectation that one key land use dynamic in frontier settlements, such as in the Amazon, involves the conversion of primary forest to various types of land use or fallowing. Second, given that the production factor inputs differ somewhat between crops and pasture, the effect of an explanatory factor on the first outcome is unlikely to be the same on the second. In addition, given the fact that much regrowth reflects fallowing of land taken out of production (Perz and Walker 2002), explanatory factors that give rise to more cropland or pasture will not always lead to more regrowth. This reflects a third expectation that land put into one form of use reduces the land available for other uses. This is why land allocation among uses is important to consider: not only do 100 ha lots with more deforestation necessarily have less forest, but lots with more pasture also tend to have less land under crops or regrowth.

The first group of explanatory factors concerns the household's "socioeconomic background," which refers to the cultural and financial capital households brought to Uruará.[7] The household head's region of birth (cultural capital) and factor-weighted indexes of the household's durable goods wealth and agricultural capital upon arrival (financial capital) are included.[8] For region of origin, colonists from more industrialized parts of Brazil (the South and Southeast) are distinguished from areas with less agricultural technology (the North, Northeast and Center-west). Coming from the south and bringing more capital should increase land use decision latitudes, leading to less forest and more of the other uses, particularly pasture. However, the bivariate correlations are mixed: though Southerners had more cropland, more wealth corresponds to less cropland and pasture.

"Initial land cover" serves as a control because many households acquired lots that already had deforested land. As Table 1 indicates, initial land cover was operationalized in terms of the ln ha deforested when the current owner acquired the lot. The antilog of the ln mean was only 1.3 ha, though the large standard deviation indicates considerable variation. More initial deforestation reduces the inputs necessary for land use and also makes more extensive regrowth possible, and the correlations, though weak, confirm these expectations.

"Context of lot" comprises four indicators. First, it refers to the place of a given lot in a farming system. This is important because many households had more than one lot, and in most instances the "first-order" lot was the most heavily used. As a result, higher-order lots (25% of all lots in the survey) will likely have more forest and less cropland, pasture, and regrowth, an expectation generally confirmed by strong correlations. Second, context of lot reflects distance to market. This influences land use decisions because transport costs are high on muddy roads in much of the study area, which reduce profits on produce as one moves farther away from town. Survey data indicate that lots on average were about 30 km from Uruará town, with substantial variation around the mean. Greater distances should correspond to more forest cover and less land under the other use types, and this expectation is confirmed by strong correlations. Third, the presence of neighborhood organizations indicates whether neighboring households were mobilized against land invasions and for cooperative labor arrangements, both of which provide informal tenure security (Rudel 1995). This may allow for more extensive land use, but it may also allow owners to hold land in primary or secondary forest as an insurance substitute, without fear of invasions and the loss of land and forest resources (Alston et al. 1999). About 34% of lots were in organized neighborhoods, but weak correlations suggest ambiguous effects of social mobilization on land allocation. Fourth, lot context refers to damage to land cover from fires set by neighbors. Such damage serves to reduce primary forest cover, thereby making it easier to bring land into production. However, damage may also exceed a household's ability to use the land productively, leading to regrowth. About 20% of lots had damage to land by fires, and this shows strong correlations in the expected directions for the outcomes.

"Institutional context" encompasses two factors. First, the use of credit indicates the importance of lending institutions. Because it is a means to offset initial capital scarcity, credit widens the latitude of households to make land investments.[9] As a result, access to credit should correspond to less forest and more of the other land uses. Nearly half of the lots surveyed were owned by households with credit, and having credit exhibits significant correlations for all outcomes in the expected directions. Second, extension assistance indicates whether government agricultural agents had ever visited a given lot to provide advice on locally appropriate farming practices. Extension agents in Uruará focus on productive activities, so assistance will likely correspond to less forest and more of the other uses. Only 16% of lots had been visited by extension agents, and in general the expected correlations that appear are significant.

"Remittances and hired labor" are included to assess the effects of local labor markets. The remittances variable refers to whether a household had absent family members sending money home, and this occurred among households who owned 11% of the lots surveyed. Like credit, remittances can offset initial capital scarcity and foster more land use, implying less forest. The correlations are weak but generally in the right direction. Similarly, hired labor, measured as the ln of days of labor paid in the previous year, can offset household capital or labor scarcity and encourage more land use and less forest. Owners of the lots surveyed paid on average for 9.5 days of hired labor, but correlations show insignificant effects on the land use outcomes.

"Land management practices" account for two key tactics that some households employ to sustain production on their lots, namely the use of agricultural inputs (e.g., pesticides and fertilizers) and the rotation of pastures. The agricultural inputs measure is a factor-weighted index that reflects intensification via the adoption of chemical inputs in order to sustain crop productivity.[10] While some households may intensify via use of inputs to reduce the land area in use, others may do so to sustain production in larger areas. The correlations suggest that the latter interpretation is correct, as a negative association with forest and positive associations with crops and pasture emerge. Pasture rotation is less ambiguous, as this practice requires more land under pasture for a given number of cattle, implying less land area for the other land use outcomes. Rotation, used on 69% of the lots surveyed, shows a strong positive correlation with the extent of pasture and a negative association with forest, but a surprising positive correlation with cropland.

Aside from the foregoing explanatory factors, "household life cycle location" should influence the allocation of land on lots owned by small farm families (Marquette 1998; McCracken et al. 1999; Perz 2001a; Walker and Homma 1996; Walker et al. 2002). Table 1 presents six variables that together "locate" households along their domestic life cycles.

The first variable captures the household's duration of ownership of a lot. Longer durations should correspond to better expertise at land use, as households adapt to local conditions through time by experimenting with and then adopting appropriate farming strategies (Moran 1989). Through the process of experimentation and adoption, households will clear more land, perhaps experience land degradation, and allow regrowth to appear. As a result, longer durations of time on a lot should correspond to less forest and more of the other land use outcomes. The survey data indicate a mean duration of 10 years with substantial variation, and significant correlations with the land use outcomes in the expected directions.

The next four life cycle variables — the number of elderly, adults, adults squared, and children — allow for assessment of age structure effects on land uses. While theoretically these four life cycle variables change in tandem with time on lot, they are independent to the extent that children are born over time and households arrive in the Amazon at different moments in their life cycles.[11] The number of elderly (persons age 66+) indicates older households declining in size, and so should correspond to less forest, but also less crops and pasture, as well as more regrowth, in reflection of older households experiencing out-migration and reductions in subsistence demand. By contrast, the number of working-age adults (persons age 15-65) indicates household labor availability, which should increase land use decision making latitude and subsistence demand and thereby correspond to larger production systems with less forest and regrowth and more cropland and pasture.[12] An "adults squared" term is also considered in a model, which can indicate whether greater labor availability has nonlinear effects on land use allocation. More adults may not monotonically lead to more crops and pasture beyond a certain point, but instead foster diversification into non-agricultural activities, therefore attenuating further increases in land use for crops and pasture. The number of children (persons under age 15) indicates younger household age structures and greater dependence, which constitutes pressure to plant annual crops to meet subsistence demands. This in turn implies more regrowth as soil fertility declines, necessitating fallowing or increasing risk of land degradation and plot abandonment. Table 1 indicates that households had on average 0.15 elderly, 4.49 adult men and women, and 2.93 children. The substantial standard deviations for the age structure variables indicate that households in the Uruará sample varied in their life cycle locations. The anticipated associations for the elderly and children are not significant, but the correlations for adults do reflect expectations.

The last life cycle variable is an interaction term that allows for evaluation of the "generational transition" argument. Households with many elderly members and children imply a generational transition in control of the farm and the emergence of a new generation with rising subsistence demands. This interaction term, net of the independent effects of elderly and children, should expand cropland and pasture and reduce the extent of regrowth on farm lots.

Findings from Multivariate Models

Conceptually, land allocation involves a zero-sum game of putting land under a specific use, in this case by removing forest for crops or pasture and then letting productive land go fallow so regrowth appears. Simply put, more of one use implies less of one or more of the others. Therefore, it makes little sense to construct separate models of forest, cropland, pasture and regrowth. Because these outcomes are correlated statistically, it is likely that residuals (error terms) from models of each outcome will also be correlated. This "stochastic jointness" implies that OLS models, which assume no correlation among residuals, will yield inefficient estimates of coefficients. A more efficient estimation technique is the seemingly unrelated regression, or SURE (Zellner 1962; Srivastava and Giles 1987). SURE simultaneously estimates multiple equations and relaxes the assumption of uncorrelated residuals, in order to adjust the standard errors of the coefficients to obtain more efficient estimates of the effects of explanatory variables on the outcomes. As a consequence, SURE can account for the interrelated nature of land uses in an allocation model and provide better estimates of the effects of life cycle variables and other factors.[13]

Table 2 presents findings from a four-equation set of SURE models for primary forest, cropland, pasture, and secondary growth. Diagnostics from these equations indicate that their error terms are non-independent. A Breusch-Pagan test of independence was significant ($\chi^2 = 15.67$, df = 6, $p < .05$), indicating that the residuals are correlated.[14] Thus, the SURE results reflect more efficient estimation than would four OLS equations.

The first column presents coefficients for the primary forest model. The "context of lot" variables show the strongest effects. Lots had more primary forest if they 1) were located farther from Uruará town and 2) had not incurred fire damage. Among the life cycle variables, the number of children was significant and negative, which suggests that subsistence demand influences forest cover among the households surveyed.

The cropland model appears in the second column and is substantially stronger than the primary forest model (R^2 = 0.32 vs. 0.17). Moreover, the significant variables differ. Lots had more land allocated to annual and perennial crops if 1) the household had less initial wealth, 2) the lot was the "first-order" lot in a farming system, 3) the lot was closer to Uruará town, and 4) the household made heavier use of agricultural

Table 2. SURE models of forest, crops, pasture, and secondary growth regressed on life cycle location and other factors, farm lots, Uruará, Pará, 1996.

	Primary Forest	Cropland	Pasture	Secondary Growth
Intercept	3.77 **	0.56	1.04 *	-0.63
Socioeconomic Background				
Region of Origin (0=South or Southeast, 1=North, Northeast or Center-west)	0.03	-0.20	0.09	0.15
Initial Wealth (Factor Index)	0.01 +	-0.07 **	-0.03 +	0.62
Initial Agricultural Capital (Factor Index)	-0.03	-0.07	0.12 +	-0.31 **
Initial Land Cover				
Ln ha Deforested at Time of Acquisition	-0.03	0.01	0.04	0.27 **
Context of Lot				
Ordinal Lot Number (1=1st, 2=2nd...6th)	-0.12	-0.99 **	-0.52 *	-0.82 **
Kilometers to Uruará Town	0.01 **	-0.02 **	-0.01 *	0.01
Neighborhood Organization (0=No, 1=Yes)	-0.03	0.15	0.41 *	-0.40 +
Damage by Fire Set by Neighbor (0=No, 1=Yes)	-0.27 **	0.13	0.35 +	0.55 *
Institutional Context				
Use of Credit (0=No, 1=Yes)	0.03	-0.02	0.51 *	-0.32
Assistance from Extension Agency (0=No, 1=Yes)	-0.21 +	0.24	0.003	-0.62 *
Remittances and Hired Labor				
Remittance Income from Absent Family Member (0=No, 1=Yes)	0.10	0.13	-0.18	0.61 +
Ln Days of Labor Hired	0.004	0.07 +	-0.01	0.03
Land Management Practices				
Agricultural Inputs (Factor Index)	-0.04 +	0.12 *	0.02	0.01
Pasture Rotation (0=No, 1=Yes)	-0.07	0.38 +	1.84 **	-0.93 **
Life Cycle Location				
Years on Lot	-0.01	-0.02	-0.01	0.14 **
Number of Elderly (Persons ages 66+)	0.16	-0.10	-0.25	0.70 *
Number of Adults (Persons ages 15-65)	0.07	0.38 **	0.09	0.08
Number of Adults Squared	-0.003	-0.03 **	-0.0004	-0.01
Number of Children (Persons under age 15)	-0.04 *	0.08 *	-0.05	0.15 **
Number of Elderly * Number of Children	-0.01	0.01	0.03	-0.12 **
R^2	0.17	0.32	0.46	0.27
F ratio	3.29 **	7.37 **	13.32 **	5.78 **
n	314	314	314	314

+ $p < .15$, * $p < .05$, ** $p < .01$

inputs. These findings reflect the strategies underlying annual and/or perennial crop cultivation. For example, the negative effect of initial wealth likely implies that poorer households cultivated more annuals for food security, and perhaps more perennials to obtain a cash income. The market distance effect more likely reflects the importance of getting perennial crops to town than selling of annuals, though small farms do that too. And the use of agricultural inputs is largely for perennials, which in recent years have incurred attacks from fungal diseases. Aside from these factors, life cycle variables, particularly indicators of age structure, confirm expectations by exhibiting strong positive effects on land use allocation for crops. The positive effects of children and adults suggest that greater subsistence demands lead to the allocation of more land to crops. Moreover, the negative effect of the adults squared term suggests that land allocation to crop cultivation peaks in households with six or seven adults, and declines thereafter. This implies that especially large households increasingly allocate their labor to non-agricultural activities.

The third column presents the pasture model, which emerges as the strongest of the four ($R^2 = 0.46$). Again, stark contrasts with previous models appear regarding the significant variables. Lots had more pasture if 1) they were the first-order lot in a farming system, 2) they were closer to Uruará town, 3) they were located in an organized neighborhood, 4) the owner had received credit, and 5) the owner practiced pasture rotation. No life cycle variables indicate significant effects on the allocation of land to pasture. Instead, smallscale ranching appears to be driven by credit, tenure security, market access, and a commitment to pasture maintenance via rotation.[15]

The fourth and final column shows the secondary growth model (R^2 = .27). Again, the significant variables contrast with those in previous models. Lots had more land under regrowth if 1) the household had less initial agricultural capital, 2) the lot had more land initially deforested, 3) the lot was first-order in a farming system, 4) the lot incurred fire damage, and 5) the owner did not practice pasture rotation. These findings indicate that capital scarcity, deforestation by uncontrolled fires, and pasture degradation (from not rotating) lead to more extensive regrowth. In addition, several life cycle variables show strongly significant effects that follow expectations. Lots also had more regrowth if 1) the ownership duration was longer, 2) there were more elderly household members, 3) there were more children, and 4) there was no generational transition underway, indicated by fewer elderly and children. The positive effects of ownership duration and elderly members confirm expectations from McCracken et al. (1999) of expanding regrowth over time and as households reach later stages of their life cycles. In addition, the positive effect of children supports arguments that annual crop cultivation is followed by fallowing early on in farm establishment and the household life cycle. Finally, the negative coefficient for the elderly/child interaction term indicates a “generational transition” effect that attenuates or reduces regrowth late in the household life cycle if the elderly generation passes control of a farm to the second generation with children, who renew subsistence demands, expand the production system, and reduce the extent of fallows (Perz and Walker 2002).

Conclusions and Discussion

The findings confirm arguments derived from life cycle theory that household durations of ownership, age structures, and generational transitions influence different aspects of land use allocation among small farms in the Amazon. This provides empirical confirmation that household demographic factors have diverse and complex effects on land use allocation, understood more broadly than with a singular focus on deforestation. The findings advance our understanding of land use dynamics in the Amazon in three ways: 1) they show that a nuanced appraisal of demographic factors is necessary to properly specify household models of resource use, 2) they go beyond commonly seen one-outcome models of land use and land cover, and in so doing, 3) they separate secondary growth from other outcomes and show very distinct explanatory factors. Together, the theoretical framework and the multivariate findings imply a broader conclusion, namely that the relevance of demographic variables for resource use and environmental outcomes extends beyond a focus on macro-level factors to those operating at the household level.

Land use dynamics in Uruará are complex and their sustainability is questionable. To review briefly, annuals cultivation does not use much land at a given time, but may require substantial deforestation over time since yields on a given plot decline; perennials offer environmental advantages because they can be planted on land previously under annuals, and because they provide shade that contributes to soil remediation; pasture for cattle requires extensive land areas which are subject to soil erosion and compacting, leading to weed invasions that prevent forest succession; and regrowth offers environmental services similar to perennials that aid in soil remediation (e.g., Fearnside 1990; Pichón 1996; Serrão and Homma 1993). In recent years, there has been a shift from perennials to pasture in many households because prices on cash crops declined since the mid-1980s boom and because of crop blights (IDESP 1990; Toni 1999; Tourrand et al. 1996; Walker et al. 2000). The shift to cattle raises many questions about pasture sustainability, as pasture degradation is common in the Amazon, even to the point where succession toward primary forests is prevented (Nepstad et al. 1991; Serrão and Toledo 1990). Furthermore, there are growing concerns about timber extraction in remaining forests as a means of financing pasture remediation (Almeida et al. 1996). Selective logging opens forest canopy gaps and increases fire risks (Nepstad et al. 1999), as witnessed by the fires in the Amazon during 1998.

In addition to the shift to pasture, data from the Uruará survey indicate largely inadequate fallowing practices. Estimates of the fallow periods required for secondary growth to renew soil productivity in the Amazon vary, but they range from 5 to 10 years or more (e.g., Fearnside 1996, 24; Scatena et al. 1996, 35; Walker 1999, 405). By contrast, among lots in the Uruará sample with cleared plots (n = 298 out of 347), 69% were managed with fallow periods under 5 years, 24% were managed by shifting plots directly from one use to another, and only 6% were managed with fallow periods of 5 years or more. As a result, it is not surprising that respondents reported soil fertility declines in 42% of the lots surveyed. The concern over land degradation under colonist land use systems has prompted many to call attention to indigenous land use strategies such as agroforestry, which combines crop cultivation with long fallow periods, where fallows include economically important tree crops planted among other species to hinder pest attacks (e.g., Beckerman 1987; Dubois 1990; Dufour 1990; Hecht 1982; Smith et al. 1995).

Recent demographic changes underway in the Amazon and the life cycle framework presented here suggest that current land use patterns may not persist. Rural population growth in the Brazilian Amazon has ceased, switching from an annual increase of 1.5% during 1980-1991 to a yearly drop of 0.9% during 1991-2000 (IBGE 1983, 1996, 2001). This was due in part to a slowdown in regional population gains due to net migration (Perz 2002a). Nonetheless, land cover change continues in the Amazon (INPE 2001). These trends imply that contemporary land use in the Amazon is the result of existing populations in frontier areas (Perz 2002b).

That said, macro-level demographic data beg questions about micro-level demographic processes that may affect current and near future resource use in the Amazon. The life cycle framework suggests that as households continue to move to later stages of their life courses, they allocate more land to perennials and secondary growth. However, this remains to be seen, and it may depend on how "generational transitions" proceed among farm households.

The issue of generational transitions raises questions of how the "second generation" of family farmholders will allocate their land. On the one hand, if the "new" households go through their life cycles and use land as their forebears, we might expect reductions in the extent of land use as pasture is abandoned to regrowth and the second generation focuses on smaller plots of annuals. Preliminary analysis of a panel of landholdings in one colonization area of the Ecuadorian Amazon suggests that this may be the case (Murphy 2000). On the other hand, the new households may choose to build on the accomplishments of the first generation and continue running cattle on pasture, perhaps even expanding cleared areas. It is therefore possible that the second generation's life cycle, as it influences land use, will be very different from that of the first. Because the second generation begins with more cleared land and greater knowledge of local agriculture, demographic changes may move small farms along a different land use trajectory than the historical record shows.

The importance of household demographic changes for land allocation therefore bears implications for policy formulation for farm households in the Amazon. There are many policy proposals for the Amazon that in some way seek to generate livelihoods while conserving ecosystems and resources. Two examples are intensification, often via technology adoption (e.g., Almeida et al. 1996; Angelsen and Kaimowitz 2001; Sanchez 1994), and diversification, often via agroforestry (e.g., Browder and Pedlowski 2000; Pichón 1996; Smith et al. 1995). A key finding of this paper is that the demographic evolution of farm households as they move through their life cycles alters land allocation because decision latitudes and risk aversion change. It is also likely that changes associated with domestic life cycles will widen or narrow the latitude families have to respond to a given policy incentive. The aging of families, and the potential for generational transitions, means that policies directed at households are in effect aiming at moving targets who may respond differently over time. An instructive example involves agroforestry proposals, which seek to improve fallows by incorporating economically valuable species that add to household income while providing environmental amenities. Promotion of productive fallows may not generate substantial results if, for example, a second generation of young householders establish new claims with little land cleared and no regrowth, or older households let land go to fallow with no need for further production. In the first case, the household has little fallow to improve; in the second case, the household has little interest in making its regrowth generate income. A policy to promote agroforestry via economic improvements to fallows may have greater effects if it is tailored in some way to households at specific points in their life cycles (Perz and Walker 2002).

While this study focused on land allocation in one Amazon colony, demographic processes involved in household life cycles likely also affect resource use elsewhere. Here it is important to bear in mind the limitations of Chayanovian theory regarding applicability to different historical, cultural, economic and biophysical contexts (e.g., Ellis 1993; Netting 1993). However, it is also crucial to recognize that adaptations, such as that of Walker and Homma (1996), allow for the incorporation of demographic factors into research on resource use in regions that differ from Chayanov's post-revolutionary Russia. The importance of household demography for farming is recognized in many contexts around the world (e.g., Binswanger and McIntire 1987; Chibnik 1987).

These observations call attention to the role of household demography in resource use among local peoples experiencing rapid changes in their cultural, economic, and political circumstances. In the context of economic globalization, sustainable and longstanding resource use practices by indigenous and traditional peoples are in many places threatened, at least in Latin America (e.g., Loker 1999; Pichón et al. 1999; Redford and Padoch 1992). As alterations occur in tenure regimes, access to credit, market prices, and other contextual factors, the ability of households to respond to new opportunities and constraints in resource use may depend in part on their life cycle location. The interaction of contextual and household changes produces varying responses in resource management, not only among contrasting households but also among contrasting communities. This ongoing interaction between changing contexts and households requires a focus on household demography alongside community circumstances in order to understand land allocation and other forms of resource use.

Endnotes

1. Department of Sociology, 3219 Turlington Hall, University of Florida, PO Box 117330, Gainesville, FL 32611-7330. Phone: 352-392-0251, ext. 234. Fax: 352-392-6568. E-mail: sperz@soc.ufl.edu.
2. I speak of land use allocation rather than land cover allocation. While land use and land cover are closely linked, the two are not the same (e.g., Turner et al. 1995). The data employed in this paper are based on categories of land uses as reported by landholders. Reported land uses reflect the "functional" categorizations of households, in contrast to land cover categorizations derived from e.g. satellite imagery. Some of the land uses discussed, such as primary forest, are often regarded as land cover categories. Nonetheless, because the categorization scheme employed here is based on the function of land as viewed by landholders, categorizing land as primary forest still reflects a use-based classification. This becomes more important for pasture and regrowth because land that appears in a satellite image as regrowth may still be functionally categorized as pasture if the landholder runs cattle on it, i.e., uses that land as pasture (Perz and Walker 2002).
3. Chayanov also considered household motivations for working more or less (i.e., "drudgery"), which he also viewed as a function of internal dependency (Thorner et al. 1986).
4. One can imagine more complex dynamics over even longer timescales. Threats of land degradation under new plots of annuals and pasture may eventually force renewed fallowing, leading to a second decline in the extent of primary forest and rise in the extent of secondary growth. Under conditions of land abundance, however, this is not likely to occur in the space of one generation.
5. Colonization of the Amazon accelerated while Brazil's military controlled state policies. A hallmark of the military's development policy was to encourage frontier colonization as an alternative to agrarian reform (e.g., Burns 1993; Skidmore 1999). Land redistribution, which had been called for by civilian politicians in the 1960s, was one of the factors that precipitated the military coup in 1964. As a result, by the 1970s, the state was building new highways into the Amazon, instituting directed colonization projects, and offering fiscal incentives for capital investment (e.g., Mahar 1979; Ozório de Almeida 1992). These policies helped stimulate rapid in-migration, land settlement, rural conflicts, the emergence of a regional agro-extractive economy, and land cover change (e.g., Browder 1988; Hall 1989; Schmink and Wood 1992).
6. A precursor to the present paper separately models the land area under annual crops and the number of productive perennial plants (Perz 2001a). These models have the shortcoming of treating the two outcomes as independent, when in fact land allocation for annuals and perennials is to an extent interdependent.
7. I also considered the household head's years of schooling as an indicator of human capital. However, it was never significant in models and had many missing values, so it is excluded from the models that follow.
8. Variables and factor weights from principal components analysis for the wealth index were: urban house 0.74, brick walls 0.48, electricity 0.63, generator 0.52, gas stove 0.63, sewing machine 0.54, refrigerator 0.73, radio 0.48, television 0.77, satellite dish 0.68, bicycle 0.54, and car 0.50. The factor with the weights used to calculate this index accounts for 42.4% of the common variance of these 12 variables. Variables and factor weights for the agricultural capital index were: chainsaw 0.81, cocoa dryer 0.63, and tractor 0.48. The factor with the weights used to calculate this index accounts for 42.8% of the common variance of these three variables.
9. I originally considered the formal tenure status of lots. Legal land titles provide a formal type of tenure security because they imply the presence of functioning legal institutions. Lots with titles may allow longer-term planning for land use, and proponents of property rights argue that this should reduce speculative deforestation (Alston et al. 1999). However, titles also valorize land and facilitate access to credit, which may prompt users to invest more heavily in crops and especially pasture. Because titles are usually necessary to obtain credit (which had a high correlation with title status, $r > 0.60$), and because credit exerted stronger effects, I exclude title status from the analysis presented.
10. Variables and factor weights from principal components analysis for the agricultural inputs index were: insecticides 0.74, fungicides 0.54, herbicides, 0.53, chemical fertilizers 0.81, and organic fertilizers 0.58. The factor with the weights used to calculate this index accounts for 42.3% of the common variance of these five variables.
11. Multicollinearity is not a problem among the life cycle variables. Time on lot, elderly, adults, and children all have correlations of $r < 0.15$ except adults and children, where $r = 0.45$.
12. One might object that men and women play distinct roles in farming systems and should therefore have separate variables to assess their effects on land allocation. However, correlation analysis indicated a strong association between the number of men and women ($r > 0.60$), which hinders observation of differentiated effects by gender. Models with separate variables for men and women tended to show strong effects for one of the terms, indicative of multicollinearity more than gender differentiation per se. Later models with a single variable for adults exhibited stronger performance.
13. Of the 300+ lots included in the analysis, three had no forest, 49 had no cropland, 39 had no pasture, and 90 had no regrowth. These zero values in many instances suggest varying degrees of "left-censoring," which can lead to biased estimates of significance in model estimation. As a result, one might object to the choice of a SURE approach and argue instead for the application of Tobit models, which adjust standard errors of coefficients for censoring (e.g., Maddala 1983). However, Tobit models of each of the four outcomes generated results that were very similar and substantively the same as those that will be presented from SURE models. Given that finding and the conceptual importance of recognizing the "jointness" inherent in land allocation, I opt for the SURE approach instead of separate Tobit equations.
14. A correlation matrix of the four SURE models' residuals indicates significant associations ($p < .05$) for forest and pasture ($r = -0.12$), forest and regrowth ($r = -0.12$), and cropland and pasture ($r = -0.12$).
15. Removal of the pasture rotation variable reveals a positive effect of adults and a negative effect of children on pasture area (both $p < .05$). This finding is consistent with the expectation that older households (with fewer children and more adults) will have more pasture. However, the model presented in Table 2 with pasture rotation was stronger ($R^2 = 0.46$ vs. 0.31).

Acknowledgements

This research was supported by a grant from the US National Science Foundation (SBR-9511965). I thank Charles H. Wood and Robert T. Walker for support in the US, and Adilson Serrão and Alfredo Homma for support in Brazil. Research team members André Caetano, Roberto Porro, Fabiano Toni, Célio Palheta, Rui Carvalho, and Luiz Guilherme Teixeira, as well as the people of Uruará, provided engaging discussions of the issues pursued here. An earlier version of this paper was presented at the 2001 meetings of the Population Association of America, and I thank participants in that session for their comments. Finally, I thank two anonymous reviewers for their comments. Remaining errors are the author's responsibility.

References

Almeida, O.T., A. Veríssimo, A. Toniolo, C. Uhl, M.M. Mattos, P. Barreto and R. Tarifa. 1996. *A Evolução da Fronteira Amazônica*. Belém, Brazil: IMAZON.

Alston, L.J., G.D. Libecap and R. Mueller. 1999. *Titles, Conflict, and Land Use: The Development of Property Rights and Land Reform on the Brazilian Amazon Frontier*. Ann Arbor, MI: University of Michigan Press.

Anderson, A.B., P.H. May and M.J. Balick. 1991. *The Subsidy from Nature: Palm Forests, Peasantry, and Development on an Amazon Frontier*. New York, NY: Columbia University Press.

Angelsen, A. and D. Kaimowitz (eds). 2001. *Agricultural Technologies and Tropical Deforestation*. New York, NY: CABI/CIFOR.

Arizpe, L., M.P. Stone and D.C. Major (eds.) 1994. *Population and Environment.* Boulder, CO: Westview Press.

Beckerman, S. 1987. Swidden in Amazonia and the Amazon Rim. In B.L. Turner II and S.B. Brush (eds.), *Comparative Farming Systems*, 55-94. New York, NY: Guilford Press.

Binswanger, H.P. and J. McIntire. 1987. Behavioral and material determinants of production relations in land abundant tropical agriculture. *Economic Development and Cultural Change* 36, 73-99.

Binswanger, H.P. and V.W. Ruttan. 1978. *Induced Innovation, Technology, Institutions and Development*. Baltimore, MD: Johns Hopkins University Press.

Bongaarts, J. 1992. Population Growth and Global Warming. *Population and Development Review* 18, 299-319.

Boserup, E. 1965. *The Conditions of Agricultural Growth*. London: Allen and Unwin.

Browder, J.O. 1988. Public policy and deforestation in the Brazilian Amazon. In R. Repetto and M. Gillis (eds.), *Public Policies and the Misuse of Forest Resources*, 247-297. Cambridge: Cambridge University Press.

Browder, J.O. and M.A. Pedlowski. 2000. Agroforestry performance on small farms in Amazonia: Findings from the Rondonia Agroforestry Pilot Project. *Agroforestry Systems* 49, 63-83.

Brown, S. and A.E. Lugo. 1990. Tropical Secondary Forests. *Journal of Tropical Ecology* 6, 1-32.

Burns, E.B. 1993. *A History of Brazil, Third Edition*. New York: Columbia University Press.

Chibnik, M. 1987. The economic effects of household demography: A cross-cultural assessment of Chayanov's theory. In M.D. Maclachlan (ed.), *Household Economies and Their Transformations*, 74-106. Lanham, MD: University Press of America.

Cohen, J.E. 1995. *How Many People Can the Earth Support?* New York, NY: W.W. Norton and Co.

Davis, K. and M.S. Bernstam (eds.) 1991. *Resources, Environment and Population*. New York, NY: Oxford University Press.

Dubois, J.C.L. 1990. Secondary forests as a land-use resource in frontier zones of Amazonia. In A.B. Anderson, (ed.), *Alternatives to Deforestation: Steps Toward Sustainable Use of the Amazon Rain Forest*, 183-194. New York, NY: Columbia University Press.

Dufour, D.L. 1990. Use of tropical rainforests by native Amazonians. *BioScience* 40, 652-659.

Ehrlich, P. and A. Ehrlich. 1990. *The Population Explosion*. New York, NY: Simon and Schuster.

Ellis, F. 1993. *Peasant Economics, Second Editon*. Cambridge, MA: Cambridge University Press.

Faminow, M.F. 1998. *Cattle, Deforestation and Development in the Amazon*. New York, NY: CAB International.

Fearnside, P.M. 1990. Environmental destruction in the Brazilian Amazon. In D. Goodman & A. Hall (eds.), *The Future of Amazonia*, 70-120. London: St. Martin's Press.

Fearnside, P.M. 1996. Amazonian deforestation and global warming: Carbon stocks in vegetation replacing Brazil's Amazon forest. *Forest Ecology and Management* 80, 21-34.

Feder, G., R.E. Just and D. Zilberman. 1985. Adoption of agricultural innovations in developing countries: A survey. *Economic Development and Cultural Change* 33, 255-298.

Gascón, C. and P. Moutinho (eds.). 1998. *Floresta Amazônica: Dinâmica, Regeneração e Manejo*. Manaus, Brazil: INPA.

Gash, J.H.C., C. Nobre, J.M. Roberts and R.L. Victoria (eds.). 1996. *Amazonian Deforestation and Climate Change*. Chichester: John Wiley and Sons.

Godoy, R., K. O'Neill, S. Groff, P. Kostishack, A. Cubas, J. Demmer, K. McSweeney, J. Overman, D. Wilkie, N. Brokaw and N. Martinez. 1997a. Household determinants of deforestation by Amerindians in Honduras. *World Development* 25, 977-987.

Godoy, R., D. Wilkie and J. Franks. 1997b. The effects of markets on neotropical deforestation: A comparative study of four Amerindian societies. *Current Anthropology* 38, 875-878.

Godoy, R., S. Groff and K. O'Neill. 1998a. The role of education in neotropical deforestation: Household evidence from Amerindians in Honduras. *Human Ecology* 26, 649-675.

Godoy, R., M. Jacobson, J. de Castro, J. Aliaga, J. Romero and A. Davis. 1998b. The role of tenure security and private time preference in neotropical deforestation. *Land Economics* 74, 162-170.

Green, C.P. 1992. The environment and population growth: Decade for action. Population Reports Series M, No. 10.

Hall, A.L. 1989. *Developing Amazonia: Deforestation and Social Conflict in Brazil's Carajás Programme*. Manchester: Manchester University Press.

Hecht, S.B. 1982. Agroforestry in the Amazon basin: Practice, theory, and limits of a promising land use. In S.B. Hecht (ed.), *Amazonia: Agriculture and Land Use Research*, 331-371. Cali, Colombia: CIAT.

Houghton, R.A., D.L. Skole, C.A. Nobre, J.L. Hackler, K.T. Lawrence and W.H. Chomentowski. 2000. Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon. *Nature* 403, 301-304.

Instituto Brasileiro de Geografia e Estatística (IBGE). 1983. *Censo Demográfico — 1980: Dados Gerais*. Rio de Janeiro: IBGE.

IBGE 1996. *Censo Demográfico — 1991: Características da População e Instrução*. Rio de Janeiro: IBGE.

IBGE 1998a. *Contagem Populacional de 1996*. Available at IBGE website, http, //www.ibge.org, June.

IBGE 1998b. *Censo Agropecuário 1995/96*. Available at IBGE website, http, //www.ibge.org, June.

IBGE. 2001. *Censo Demográfico 2000: Características da População e dos Domicílios*. Rio de Janeiro: IBGE.

Instituto de Desenvolvimento do Estado do Pará (IDESP) 1990. *Uruará*. Belém, Brazil: IDESP.

Instituto Nacional de Pesquisas Espaciais (INPE). 2001. Monitoramento da Floresta Amazônica por Satélite, 1999-2000. Website available at http://www.inpe.br/Informacoes_Eventos/amazonia.htm, May.

Jolly, C. 1994. Four theories of population change and the environment. *Population and Environment* 16, 61-90.

Jones, D.W., V. H. Dale, J. J. Beauchamp, M. A. Pedlowski and R. V. O'Neill. 1995. Farming in Rondônia. *Resource and Energy Economics* 17, 155-188.

Jordan, C.F. 1986. Local effects of tropical deforestation. In M. Soulé (ed.), *Conservation Biology: The Science of Scarcity and Diversity*, 410-426. Sutherland: Sinauer Associates.

Kates, R.W. 1996. Population, technology and the human environment: A thread through time. *Daedalus* 125, 43-71.

Keyfitz, N. 1991. Population and development within the ecosphere: One view of the literature. *Population Index* 57, 5-22.

Lambin, E.F., X. Baulies, N. Bockstael, G. Fischer, T. Krug, R. Leemans, E.F. Moran, R.R. Rindfuss, Y. Sato, D. Skole, B.L. Turner II and C. Vogel. 1999. *Land-use and Land Cover Change (LUCC) Implementation Strategy*. Available at http, //www.geo.ucl.ac.be/LUCC/implstrategy/implementation.html, June 2001.

Loker, W.M. (ed.) 1999. *Globalization and the Rural Poor in Latin America*. Boulder, CO: Lynne Rienner.

Lugo, A. and S. Brown. 1992. Tropical forests as sinks of atmospheric carbon. *Forest Ecology and Management* 54:239-255.

Lutzenheiser, L. and B. Hackett. 1993. Social stratification and environmental destruction: Understanding household CO_2 production. *Social Problems* 40, 50-73.

MacKellar, F.L., W. Lutz, A.J. McMichael, A. Suhrke, V. Mishra, B. O'Neill, S. Prakeesh and L. Wexler. 1998. Population and climate change. In S. Rayner and E.L. Malone (eds.), *Human Choice and Climate Change, Volume 1: The Societal Framework*, 89-193. Columbus: Battelle Press.

Maddala, G. 1983. *Limited-dependent and Qualitative Variables in Econometrics*. Cambridge: Cambridge University Press.

Mahar, D.J. 1979. *Frontier Development Policy in Brazil: A Study of the Amazon*. New York: Praeger.

Marquette, C.M. 1998. Land use patterns among small farmer settlers in the Northeastern Ecuadorian Amazon. *Human Ecology* 264, 573-593.

Maxwell, S. 1980. Marginalized colonists to the north of Santa Cruz: Avenues of escape from the barbecho crisis. In F. Barbira-Scazzocchio (ed.), *Land, People and Planning in Contemporary Amazonia*, 162-170. Cambridge: Cambridge University Press.

Mazur, L.A., (ed.). 1994. *Beyond the Numbers: A Reader on Population, Consumption and the Environment*. Washington, DC: Island Press.

McCracken, S.D., E.S. Brondizio, D. Nelson, E.F. Moran, A.D. Siqueira and C. Rodriguez-Pedraza. 1999. Remote sensing and GIS at farm property level: Demography and deforestation in the Brazilian Amazon. *Photogrammetric Engineering and Remote Sensing* 65, 1311-1320.

Moran, E.F. 1989. Adaptation and maladaptation in newly settled areas. In D. Schumann and W. Partridge (eds.), *The Human Ecology of Tropical Land Settlement in Latin America*, 20-41. Boulder, CO: Westview Press.

Moran, E.F., E. Brondizio, P. Mausel and Y. Wu. 1994. Integrating Amazonian vegetation, land-use, and satellite data. *BioScience* 445, 329-338.

Moran, E.F., E.S. Brondizio, J. Tucker, M.C. da Silva-Forsberg, I.C. Falesi and S. McCracken. 2000. Strategies for Amazonian forest restoration: Evidence for afforestation in five regions of the Brazilian Amazon. In A. Hall (ed.), *Amazonia at the Crossroads: The Challenge of Sustainable Development*, 129-149. London, England: Institute of Latin American Studies.

Murphy, L. 2000. Land use and deforestation by migrant colonists in the Amazon: Permanence and adaptation. Paper presented at the XXII meetings of the Latin American Studies Association, Miami, March 16-18.

Nair, P.K.R. 1993. *An Introduction to Agroforestry*. New York, NY: Kluwer.

Nepstad, D., C. Uhl and E.A.S. Serrão. 1991. Recuperation of a degraded Amazonian landscape: Forest recovery and agricultural restoration. *Ambio* 20, 248-55.

Nepstad, D., A. Veríssimo, A. Alencar, C. Nobre, E. Lima, P. Lefebvre, P. Schlesinger, C. Potter, P. Moutinho, E. Mendoza, M. Cochrane and V. Brooks. 1999. Large-scale impoverishment of Amazonian forests by logging and fire. *Nature* 398, 505-508.

Ness, G.D., W.D. Drake and S.R. Brechin (eds.). 1993. *Population-Environment Dynamics*. Ann Arbor, MI: University of Michigan.

Netting, R. McC. 1993. *Smallholders, Householders*. Stanford, CA: Stanford University Press.

Nicholaides, J.J., D.E. Bandy, P.A. Sanchez, J.H. Villachica, A.J. Coutu and C.S. Valverde. 1984. Continuous cropping potential in the upper Amazon basin. In M. Schmink and C.H. Wood (eds.), *Frontier Expansion in Amazonia*, 337-365. Gainesville: University of Florida Press.

Ozório de Almeida, A.L. 1992. *The Colonization of the Amazon*. Austin: University of Texas Press.

Ozório de Almeida, A.L. and J.S. Campari. 1995. *Sustainable Settlement in the Brazilian Amazon*. Oxford: Oxford University Press.

Panayotou, T. 1996. An inquiry into population, resources, and environment. In D.A. Ahlburg, A.C. Kelley and K. Oppenheim Mason (eds.), *The Impact of Population Growth on Well-being in Developing Countries*, 259-298. New York, NY: Springer-Verlag.

Pebley, A.R. 1998. Demography and the environment. *Demography* 35, 377-389.

Perz, S.G. 1998. Reassessing the rationality of land settlement in the Amazon: Farming strategies and wealth accumulation in Uruará, Pará, Brazil. Presented at the Latin American Studies Association meetings, Chicago, Illinois, September 24-26.

Perz, S.G. 2001a. Household demographic factors as life cycle determinants of land use in the Amazon. *Population Research and Policy Review* 203, 159-186.

Perz, S.G. 2001b. From sustainable development to "productive conservation": Forest conservation options and agricultural income and assets in the Brazilian Amazon. *Rural Sociology* 66, 93-112.

Perz, S.G. 2002a. Population growth and net migration in the Brazilian Legal Amazon, 1970-1996. In C.H. Wood and R. Porro (eds.), *Deforestation and Land Use in the Amazon*, 107-129. Gainesville: University of Florida Press.

Perz, S.G. 2002b. The changing social contexts of deforestation in the Brazilian Amazon. *Social Science Quarterly* 83(1), 35-52.

Perz, S.G. and R.T. Walker 2002. Household life cycles and secondary forest growth among smallholders in the Amazon. Forthcoming in *World Development* 30(6).

Pfaff, A.S.P. 1999. What drives deforestation in the Brazilian Amazon? *Journal of Environmental Economics and Management* 37, 26-43.

Pichón, F.J. 1996. The forest conversion process: A discussion of the sustainability of predominant land uses associated with frontier expansion in the Amazon. *Agriculture and Human Values* 13, 32-51.

Pichón, F.J. 1997. Colonist land-allocation decisions, land use, and deforestation in the Ecuadorian Amazon frontier. *Economic Development and Culture Change* 45, 707-744.

Pichón, F.J., J.E. Uquillas and J. Frechione (eds.). 1999. *Traditional and Modern Natural Resource Management in Latin America*. Pittsburgh, PA: University of Pittsburgh Press.

Preston, S.H. 1996. The effects of population growth on environmental quality. *Population Research and Policy Review* 15, 95-108.

Redford, K.H. and C. Padoch (eds.) 1992. *Conservation of Neotropical Forests: Working from Traditional Resource Use*. New York, NY: Columbia University Press.

Reis, E.J. and S. Margulis. 1991. Options for slowing Amazon jungle clearing. In R. Dornbusch and J. Poterba (eds.), *Economic Policy Responses to Global Warming*, 336-375. Cambridge: MIT Press.

Reis, E.J. and R. Guzm·n 1994. An econometric model of Amazon deforestation. In K. Brown and D.W. Pearce (eds.), *The Causes of Tropical Deforestation*, 172-191. Vancouver, BC: UCL Press.

Rudel, T.K. 1995. When do property rights matter? Open access, informal social controls, and deforestation in the Ecuadorian Amazon. *Human Organization* 54, 187-94.

Sanchez, P. 1994. Alternatives to slash-and-burn: A pragmatic approach for mitigating tropical deforestation. In J.R. Anderson (ed.), *Agricultural Technology: Policy Issues for the International Community*, 451-479. Wallingford: CAB International.

Scatena, F.N., R.T. Walker, A.K.O. Homma, A.J. de Conto, C.A.P. Ferreira, C.A.P., R. de Amorim Carvalho, A.C.P. Neves da Rocha, A. Itaguara Moreira dos Santos and P. Mourão de Oliveira. 1996. Cropping and fallowing sequences of small farms in the "terra firme" landscape of the Brazilian Amazon: A case study from Santarém, Pará. *Ecological Economics* 18, 29-40.

Schmink, M. and C.H. Wood. 1992. *Contested Frontiers in Amazonia*. New York: Columbia University Press.

Serrão, E.A.S. and A.K.O. Homma. 1993. Brazil. In *Sustainable Agriculture and the Environment in the Humid Tropics*, 265-351. Washington, DC: National Academy Press.

Serrão, E.A.S. and J.M. Toledo. 1990. The search for sustainability in Amazonian pastures. In A.B. Anderson, (ed.), *Alternatives to Deforestation: Steps Toward Sustainable Use of the Amazon Rain Forest*, 195-213. New York: Columbia University Press.

Skidmore, T. E. 1999. *Brazil: Five Centuries of Change*. New York: Oxford University Press.

Skole, D. L. and C. J. Tucker. 1993. Tropical deforestation and habitat fragmentation in the Amazon: Satellite data from 1978 to 1988. *Science* 260, 1905-1910.

Smail, J. K. 1997. Beyond population stabilization: The case for dramatically reducing global human numbers. *Politics and the Life Sciences* 16, 183-192.

Smil, V. 1994. How many people can earth feed? *Population and Development Review* 20, 255-292.

Smith, N.J.H, E.A.S. Serrão, P.T. Alvim and I.C. Falesi. 1995. *Amazonia: Resiliency and Dynamism of the Land and its People*. Washington, DC: National Academy Press.

Srivastava, V.K. and D.E.A. Giles. 1987. *Seemingly Unrelated Regression Equations Models: Estimation and Inference*. New York, NY: Marcel Dekker.

Thiele, G. 1993. The dynamics of farm development in the Amazon: The barbecho crisis model. *Agricultural Systems* 42, 179-197.

Thorner, D., B. Kerblay and R.E.F. Smith (eds.). 1986. *A.V. Chayanov on the Theory of Peasant Economy*. Madison. WI: University of Wisconsin Press.

Toni, F. 1999. *State-Society Relations on the Agricultural Frontier: The Struggle for Credit in the Transamazonica Region*. Doctoral Dissertation, University of Florida.

Tourrand, J.-F., J.B. Veiga, M. Simão-Neto, W.G. Vale, L.A. Ferreira, R.R. Ludovino and A.P.O. Mares Guia 1996. Animal husbandry in agricultural frontiers of the Brazilian Amazon. Belém, Brazil: Unpublished manuscript.

Turner, B.L. II and S. Brush (eds.) 1987. *Comparative Farming Systems*. New York, NY: Guilford Press.

Turner, B.L.II, D. Skole, S. Sanderson, G. Fischer, L. Fresco and R. Leemans. 1995. *Land-use and Land-cover Change: Science/Research Plan*. Stockholm and Geneva: IGBP/HDP.

United Nations (UN) 1994. *Population, Environment and Development*. New York, NY: UN.

Unruh, J.D. 1988. Ecological aspects of site recovery under swidden-fallow management in the Peruvian Amazon. *Agroforestry Systems* 7, 161-84.

Walker, R.T. 1999. The structure of uncultivated wilderness: Land use beyond the extensive margin. *Journal of Regional Science* 39, 387-410.

Walker, R.T. and A.K.O. Homma. 1996. Land use and land cover dynamics in the Brazilian Amazon: An overview. *Ecological Economics* 18, 67-80.

Walker, R.T., E.F. Moran and L. Anselin. 2000. Deforestation and cattle ranching in the Brazilian Amazon: External capital and household processes. *World Development* 28, 683-699.

Walker, R.T., S.G. Perz, M. Caldas and L.G. Teixeira da Silva. 2002. Land use and land cover change in forest frontiers: The role of household life cycles. *International Regional Science Review* 252, 169-199.

Wood, C.H. and D.L. Skole. 1998. Linking satellite, census and survey data to study deforestation in the Brazilian Amazon. In D. Liverman, E.F. Moran, R.R. Rindfuss and P.C. Stern (eds.), *People and Pixels: Linking Remote Sensing and Social Science*, 70-93. Washington, DC: National Academy Press.

Zellner, A. 1962. An efficient method of estimating seemingly unrelated regressions and tests for aggregation bias. *Journal of the American Statistical Association* 57, 348-368.