Cattle Accumulation and Land Use Intensification by Households in the Brazilian Amazon

Jill L. Caviglia-Harris

In developing countries across the globe the impact of livestock on deforestation levels has been profound. This paper explores the role of the cattle industry in household decision making for small landholders in the Brazilian Amazon. Important inquiries raised in the literature are addressed, including the determinants of the co-evolution of deforestation and cattle herds, the possibility of production specialization, and the role of cattle in household livelihoods. Panel data suggest that households have changed focus from crop production to cattle. Empirical models reveal that location, wealth, and education are among the important determinants of production decisions and cattle accumulation. Policy recommendations include a focus on the cattle sector coupled with initiatives to establish and enforce protected areas.

Key Words: Latin America, Brazil, household production, land use, cattle, deforestation

Tropical deforestation continues to be a major concern on global, regional, and local levels (Anderson 1993, Mahar and Schneider 1994, Myers 1994, Watson et al. 2000, Laurance et al. 2001). In Brazil, as in many Latin American countries, migration and subsequent deforestation have continued, making the land use choices of its inhabitants an important aspect of deforestation rates (Batistella, Robeson, and Moran 2003). In the 1970s, settlers from the more populated southern and northeastern regions of Brazil migrated to the Amazon, inhabited forested tracts, and began the process of acquiring property rights through informal and formal processes (Alston, Libecap, and Schneider 1996). An integral part of the acquisition of property rights was the clearing of forests and populating landholdings with individuals and cattle.[11] Since the colonization period, Brazilian laws have altered incentives to clear land, making it illegal to deforest more than 50 percent of the holding (Alves et al. 1999). However, the impact of land use decisions for the cattle industry endures and is an increasing focus of research in the area (Faminow 1998, Walker, Moran, and Anselin 2000, Mertens et al. 2002; see Behrman and Oliver 2000).

Agricultural households throughout Latin America's forest margins are increasingly creating pasture to support cattle (Locker 1993, Humphries 1998, Murphy 2001, Wood forthcoming). In the Brazilian Amazon, cattle ownership has become one of the major sources of investment and asset accumulation (Caviglia-Harris and Sills 2005, Walker, Moran, and Anselin 2000, McCracken et al. 1999, Fujisaka et al. 1996). Although the buying and selling of beef and other cattle products are not currently linked to external markets, local trade and consumption in the region have grown over recent years (Caviglia-Harris 2004). In developing countries across the globe the livestock sector has increased so rapidly that the International Food Policy Research Institute has called this growth "the next food revolution." Specifically in Brazil, the term "pecuarizaçao," or cattleization, has been adopted to depict the increase of cattle herds for landowners of all sizes (Mertens et al. 2002). Until recently, ranchers with large landholdings (more than 500 hectares) played a predominant role in the cattle industry in the Amazon. However, cattle are becoming an increasingly important aspect of house-

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[1] The terms "cleared land" and "deforestation" are used interchangeably throughout the paper.

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hold livelihood strategies for small landholders (those households with an average 100 hectares or less) as well (Faminow 1998, Porro 2002).

This paper explores links between cattle ownership and deforestation for households in Ouro Preto do Oeste, Rondônia, Brazil, a government-sponsored settlement within the "arc of deforestation."[2] The state and study region have experienced some of the highest rates of deforestation in the Amazon, placing them in the priority area for monitoring and managing development pressures (Alves 2002, Lele et al. 2000). Panel data collected in 1996 and 2000 are used to investigate the role of the cattle industry in household land use decisions. The empirical analysis addresses important inquiries raised in the literature, including the determinants of the co-evolution of deforestation and cattle herds, the possibility of production specialization, and the role of cattle in household livelihoods. One important goal is to ascertain whether overall changes in land use related to cattle herds are systematically higher for certain households or whether households tend to trade and own cattle at average rates and deforest at similar levels over time. The role of wealth status in the livestock and milk trade is of particular interest since certain households may use the purchase and trade of cattle as a means for climbing out of poverty. Under this scenario, cattle and the resulting pasture formation may create opportunities for colonists to improve their livelihoods, but actually conflict with the goals of environmental policy.

The intensification of cattle production is also an important issue to examine since deforestation levels resulting from pasture creation have increased over time, leading to questions concerning the sustainability of cattle as an income source. Since property rights are well established for most households, it is expected that there is incentive for farmers to intensify production as long as negative impacts on soil quality are not expected. Although the study region is unique in many aspects, including the relatively rich soils and wealthy settlers (although poor by national and international standards), the similarities are significant enough to draw some general conclusions that may apply to other agrarian settlements across the Amazon and many other regions of Latin America as well.

The remainder of the paper includes a review of the literature on land use and cattle ownership in the tropics, the conceptual framework for household decision making, a description of the study site, survey design, and data, and the empirical models with estimation results. The paper concludes with a discussion of how these findings may be applicable for policy in the Brazilian Amazon as this region continues to develop.

Land Use and the Impact of Cattle

Research on land cover and land use change has been particularly productive in tropical regions (Parks and Hardie 2003, Lambin, Rounsevell, and Geist 2002, Coxhead, Rola, and Kim 2001, Kaimowitz and Angelsen 1998, Skole et al. 1994). Models have been developed on multiple scales largely based on data collected at macro or regional levels (Kaimowitz and Angelsen 1998, Pfaff 1999, Geoghegan et al. 2001). This study contributes to the "second wave" of these studies emphasizing agricultural households (Barbier and Burgess 2001, Barbier 2001). An issue critical to this literature is whether deforestation and poverty are complementary and if policies to reduce deforestation, such as improvements in agricultural intensification, can improve the livelihoods of small landholders (Reardon and Vosti 1995, Duraiappah 1998; cf. Swinton, Escobar, and Reardon 2003). Studies suggest that many settlers arriving to the Brazilian Amazon region as poor colonists have improved their livelihoods and that some have done so at markedly higher rates than other populations in Brazil (Andersen et al. 2002). This suggests that an optimal strategy for households may be to clear forest for agriculture and pasture; however, increases in the intensity of land use may also serve to reduce these incentives to clear forest (see Vosti et al. 2003).

Opposed to the prediction of some studies, the establishment of a secure property regime has not reduced the incentive for farmers to deforest at relatively high rates (Southgate 1990, Pichón 1997; cf. Mendelsohn 1994, Nelson, Harris, and Stone 2001). Households are increasingly investing in multipurpose cattle to store wealth, produce

[2] The "arc of deforestation" is defined as the northern and southeastern borders of the Legal Amazon, including the highly deforested states of Rondônia, Mato Grosso, and Pará.

dairy products, and insure against poor crop harvest. Mattos and Uhl (1994) first noted that large ranchers in Pará, Brazil, were specializing in cattle for meat or dairy purposes in 1990. Since then, it has been noted that small landholders (those with lots averaging 100 hectares or less) are increasing participation in cattle markets because ranching proves to be a low labor alternative to crop production (Pichón 1997, McCracken et al. 1999, Walker, Moran, and Anselin 2000, Porro 2002).

It is now believed that small landholders may be filling a niche in the market, focusing on the production of milk for processing centers and/or calves for larger ranchers (Faminow 1998, White et al. 2001). In the past, large ranchers had to produce their own calves or have them imported from other regions of the country. However, as cattle become a more popular production choice for small landholders and the region becomes more urban, these households are also beginning to participate in the calf trade and extend their supply of milk to regional markets. It is expected that the regional supply of beef and other agricultural products (such as pork, coffee, oranges, papaya, and many other fruits) will continue to expand in the future as regional farmers increase the supply of these goods, thus reducing the demand for imported national goods.

Several studies have also suggested that many of the patterns in observed land use and cattle ownership can be explained by the life-cycle considerations, theorizing that households acquire wealth by first planting and harvesting annual crops, then investing in perennial crops, and later owning cattle (Walker and Homma 1996, Pichón 1997, McCracken et al. 1999, Perz 2001, Walker et al. 2002). These land use patterns are likely to continue for new colonists arriving with little acquired wealth. However, the existence of more developed infrastructure for electricity, schools, and the beef and milk markets by 2000 may also serve to alter these trajectories in the near future.

The panel data collected as part of this study include information on household participation in agriculture, cattle raising, and off-farm labor, thus allowing for further investigation of the trends in cattle ownership suggested in previous studies. In addition, detailed production data enable the investigation of land use intensification. While scholars continue to investigate methods for addressing the dual goals of improving agriculture and forest conservation, the identification of such policies has been problematic (Angelsen and Kaimowitz 2001). For example, Cattaneo (2001) finds that a reduction in transportation costs for agricultural goods leads to an increase in deforestation, while White et al. (2001) find that households increase the intensification of pasture management only when this option is cheaper than cutting surrounding forest. Vosti, Carpentier, Witcover, and Valentim (2001) find that deforestation continues to increase when intensive systems of pasture are adopted, and Pichón et al. (2001) find that labor intensification strategies are linked to a reduction in land-clearing only in cases where the household is labor-constrained.

This paper adds to this continuing research by investigating the intensification of cattle and dairy production. While cattle are often noted as one of the driving forces of tropical deforestation, it must be recognized that they are also a vital part of the small landholder's income and insurance base. And, since cattle are only likely to increase in numbers in these regions, the study of intensification and management issues is imperative to the design of constructive developmental policy.

Theoretical Framework

The household production of agricultural goods (including cattle products and farm crops) influence deforestation levels because cleared land, in addition to household labor, fertilizers, and pesticides, are inputs to farm production for these forested lots. Small-scale farm management strategies in the Amazon involve a variety of activities, including the production of annual and/or perennial crops alone or in integrated systems, cattle ranching, and the husbandry of other farm animals. Households do not typically use mechanized inputs but rather rely on available household labor, minimal chemical inputs, and the sporadic hiring of outside labor. The following theoretical model examines household agricultural activity with a focus on links between alternative production choices (crops, milk, and cattle) to highlight the processes that are investigated in the empirical analysis. The household production framework assumes that production and consumption decisions are nonseparable due to im-

perfect markets. A brief derivation of the equations to be estimated in the empirical analysis follows. For further details see Singh, Squire, and Strauss (1986), de Janvry, Fafchamps, and Sadoulet (1991), Melmed-Sanjak and Santiago (1996), Shively (2001), and Sills et al. (2003).[3]

Households are assumed to maximize utility over an infinite time horizon, a function of the consumption of home-produced agricultural goods (X_A), market goods (X_M), and leisure (L_L), through the quasi-fixed inputs labor (L) and land (D), conditioned on household and lot characteristics (H):

$$(1) \qquad \text{Max } E_t \sum_{t=0}^{\infty} (1+\delta)^{-t} U(X_A X_M, L_L; H),$$

subject to

$$(2) \quad P_M X_M = P_A(Q - X_A) - P_N X_N + W\bar{L}$$
$$W = \sum_{i=1}^{I} W_i \qquad \bar{L} = L + L_H \qquad L \geq L_A + L_W + L_L$$
$$L = \sum_{i=1}^{I} L_i \qquad D = D_A + D_F.$$

The number and age of household members restrict the household's labor allocation (L) and can be divided between different uses, including agriculture (L_A), off-farm or wage employment (L_W), and leisure (L_L). The total labor used in production, ($\bar{L}$), is the addition of hired labor (L_H) to the household labor endowment (L). Land available for production is constrained by the size of the lot (D) and divided between use in agriculture, including crops and pasture (D_A) (i.e., land that has been deforested) and forest (D_F). The consumption of market goods ($P_M Q_M$) is constrained by the cash income from agricultural production $P_A(Q-X_A)$, input costs (excluding hired labor) ($P_N X_N$), and off-farm income and/or labor costs ($W_W L_w$), where P_A is a matrix of agricultural prices and P_N is the matrix of input prices. W represents a matrix of wages in i alternatives, including that for home production (W_A), leisure (W_L), off-farm labor (W_W), and hired labor (W_H).[4] It is assumed that family and hired labor cannot be substituted perfectly and that the household is a price taker (i.e., it has no influence on the prices for off-farm labor, agricultural goods, or the prices of inputs). These assumptions together imply imperfect labor markets. Combined with imperfect information, consumption and production decisions are inseparable (Melmed-Senjak and Santiago 1996).

Under the assumption of profit maximization in production choices, one can solve for all factor demand functions:

$$(3) \qquad X_i = X_i(W_i, P_A, P_M, P_N, Y, D, \theta, H),$$

where X_i represents those goods consumed by the household including inputs and market goods, and Y represents the full household income, including farm profits and off-farm labor. Therefore the variable demand functions for goods "purchased" by the household are functions of all exogenous variables, including those household characteristics not commonly found to be relevant in production decisions.

The focus of the empirical analysis is to investigate how households allocate labor and other inputs to influence cattle husbandry and milk production. The factor demand functions for cattle and milk are therefore estimated utilizing the exogenous variables identified by this framework and available from the survey data. These estimations will be used to provide evidence of the significant determinants of cattle accumulation, the stocking rate of cattle, and the production of milk, some of the driving forces of local markets and general land use patterns in the region. Significant household, soil, and lot characteristics may be identified, and therefore serve as policy levers to alter the current land use patterns as related to cattle and pasture creation.

Study Region, Survey Design, and Data Description

Large-scale migration to the Ouro Preto do Oeste region of Rondônia began in the 1970s as part of

[3] Household production models remain the well-developed alternative to standard separable microeconomic models for studies in less-developed countries and regions in which labor and markets are incomplete and market information is constrained.

[4] The time period subscript (t) has been suppressed but applies to all variables except for D and some elements of H (including lot characteristics exogenous at the time of arrival).

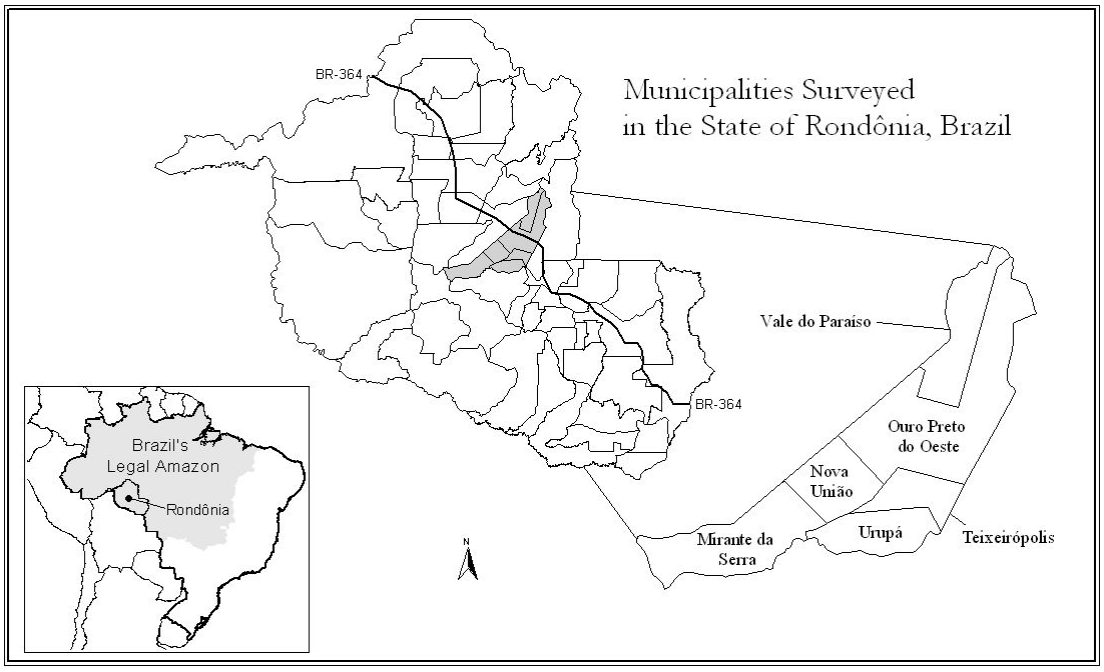

Figure 1. Map of the Survey Site in Ouro Preto do Oeste, Rondônia, Brazil

the government colonization program Operation Amazonia (Figure 1). Considered a model colonization project, government plans included sectioning lots for 500 families. However, four thousand colonists settled the city and surrounding region by 1974, attracted to the relatively fertile soils and easy access provided by the creation of the major state highway, BR-364. During the 1980s, Operation Amazonia continued in Rondônia with additional funding from the World Bank sponsored project POLONOROESTE. The $1.6 billion project included paving BR-364, further opening the region to migration of individuals and cattle (Mahar 1989). The region was subdivided into four municipalities in the early 1990s, and now comprises six—Ouro Preto do Oeste, Vale do Paraíso, Urupá, Mirante da Serra, Nova União, and Teixeirópolis (Figure 1)—with a population over 92,000 (IBGE 2003b). The region remains relatively rural, with 68 percent of the urban population concentrated in the single municipality of Ouro Preto do Oeste. Many of the major side roads within the municipalities are paved, or in the process of being paved. Side roads leading to a majority of households remain unpaved and difficult to travel, especially during the rainy season. Year-round bus service is available along BR-364 and most major side roads throughout the six municipalities.

The cattle herd in Rondônia grew from minimal levels in the 1970s to the second largest in the Amazon by 1991, and continues to increase (Faminow 1998). In the Ouro Preto do Oeste region, herd size increased from just under 200,000 in 1991 to over 630,000 by 2000 (IBGE 2003a), while herd size per household increased from 41 to 104 for the same years (Pedlowski and Dale 1992).

The empirical analysis is based on a stratified random sample of households collected in 1996 and 2000.[5] The data include a balanced panel of 152 households, or 304 combined observations, stratified by the rural population in each municipality. In the initial data collection, 171 households were interviewed over a five-month period (September 1996 through January 1997). The author, assisted by a local farmer, conducted each of the interviews. The distance between inter-

[5] The 2000 data collection was supported by the National Science Foundation Grant No. SES-0076549. The 1996 data collection was supported by grants from the National Security Education Program, the Organization of American States, the Institute for the Study of World Politics, and the McClure Fund Foundation.

views was designed to obtain spatial variation in topography, soil type, and distance to market. If the house was unoccupied at the time of the interview or the owner of the lot was not available, the next household on the same side of the road was interviewed, and if the same occurred at that house, the household on the same side of the road after that was interviewed. This contingency was generally unnecessary since most of the farmers stay close to, or on, their lots during the time of year the surveys were conducted (September through December), the end of the burning period and beginning of the planting season.[6] In 2000, a Brazilian graduate student and the farmer that participated in the first survey in 1996 conducted the surveys with assistance and training from the author. Data were collected from the same farm lots between August and November 2000.[7] Some of the original 171 lots were dropped from the panel because they were sold to land speculators who did not take up residence on the land. This reduced the stratified random sample to 152 households, a combined set of 304 observations across both years. [See Caviglia-Harris (2004, 2003) and Caviglia (1999) for further details.]

The following tables present variable definitions (Table 1) and household and lot characteristics (Table 2). Overall trends in agricultural production, land use, and household dynamics occurring over the four-year period are evident from a comparison of these means. For example, the ownership of legal tenure rights increased from 92 to 100 percent for the sample. In addition, average landholding decreased due to the subdivision of lots between family members and the selling of lot portions, and cattle ownership increased as did the percentage of deforestation (from 77 percent in 1996 to 82 percent by 2000). Household composition was consistent, with 2–3 adult males, 2–3 adult females, and 2–3 children for each time period.

An interesting change noted is in income levels by type and percentage over the interview years. Total income[8] from crops was found to fall significantly, while milk and off-farm labor income increased. In comparison, the percentage of income from crops declined over the four years, while the share of income from milk was relatively constant and off-farm labor increased as a percentage of total income. Market conditions for both inputs and outputs have changed dramatically in the region since the early settlement period. In response, households appear to have altered their patterns of activity over time. A 1991 study from the same region found that approximately 72 percent of the average household's income was derived from crops and 14 percent was derived from both milk and off-farm labor (Pedlowski and Dale 1992). By 1996 these percentages changed to 33 percent for crops, 43 percent for milk, and 23 percent for off-farm labor. By 2000, a continuing shift towards milk and away from crops was evident. In 2000, crops made up 17 percent of total household income, milk contributed 44 percent, off-farm labor supplied 21 percent, calves made up 17 percent, and the trading of adult cattle for beef and other purposes contributed 9 percent. In addition, total income rose faster than inflation rates.

Information on calf and beef trade is not available for the 1996 observations. Households were not specifically asked about these income sources in 1996 because this market was not identified as important to the livelihood of households through pre-tests and informal questioning. However, by 2000 the role of this market appeared to be greater for the small landholder. Even though similar data are not available for 1996, the small percentage of the total income attributed to the trading of cattle in 2000 suggests that participation in these markets was relatively new. Another indication of increasing participation in this trade is that none of the survey participants responded that they relied on the cattle trade solely for income. At the same time, many responded that one of the more established sources of revenue—crops, milk, or off-farm labor—served as their only income source (see Table 2).

[6] There is no expected bias resulting from the skipping of unoccupied homes at the time of interview since the occurrence was low and the interviews did not coincide with seasonal events or opportunities.

[7] The panel data is consistent across lots. Therefore, if land was sold and another family occupied the lot in 2000, this new household was interviewed. The primary purpose of the continuing data collection is to investigate how land use changes over time. An important factor to the analysis with such data is the number of years a family occupies a lot, and whether ownership changes or not.

[8] Income is measured in 2000 reais, R$, and adjusted for inflation. Statistical significance is tested with a t-test.

Table 1. Variable Definitions

	Definition
Household characteristics	
AGEHH	Average age of the household heads, years
EDUHH	Average number of years of education completed by the household heads
FAMILY	Number of family members residing on the lot
MALES	Number of adult males in the household
FEMALES	Number of adult females in the household
CHILDREN	Number of children in the household
OWNER	Dummy variable for tenure rights: = 1 if the one if the household has legal title, = 0 otherwise
YEARS ON LOT	Number of years household members have lived on the lot
VEHICLES	Value of all vehicles owned by the household (motorcycles, cars, and trucks), thousands of reais calculated in 2000 reais[b]
YEAR	Interview year: 1996 or 2000
Lot characteristics	
LOTSIZE	Size of the lot, hectares
CHANGE IN LOT SIZE	Change in lot size between the interview years (1996 and 2000), hectares
PASTURE	Number of hectares cleared for pasture on the lot (includes secondary forest, but not land in agriculture)
CLEARED	Number of hectares cleared (deforested) on the lot (includes secondary forest, pasture, and agriculture)
PERCENT CLEARED	Percentage of the lot that is cleared or deforested
CHANGE CLEARED	Change in the number of hectares cleared between interview years, 1996 and 2000
SOIL	Dominant soil type on lot, characterized by ability to support agriculture (1 = good, 2 = moderate, 3 = restricted, 4 = unsuitable)
DISTANCE MARKET	Distance to the city center (central market area), kilometers
Livestock entitlements	
CATTLE	Number of cattle owned by the household
NON DAIRY CATTLE	Number of cattle owned not producing milk in the interview year
DAIRY CATTLE	Number of cattle owned producing milk in the interview year
Income sources	
INC CROPS	Income from agricultural crops (including perennials and annuals), in 2000 reais
INC MILK	Income from milk, in 2000 reais
INC OFF	Income from off-farm labor (including pensions), in 2000 reais
INC CALVES[a]	Income from calf trade, in 2000 reais
INC BEEF[a]	Income from beef trade (older cattle), in 2000 reais
Income shares	
CROP PERCENT	Crop income as a percentage of total income
MILK PERCENT	Milk income as a percentage of total income
OFF PERCENT	Off-farm labor income as a percentage of total income
CALVES PERCENT	Calf income as a percentage of total income
BEEF PERCENT	Beef income as a percentage of total income
Agriculture intensification measurements	
ANNUAL PER HEC	Harvest value of all annuals per hectare of land in annuals, in 2000 reais
PERRENIAL PER HEC	Harvest value of all perennials per hectare of land in perennials, in 2000 reais
LITERS PER COW – DRY	Liters of milk harvested per milk cattle owned in the dry season
LITERS PER COW – WET	Liters of milk harvested per milk cattle owned in the rainy season
CATTLE STOCK RATE	Cattle owned per hectare of cleared land

[a] Data not collected in the 1996 survey. Households were asked about all sources of income. However, the 1996 survey did not specify income from beef or the selling of calves, and therefore most households did not report.
[b] In 2000, one U.S. dollar was approximately equal to R$1.83 [National Trade Data Bank, U.S. Department of Commerce, http://www.stat-usa.gov (accessed July 2001)].

Table 2. Descriptive Statistics for Households in Ouro Preto do Oeste, Rondônia

	Survey Data for 1996 (N = 152)				Survey Data for 2000 (N = 152)			
	Mean	Std. Dev.	Min.	Max.	Mean	Std. Dev.	Min.	Max.
Household Characteristics								
AGEHH	46.40	12.84	18.50	74.50	48.38	12.23	23.50	72.00
EDUHH	2.38	2.40	0.00	11.00	2.54	1.61	0.00	8.00
FAMILY	8.70	6.00	1.00	37.00	7.40	5.65	0.00	36.00
MALES	3.49	2.36	1.00	15.00	2.96	2.13	0.00	11.00
FEMALES	2.96	2.35	0.00	14.00	2.66	2.09	0.00	12.00
CHILDREN	2.25	2.40	0.00	14.00	1.78	2.52	0.00	21.00
OWNER	0.92	0.27	0.00	1.00	1.00	0.00	1.00	1.00
YEARS ON LOT	11.51	6.67	1.00	26.00	14.37	7.69	0.00	30.00
VEHICLES	1.401	2.86	0.00	13.00	1.737	2.523	0.00	13.00
Lot Characteristics								
LOT SIZE	68.75	43.24	10.00	300.00	62.65	35.26	10.00	150.00
CLEARED	53.06	37.39	4.50	260.00	51.11	31.81	2.50	137.50
PERCENT CLEARED	0.77	0.19	0.27	1.00	0.82	0.18	0.03	1.00
DISTANCE MARKET	48.06	23.16	3.50	91.00	47.12	23.13	3.50	92.50
Livestock Entitlements								
CATTLE	69.11	73.13	0.00	400.00	99.12	96.32	0.00	500.00
NON DAIRY CATTLE	52.82	58.77	0.00	360.00	77.61	83.53	0.00	460.00
DAIRY CATTLE	16.29	18.49	0.00	140.00	21.51	21.49	0.00	150.00
Income Sources								
INC CROPS	2830.33	5637.52	0.00	39647.00	2413.73	5610.70	0.00	48000.00
INC MILK	3305.98	3985.73	0.00	30106.90	6791.80	7529.09	0.00	51660.00
INC OFF	1697.96	3485.91	0.00	26319.40	3887.01	7836.94	0.00	50000.00
INC CALVES[a]	NA	NA	NA	NA	989.11	2214.82	0.00	20000.00
INC BEEF[a]	NA	NA	NA	NA	2693.63	11070.70	0.00	90000.00
Income shares								
CROP PERCENT	32.76	31.16	0.00	100.00	17.58	24.28	0.00	100.00
MILK PERCENT	43.14	33.47	0.00	100.00	43.90	29.89	0.00	100.00
OFF PERCENT	23.33	31.05	0.00	100.00	21.35	27.88	0.00	100.00
CALVES PERCENT	NA	NA	NA	NA	8.55	17.26	0.00	95.39
BEEF PERCENT	NA	NA	NA	NA	6.22	9.02	0.00	41.12
Agriculture intensification measurements								
ANNUAL PER HEC	741.42	1040.50	35.61	6816.78	718.98	653.45	48.03	4199.33
PERRENIAL PER HEC	28.29	50.84	0.07	260.58	68.50	132.58	0.01	744.50
LITERS PER COW – DRY	2.53	1.05	0.20	6.00	3.49	1.26	1.13	9.33
LITERS PER COW – WET	3.75	1.64	1.00	14.00	4.87	2.23	1.38	16.67
CATTLE STOCK RATE	1.59	1.14	0.00	6.15	2.49	2.30	0.00	20.00

[a] Data not collected in the 1996 survey. Households were asked about all sources of income. However, the 1996 survey did not specify income from beef or the selling of calves, and therefore most households did not report.

At the same time that notable changes were found in income choices, the number of cattle owned by households increased significantly. Average herd size increased from 69 in 1996 (76 percent non-dairy and 24 percent dairy) to 99 in 2000 (78 percent non-dairy and 22 percent dairy). Together these data suggest relative stability in the region in relation to migration as well as the family structure, and a more rapid transformation in market participation and production choice. Many of these trends in the household income base can be attributed to the development and growth occurring in the region. Human and cattle populations have increased at annual rates between 100 and 200 percent since 1970, bringing advances in infrastructure, including road networks, a regional hospital, a banking center, and a school system. All of these developments have assisted in the establishment of well-defined markets for staple crops, household items, and livestock. As a result, many households have used agriculture as a means of income growth and wealth accumulation in patterns consistent with the "lifecycle" theory.

Another important aspect of agriculture in the Amazon is the implementation of agroforestry systems. Although the average household in Ouro Preto do Oeste does not participate in sustainable practices, a minority of households do produce non-timber forest products. These households tend to have significantly higher levels of diversification (Caviglia-Harris and Sills 2005). On the other hand, those households that produce milk or beef tend to specialize in these activities and produce a significantly smaller variety of annual and perennial crops (Caviglia-Harris 2004).

The last set of variables provided in Table 2 includes five different measurements of agriculture intensity: per hectare production of annual and perennial crops, liters per head of dairy cattle (separated into rainy and dry seasons), and the stocking rate of cattle. Agriculture intensity increased on average between 1996 and 2000 according to all but one of these measurements: the production of annual crops.[9] This reduction in intensification may be a result of declining soil productivity. However, this is an unlikely cause since landholders generally have sufficient landholdings to be able to clear more land for crops when soils fail. A more likely explanation is the decision to reduce the amount of labor and time devoted to annual crops as households focus on perennials and cattle. All remaining intensity measures increased between the interview years. It is interesting to note that the amount of milk produced per head is lower in the dry season for both years. This occurs because a majority of households in Ouro Preto do Oeste do not supplement cattle diets with feed but depend on pasture as the main nutrition source (Jones et al. 1995, Caviglia 1999, Walker, Moran, and Anselin 2000). Large landholders have the means to supplement cattle diets and are therefore the main supplier of beef in regional markets. (These herds often include cattle purchased from small landholders as calves.)

In summary, these descriptive statistics suggest that deforestation has increased in the study area in both absolute (total deforestation for the region) and percentage terms, as agriculture intensification and household welfare (wealth and income) rose. A more detailed look at the determinants of cattle ownership and intensification, and changes in these activities, follows in the empirical section of the paper. A better understanding of how and why these changes in household production choices have occurred can help facilitate forest conservation policy.

Empirical Models and Results

The empirical analysis begins with the estimation of deforestation and cattle ownership (Table 3) and continues with the evaluation of production intensity and household income (Table 4). The application of panel data is advantageous for tracking these household production choices over the survey time frame. The data represent a panel collected with residence as the unit of analysis—stipulating that lots, rather than household members, remain constant between the interview periods. Therefore, it is only lots that did not change ownership that are included in the estimations that make direct use of the panel observations, while the entire sample collected over both years is used to estimate stock values. The total number of observations is 152 per interview year, or 304

[9] This measurement includes all annuals consumed and sold and is calculated using reported household prices for those annuals sold and average prices for the goods consumed. The value is adjusted for inflation.

Table 3. Estimation of Deforestation and Cattle Ownership

	Deforestation on lot (in hectares)	Deforestation on lot (percent of lot)	Cattle (head)	Non-Dairy Cattle (head)	Dairy Cattle (head)	Change in Cattle
CONSTANT	-1379.650*	-23.654**	-10807.80**	-1629.02	-9178.76**	119.639***
	(798.403)	(10.839)	(4504.11)	(1071.15)	(3883.99)	(44.163)
AGEHH	-0.057	-0.001	0.635	0.131	0.503	-0.219
	(0.071)	(0.001)	(0.406)	(0.096)	(0.350)	(0.613)
EDUHH	-0.365	-0.006	2.569	-0.251	2.820	0.645
	(0.442)	(0.006)	(2.513)	(0.598)	(2.167)	(4.494)
FAMILY	-0.210	-0.002	-0.797	-0.193	-0.604	-0.311
	(0.140)	(0.002)	(0.801)	(0.190)	(0.690)	(1.183)
YEARS ON LOT	-0.066	-0.002	1.084*	0.290*	0.795	-0.017
	(0.119)	(0.002)	(0.655)	(0.156)	(0.565)	(0.970)
SOIL	0.122	-0.009	5.425	0.463	4.962	6.064
	(0.733)	(0.010)	(4.161)	(0.990)	(3.588)	(5.931)
DISTANCE MARKET	-0.147***	-0.003***	-1.502***	-0.297***	-1.205***	-1.182***
	(0.040)	(0.001)	(0.204)	(0.049)	(0.176)	(0.327)
VEHICLES	0.094	-0.001	2.890*	1.013***	1.874	-3.762
	(0.301)	(0.004)	(1.726)	(0.411)	(1.490)	(2.653)
YEAR	0.697*	0.012**	5.459**	0.827	4.632**	
	(0.400)	(0.005)	(2.256)	(0.537)	(1.945)	
LOT SIZE	0.781***	0.000				
	(0.024)	(0.000)				
DAIRY CATTLE–96						-1.514***
						(0.499)
NON DAIRY CATTLE–96						0.065
						(0.168)
CHANGE IN LOT SIZE						0.645***
						(0.239)
R-squared	0.86	0.12	0.26	0.22	0.23	0.19
Adj R-squared	0.85	0.10	0.24	0.20	0.20	0.13
n	304	304	304	304	304	136

Notes: Standard errors in parentheses. *, **, and *** indicate significance at the 10, 5, and 1 percent levels, respectively.

Table 4. Estimation of Production Intensity and Household Dairy Income

	Cattle Stoking Rate (head per hectare of pasture)	Milk Production in Rainy Season (daily liters per head)	Milk Production in Dry Season (daily liters per head)	Milk Sales (2000 reais)	Change in Milk Sales (2000 reais)
CONSTANT	-441.677***	-480.088***	-453.731***	-1448230.00***	601.370
	(108.128)	(123.794)	(74.072)	(313645.00)	(3998.370)
AGEHH	0.025***	0.002	0.004	33.919	78.833
	(0.010)	(0.011)	(0.007)	(28.204)	(55.664)
EDUHH	0.072	0.157**	0.040	342.412**	1217.930***
	(0.060)	(0.070)	(0.042)	(174.934)	(408.298)
FAMILY	-0.005	-0.024	-0.012	58.194	122.991
	(0.019)	(0.022)	(0.013)	(55.652)	(107.225)
YEARS ON LOT	-0.030*	0.019	0.000	7.454	-2.448
	(0.016)	(0.018)	(0.011)	(46.215)	(87.784)
SOIL	-0.028	0.025	-0.073	-4.531	-65.879
	(0.100)	(0.118)	(0.070)	(291.213)	(537.131)
DISTANCE MARKET	-0.001	-0.005	0.000	-46.044***	-72.904***
	(0.005)	(0.007)	(0.004)	(16.461)	(29.656)
VEHICLES	0.130**	0.049**	0.029**	0.655***	0.930***
	(0.041)	(0.572)	(0.205)	(0.120)	(0.241)
YEAR	0.222***	0.242***	0.229***	725.813***	
	(0.054)	(0.062)	(0.037)	(157.078)	
LOT SIZE	-0.004				
	(0.003)				
PASTURE		-0.010**	-0.005*	25.006**	
		(0.004)	(0.002)	(10.731)	
DAIRY CATTLE–96					-215.580***
					(45.165)
NON DAIRY CATTLE–96					5.445
					(15.232)
CHANGE IN LOT SIZE					-26.961
					(21.605)
R-squared	0.14	0.12	0.18	0.30	0.37
Adj R-squared	0.11	0.09	0.15	0.28	0.32
n	291	265	265	304	136

Notes: Standard errors in parentheses. *, **, *** indicate significance at the 10, 5, and 1 percent levels, respectively.

total. The observations are reduced to 136 for the regressions that utilize the sub sample of households (and individuals) that did not move between the interview years. This ensures that changes in the dependent variables are actually representative of household choice and not due to changes in land ownership, and that the lagged independent variables are correctly utilized as predictors of same household activities.[10] All lagged variables are represented by the variable name, and "-96" at the end represents the value collected in 1996 for the same household.

According to the theoretical model presented earlier, household production is influenced by available exogenous variables, including the number of years the household has occupied the lot, distance to market, the average age and education of the household heads (to account for joint decision making), wealth (value of total vehicles owned by the household), the household labor endowment (number of family members), and lot size.[11] The prices of cattle and crops are not included in the estimations since households are considered price takers, resulting in a lack of price variation.[12]

Estimation of Cattle and Deforestation

The first group of regressions corresponds to the ownership and accumulation of cattle herds and deforestation. Cattle are divided into two categories: dairy cattle and non-dairy cattle, where dairy cattle are those that produced milk at the time of the interview and non-dairy cattle represent the remaining herd (Table 3). Total deforestation (in hectares), the percentage of deforestation on the lot, cattle ownership, and changes in cattle ownership[13] are estimated with ordinary least squares (OLS) as reduced-form equations.[14]

According to the estimation results, the total stock of deforestation and percentage of deforestation on the lot are both significantly influenced by location (relative to the main market center) and the interview year. Distance to market is negatively related to deforestation, indicating that households located further from the center market have deforested significantly less of their lots in percentage and absolute terms. According to the estimated coefficients, for every kilometer a household is located from the city center, deforestation falls by 0.15 hectares or by 0.003 percent of the lot. As expected, the interview year dummy variable is found to increase both the total number of hectares deforested as well as the percentage of the lot. Specifically, the four-year time interval resulted in 0.70 hectares of deforestation, holding other factors constant. Finally, lot size is found to significantly increase the number of hectares deforested. Each additional hectare that is added to the total lot is found to result in approximately 0.78 more hectares of deforestation; however, no significant effect is found on the percentage of the lot deforested. Household characteristics, including education, age, family size, and wealth, are not found to be significant determinants of land clearing, suggesting that incomplete labor markets may not exist for this resource.

Cattle ownership and the division between dairy and non-dairy cattle are estimated with the same set of exogenous variables, with the exception of lot size.[15] In the estimation of the full cattle herd, significant determinants include years on the lot, household wealth, distance to the city center, and the interview year. Those households located closest to the city center, who have lived on their lots for a longer period of time, and who are wealthier tend to have greater herds. The cattle herd increased by almost 30 head for the average household over the four-year time period, a 44 percent increase. The coefficient on interview

[10] The likelihood that a lot was sold between 1996 and 2000 was estimated. It was determined through a Heckman selection and a dummy variable test that no bias results from dropping these observations.

[11] Human capital is a limited choice variable for these households since most individuals receive minimal levels of education and begin work on the household farm at the age of 10. Lot locations and distance to markets are considered exogenous because location was determined by land settlement plans instead of chosen by the household.

[12] Price variation is also tested. There is no significant difference in crop prices between households or by municipality.

[13] A log-log specification may better represent the estimations of the change in cattle ownership and change in milk income; however, several of the independent variables have values of "0" (such as education and wealth levels of the households), requiring one to either drop several of the observations or "fix the data" to fit a log specification. Neither of these options is desirable given the small sample size.

[14] Although pasture is an input to cattle production, land cleared for pasture is not included in this estimation due to issues of endogeneity and a lack of available instruments. Hausman tests suggest that deforestation is endogenous to cattle herd size; however, the number of cattle owned on the lot is not found to be an endogenous determinant of deforestation.

[15] A Hausman test suggests that lot size is endogenous in the estimation.

year suggests that approximately 5.5 cattle were added to each cattle herd due to regional changes or changes in household preferences not captured by other variables included in the regression.

In the estimations of non-dairy and dairy cattle, different variables appear to influence the levels of these cattle types. Both are influenced by distance to the town center. Again, households located further from the city center have smaller herds. Wealth and the number of years a household has occupied a lot positively impact the number of non-dairy cattle owned, but the same is not true for dairy cattle. The interview year is found to significantly impact the number of dairy cattle owned, but does not significantly impact non-dairy cattle. This suggests that other changes occurring between these interview years and not captured in the regression may explain differences in the dairy herd, while wealth and the possibly greater networking ability of these households explain the ownership of non-dairy cattle. Since calves and beef cattle are generally sold to larger ranches rather than directly to food markets, it is likely that more experienced households with better networking abilities and greater wealth participate in the market.

Household changes in the cattle herd size are estimated with the sub sample of households in residency for both interview years. The average household in this sample increased its herd by 28 head. Estimation results reveal that location, dairy cattle owned in 1996, and change in the lot size are significant determinants of cattle accumulation (Table 3). The coefficient on the variable for dairy cattle owned in 1996 is negative, suggesting that households with the largest herds of dairy cattle in 1996 increased the total herd by the fewest numbers by 2000. While wealth is found to increase the non-dairy herd, it is also found that dairy cattle owners experienced the smallest increase in the total herd. Each dairy cow owned in 1996 led to 1.5 fewer cows acquired by 2000. Also significant is the coefficient on the change in lot size. The average lot was reduced by almost seven hectares through subdivision to family members or sale. The estimation results suggest that for every 0.65 hectares that the lot was reduced, a household increased the cattle herd by one head. One interpretation of this result is that households may have invested profit from land sales into cattle. Together, these estimation results and interpretations imply that households may not be focusing on dual-purpose cattle. Instead, wealthier households appear to have a greater interest in the cattle trade, while other households may rely on cattle for milk production to a greater degree. Interestingly, these differences cannot be accounted for by household characteristics such as age or education, but rather are accounted for by previous holdings and wealth.

Estimation of Production Intensity and Household Dairy Income

To further address links between household agriculture decisions and the cattle industry, three different measurements of intensification, milk income, and the change in milk sales are also investigated. The production values estimated include the amount of the good consumed and sold [calculated in 2000 reais (R$)], while income values include only those goods sold in regional markets (Table 4). These estimations include the same set of exogenous variables, with the exception of lot size. Pasture is included in place of lot size in the estimation of milk production per head of cattle and milk sales since this land use is a direct input, and the change in property size is used in place of total land area in the estimation of the change in milk sales to account for changes in available land over the same time period. The estimations of agriculture intensification are made with the sub sample of participating households to capture the efficiency level of households that produce milk and own cattle. The remaining estimations include the full sample of households to reflect decisions of the average household in the survey area.

According to the three estimations of production intensity, household wealth and the interview year are significant and positive. The coefficients indicate that for every R$1,000, the stocking rate of cattle increases by 0.13 head and milk production increases by approximately 0.40 liters daily per head. The coefficient on year indicates an increase in intensification for all three measurements and captures changes occurring between 1996 and 2000 not represented by the remaining variables. Differences in the significant determinants of intensification include age of the household heads, education level, and pasture. Older households tend to have greater stocking rates of

cattle, while education level has a positive impact on milk production in the rainy season. It appears that the more educated households have a greater ability to utilize the increases in water and grasses that accompany this season. However, this is not the case in the dry season when both inputs are more limited. Finally, the amount of land cleared for pasture on the lot negatively impacts daily milk production per head of dairy cattle in both seasons. Since the area cleared for pasture includes secondary forest and other land that was once used for pasture but may no longer support grasses, this result may suggest that extensive areas of cleared land do not result in more productive dairy cattle.

The final regression results to be discussed include the estimation of milk sales and changes in sales experienced by households between 1996 and 2000. As shown in Table 2, average sales increased by R$3,313, or by more than 100 percent. This significant change likely resulted from improvements in infrastructure for the milk industry and increasing participation due to relatively small labor requirements. Households provide milk to large processing plants through farm gate pickup by the Parmalat Corporation, among other small and large processors. Education and wealth are both found to positively impact milk sales. According to the estimation results, every additional year of education adds R$342 to this income category. Those households located closest to the city center and Parmalat processing plant have greater incomes from milk sales. Since households rely on daily pickup (likely to be more reliable on the paved roads closer to the city center), this may encourage greater participation by these households. And finally, pasture is found to positively impact milk sales. This is an interesting result since the production per head of cattle is negatively impacted by land in pasture. Even though production efficiency falls with land cleared for pasture, total milk sales are found to increase as pasture increases, suggesting that total milk sales may be greater for households that use cattle extensively rather than intensively. Households likely increase sales through the allocation of a greater number of cattle rather than by adopting more expensive efficient production measures such as feed or inoculations for disease.

The significant determinants of the increase in milk income experienced between the survey years are similar to the estimation of total milk sales. Education, household wealth, and proximity to the city center all positively influence the change in milk income. In addition, households with larger milk herds in 1996 increased their milk income by 2000 at significantly lower rates. This may represent a leveling-off effect for households that own dairy cattle. Each additional cattle owned in 1996 resulted in a R$216 smaller increase in milk income.

Discussion of Empirical Results

The regression analyses presented in Tables 3 and 4 provide one method of examining the determinants of household decisions related to cattle ownership, changes in this ownership, and other production decisions related to cattle. Overall, it is found that certain household characteristics determine production behavior, providing some evidence of incomplete markets. Specifically, the average education level of the household heads is found to influence production intensification and milk income. In addition, wealthier and more highly educated households are found to own more cattle and take greater advantage of changes occurring in dairy markets. Interestingly, household labor is not a significant factor in these production decisions. Since cattle ranching and dairy production require relatively small amounts of labor when compared to agriculture, the number of household members residing on the lot does not serve as a constraint in this market segment. Instead, the family labor constraint has been found to significantly impact crop production, a production choice that appears to be increasingly unpopular for households (Caviglia-Harris 2004).

Labor constraints most likely limit the ability of a household to focus on both cattle and crops and therefore may be one reason for the specialization in cattle. In this same region, Jones et al. (1995) found evidence of increasing returns to scale in cattle activity 10 years earlier. Together with the increasing herd size per household, these findings imply that future increases in cattle ownership are likely as the markets for both milk and beef expand. Although the surveyed households did not trade beef often in 1996, by 2000 such commerce was more common, suggesting that regional consumption may be met by local harvest in the near future rather than purchased from the southern region of the country.

Conclusions

This paper investigates a variety of ways in which the small landholder's cattle production decisions impact land use in the Brazilian Amazon. In particular, cattle ownership and dairy production are investigated, with household panel data collected over a four-year time period. This analysis depicts a changing role for the cattle industry in relation to the small landholder. Summary data reveal that agricultural households have changed focus from crop production to cattle. In addition, regression analyses reveal that households focus on the production of either milk or calves rather than diversifying into the dual role as suggested by previous observations (White et al. 2001). Wealth is found to positively influence the ownership of cattle, the production of milk, production intensification, and increasing trends in milk sales. However, when cattle are divided between dairy and non-dairy, wealth is found to significantly influence the ownership of non-dairy cattle only. This suggests that the relatively wealthy (and perhaps better connected) households may have the means and ability to contribute to the calf and beef trade as regional markets develop.

As the intensity of livestock activities continues to expand, a natural question to ask is whether more sustainable methods of livestock production would actually reduce pressure on forests. Vosti, Carpentier, Oliviera, and dos Santos (2001) and Pagiola and Holden (2001) find tradeoffs between the adoption of intensified cattle ranching systems and benefits to households and/or the environment. This study makes similar conclusions based on four-year trends in deforestation and production intensification. While deforestation in the region continues to increase, intensification methods are found to be utilized by many households, resulting in higher levels of income from agriculture. Therefore one may conclude that both intensification and increased pressure on forests have resulted in increases in the profitability of farming.

Within the context of the literature on poverty and deforestation, it does not appear that higher levels of household wealth lead to reduced levels of deforestation (Panayotou and Ashton 1992, Deininger and Minten 1999). Instead, a more complicated relationship between wealth and environmental degradation has been identified (c.f. Duraiappah 1998, Swinton, Escobar, and Reardon 2003, Agudelo et al. 2003). It appears that these recent migrants have chosen cattle as a source of insurance and a means to increase future wealth in place of the non-timber forest products that can be found in their forests. This is in marked contrast to results from studies on indigenous populations (c.f. Pattanayak and Sills 2001, Arnold and Perez 2001).

Future developmental policy should target this industry as the specialization in cattle becomes more common for the small landholder. Muchagata and Brown (2000) find similar trajectories for colonists in Pará, Brazil, who perceive pasture as a more stable system of agriculture than annual and perennial crops. They find knowledge about agroforestry and silvopastural methods as well as methods for combating environmental deterioration to be severely lacking and identify this as a critical issue to be addressed in the design of environmental policy. In addition, their findings suggest that the development of alternative ranching and agriculture methods (including fertilizers for pasture and shade trees for cattle) is necessary to minimize the negative environmental impacts of the expanding and enduring cattle industry. Similar initiatives including regeneration of soils and tree planting are included in the Brazilian government's recent "Pro-environment" (Proambiente) program in which farmers are provided seedlings, support from agronomists, and monetary payments for forest reserves (Ministério do Meio Ambiente 2005). One potential problem that can be linked with such initiatives is that the more active and well connected households are often more likely to benefit from such programs if significant effort is not made to reach farmers that do not attend regular union and/or other farmer organization meetings (Caviglia-Harris 2003).

Such policies coupled with initiatives to establish and enforce a park system with protected areas to deter future colonist settlements in critical areas may be one method for reducing pressure on forests while jointly addressing the welfare issues of Amazonian settlers. Since deforestation rates and increases in the cattle herd do not show any signs of slowing, forest reserves should play a vital role in environmental policy.

References

Agudelo, C., B. Rivera, J. Tapasco, and R. Estrada. 2003. "Designing Policies to Reduce Rural Poverty and Environmental Degradation in a Hillside Zone of the Colombian Andes." *World Development* 31(11): 1921–1931.

Alston, L.J., G.D. Libecap, and R. Schneider. 1996. "The Determinants and Impacts of Property Rights: Land Titles on the Brazilian Frontier." *The Journal of Law Economics and Organization* 12 (1): 25–61.

Alves, D.S. 2002. "An Analysis of Geographic Patterns of Deforestation in the Brazilian Amazon in the Period 1991–1996." In C.H. Wood and R. Porro, eds., *Deforestation and Land Use in the Amazon*. Gainesville, FL: University Press of Florida.

Alves, D.S., J.L.G. Pereira, C.L. de Sousa, J.V. Soares, and F. Yamaguchi. 1999. "Characterizing Landscape Changes in Central Rondônia Using Landsat TM Imagery." *International Journal of Remote Sensing* 20(14): 2877–2882.

Andersen, L.E., C.W.J. Granger, E.J. Reis, D. Weinhold, and S. Wunder. 2002. *The Dynamics of Deforestation and Economic Growth in the Brazilian Amazon*. Cambridge, UK: Cambridge University Press.

Anderson, A.B. 1993. "Deforestation in Amazonia: Dynamics, Causes, and Alternatives." In S. Rietbergen, ed., *The Earthscan Reader in Tropical Forestry*. London: Earthscan.

Angelsen, A., and D. Kaimowitz (eds.). 2001. *Agricultural Technologies and Tropical Deforestation.* Oxfordshire, UK: CABI Publishing.

Arnold, J.E.M., and M.R. Perez 2001. "Can Non-Timber Forest Products Match Tropical Forest Conservation and Development Objectives?" *Ecological Economics* 39(3): 437–447.

Barbier, E.B. 2001. "The Economics of Tropical Deforestation and Land Use: An Introduction to the Special Issue." *Land Economics* 77(2): 155–171.

Barbier, E.B., and J.C. Burgess. 2001. "The Economics of Tropical Deforestation." *Journal of Economic Surveys* 15(3): 413–433.

Batistella, M., S. Robeson, and E.F. Moran. 2003. "Settlement Design, Forest Fragmentation and Landscape Change in Rondônia, Amazon." *Photogrammetric Engineering and Remote Sensing* 69(7): 805–812.

Behrman, J.R., and R. Oliver. 2000. "Basic Economic Models and Econometric Tools." In M. Grosh and P. Glewwe, eds., *Designing Household Survey Questionnaires for Developing Countries: Lessons From 15 Years of the Living Standards Measurement Survey.* Washington, D.C.: The World Bank.

Cattaneo, A. 2001. "A General Equilibrium Analysis of Technology, Migration, and Deforestation in the Brazilian Amazon." In A. Angelsen and D. Kaimowitz, eds., *Agricultural Technologies and Tropical Deforestation*. Oxfordshire, UK: CABI.

Caviglia, J.L. 1999. *Sustainable Agriculture in Brazil: Economic Development and Deforestation* (New Horizons in Environmental Economics series). Cheltenham, UK: Edward Elgar.

Caviglia-Harris, J.L. 2003. "Sustainable Agricultural Practices in Rondônia, Brazil: Do Local Farmer Organizations Impact Adoption Rates?" *Economic Development and Cultural Change* 52(1): 23–50.

____. 2004. "Household Production and Forest Clearing: The Role of Farming in the Development of the Amazon." *Environment and Development Economics* 9(2): 181–202.

Caviglia-Harris, J.L., and E.O. Sills. 2005. "Land Management and Income Diversification: Comparing Traditional and Colonist Populations in the Brazilian Amazon." *Agricultural Economics* 32(3): 221–237.

Coxhead, I., A. Rola, and K. Kim. 2001. "How Do National Markets and Price Policies Affect Land Use at the Forest Margin? Evidence from the Philippines." *Land Economics* 77(2): 250–267.

Deininger, K.W., and B. Minten. 1999. "Poverty, Policies and Deforestation: The Case of Mexico." *Economic Development and Cultural Change* 47(2): 313–344.

de Janvry, A., M. Fafchamps, and E. Sadoulet. 1991. "Peasant Household Behavior with Missing Markets: Some Paradoxes Explained." *Economic Journal* 101(409): 1400–1407.

Duraiappah, A. 1998. "Poverty and Environmental Degradation: A Review and Analysis of the Nexus." *World Development* 26(12): 2169–2179.

Faminow, M.D. 1998. *Cattle, Deforestation and Development in the Amazon: An Economic, Agronomic and Environmental Perspective.* New York: CABI International.

Fujisaka, S., W. Bell, N. Thomas, L. Hurtado, and E. Crawford. 1996. "Slash-and-Burn Agriculture, Conversion to Pasture and Deforestation in Two Brazilian Amazon Colonies." *Agriculture, Ecosystems, and the Environment* 59(1–2): 115–130.

Geoghegan, J., S.C. Villar, P. Klepeis, P.M. Mendoza, Y. Ogneva-Himmelberger, R.R. Chowdhury, B.L. Turner II, and C. Vance. 2001. "Modeling Tropical Deforestation in the Southern Yucatan Peninsular Region: Comparing Survey and Satellite Data." *Agriculture, Ecosystems, and Environment* 84(1): 25–46.

Humphries, S. 1998. "Milk Cows, Migrants and Land Markets: Unraveling the Complexities of Forest-to-Pasture Conversion in Northern Honduras." *Economic Development and Cultural Change* 47(1): 95–124.

IBGE (Instituto Brasileiro de Geografia e Estatistica). 2003a. "Pesquisa Pecuária Municipal (PPM)." Tabela 73—Efetivo dos rebanhos por tipo de rebanho. Available at http://www.ibge.gov.br (accessed August 2003).

____. 2003b. "Censo Demográfico 2000—Sinopse Preliminary." Tabela—População residente, em valores absolutos e relativos, total, em situação urbana e em situação urbana na sede municipal, área total e densidade demográfica, segundo as Unidades da Federação e Municípios. Available at http://www.ibge.gov.br (accessed August 2003).

Jones, D., V.H. Dale, J.J. Beauchamp, M.A. Pedlowski, and R.V. O'Neill. 1995. "Farming in Rondônia." *Resource and Energy Economics* 17(2): 155–188.

Kaimowitz, D., and A. Angelsen. 1998. *Economic Models of Tropical Deforestation: A Review.* Bogor Barat, Indonesia:

Center for International Forestry Research.

Lambin, E.F, M.D.A. Rounsevell, and H. Geist. 2002. "Are Agricultural Land-Use Models Able to Predict Change in Land-Use Intensity?" *Agricultural Ecosystems and the Environment* 82(1–3): 321–331.

Laurance, W.F., M.A. Cochrane, S. Bergen, P.M. Fearnside, P. Delamoncia, C. Barber, S. D'Angelo, and T. Fernandes. 2001. "The Future of the Brazilian Amazon." *Science* 291 (5503): 438–439.

Lele, U., V. Viana, A. Verissimo, S. Vosti, K. Perkins, and S.A. Husain. 2000. *Brazil—Forests in the Balance: Challenges of Conservation with Development* (Evaluation Country Case Study Series). Washington, D.C.: The World Bank.

Locker, W.M. 1993. "The Human Ecology of Cattle Raising in the Peruvian Amazon: The View from the Farm." *Human Organization* 52(1): 14–24.

Mahar, D. 1989. *Government Policies and Deforestation in Brazil's Amazon Region*. Washington, D.C.: The World Bank.

Mahar, D., and R. Schneider. 1994. "Incentives for Tropical Deforestation: Some Examples from Latin America." In K. Brown and D.W. Pearce, eds., *The Causes of Tropical Deforestation: The Economic and Statistical Analysis of Factors Giving Rise to the Loss of the Tropical Forests*. London: University College London Press.

Mattos, M.M., and C. Uhl. 1994. "Economic and Ecological Perspectives on Ranching in the Eastern Amazon." *World Development* 22 (2): 145–158.

McCracken, S., E.S. Brondizio, D. Nelson, E.F. Moran, A.D. Siqueria, 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(11): 1311–1320.

Melmed-Sanjak, J., and C.E. Santiago. 1996. "The Household and Employment in Small-Scale Enterprises." *World Development* 24(4): 749–764.

Mendelsohn, R. 1994. "Property Rights and Tropical Deforestation." *Oxford Economic Papers* 46(October): 750–756.

Mertens, B., R. Poccard-Chapuis, M.G. Piketty, A.E. Lacques, and A. Venturieri. 2002. "Crossing Spatial Analyses and Livestock Economics to Understand Deforestation Processes in the Brazilian Amazon: The Case of Sao Felix do Xingu in South Para." *Agricultural Economics* 27(3): 269–294.

Ministério do Meio Ambiente. 2005. "Proambiente." Available at http://www.mma.gov.br/index.cfm?id_estrutura=33 (accessed September 2005).

Muchagata, M., and K. Brown. 2000. "Colonist Farmers' Perceptions of Fertility and the Frontier Environment in Eastern Amazonia." *Agriculture and Human Values* 17(4): 371–384.

Murphy, L. 2001. "Colonist Farm Income Off-Farm Work Cattle and Deforestation in Ecuador's Northern Amazon." *Human Organization* 60(1): 67–79.

Myers, N. 1994. "Tropical Deforestation: Rates and Patterns." In K. Brown and D.W. Pearce, eds., *The Causes of Tropical Deforestation: The Economic and Statistical Analysis of Factors Giving Rise to The Loss of the Tropical Forests*. London: University College London Press.

Nelson, G.C., V. Harris, and S.W. Stone. 2001. "Deforestation, Land Use and Property Rights: Empirical Evidence from Darien, Panama." *Land Economics* 77(2): 187–205.

Pagiola, S., and S. Holden. 2001. "Farm Household Intensification: Decision and the Environment." In D.R. Lee and C.B. Barrett, eds., *Tradeoffs or Synergies? Agricultural Intensification, Economic Development and the Environment.* Oxfordshire, UK: CABI Publishing.

Panayotou, T., and P. Ashton. 1992. *Not by Timber Alone: Economics and Ecology for Sustaining Tropical Forests*. Washington, D.C.: Island Press.

Parks, P.J., and I.W. Hardie. 2003. *The Economics of Land Use* (International Library of Environmental Economics and Policy Series). Aldershot, UK: Ashgate.

Pattanayak, S.K., and E.O. Sills. 2001. "Do Tropical Forests Provide Natural Insurance? The Microeconomics of Non-Timber Forest Product Collection in the Brazilian Amazon." *Land Economics* 77(4): 595–612.

Pedlowski, M.A., and V.H. Dale. 1992. "Land Use Practices in Ouro Preto do Oeste, Rondônia, Brazil." Publication No. 3850, ORNL/TM 114770, Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN.

Perz, S.G. 2001. "Household Demographic Factors as Life Cycle Determinants of Land Use in the Amazon." *Population Research and Policy Review* 20(3): 159–186.

Pfaff, A. 1999. "What Drives Deforestation in the Brazilian Amazon?" *Journal of Environmental Economics and Management* 37(1): 26–43.

Pichón, F.J. 1997. "Colonist Land-Allocation Decisions Land-Use and Deforestation in the Ecuadorian Amazon Frontier." *Economic Development and Cultural Change* 44(4): 707–744.

Pichón, F., C. Marquette, L. Murphy, and R. Bilsborrow. 2001. "Land Use, Agricultural Technology, and Deforestation Among Settlers in the Ecuadorian Amazon." In A. Angelsen and D. Kaimowitz, eds., Agricultural Technologies and Tropical Deforestation. Oxfordshire, UK: CABI Publishing.

Porro, R. 2002. "Land Use, Cattle Ranching, and the Concentration of Landownership in Maranhão, Brazil." In C.H. Wood and R. Porro, eds., *Deforestation and Land Use in the Amazon.* Gainesville, FL: University Press of Florida.

Reardon, T.A., and S.A. Vosti. 1995. "Links Between Rural Poverty and Environment in Developing Countries: Asset Categories and 'Investment Poverty'." *World Development* 23(9): 1495–1506.

Shively, G.E. 2001. "Agricultural Change, Rural Labor Markets, and Forest Clearing: An Illustrative Case from the Philippines." *Land Economics* 77(2): 268–285.

Sills, E., S. Lele, T. Holmes, and S. Pattanayak. 2003. "Role of Nontimber Forest Products in the Rural Household Economy." In E. Sills and K. Abt, eds., *Forests in a Market Economy.* Dordrecht: Kluwer Academic Publishing Group.

Singh, I., L. Squire, and J. Strauss. 1986. "The Basic Model:

Theory, Empirical Results, and Policy Conclusions." In I. Singh, L. Squire, and J. Strauss, eds., *Agricultural Household Models: Extensions, Applications, and Policy*. Washington, D.C.: The World Bank.

Skole, D.L., W.H. Chomentowski, W.A. Salas, and A.D. Nobre. 1994. "Physical and Human Dimensions of Deforestation in Amazonia." *Bioscience* 44(5): 314–322.

Southgate, D. 1990. "The Causes of Land Degradation Along 'Spontaneously' Expanding Agricultural Frontiers in the Third World." *Land Economics* 66(1): 93–101.

Swinton, S., G. Escobar, and T. Reardon. 2003. "Poverty and Environment in Latin America: Concepts, Evidence and Policy Implications." *World Development* 31(11): 1865–1872.

Vosti, S.A., E.M. Braz, C.L. Carpentier, M.V.N. D'Oliveira, and J.E. Whitcover. 2003. "Rights to Forest Products, Deforestation and Smallholder Income: Evidence from the Western Brazilian Amazon." *World Development* 31(11): 1889–1901.

Vosti, S.A., C.L. Carpentier, J. Witcover, and J.F. Valentim. 2001. "Intensified Small-Scale Livestock Systems in the Western Brazilian Amazon." In A. Angelsen and D. Kaimowitz, eds., *Agricultural Technologies and Tropical Deforestation.* Oxfordshire, UK: CABI Publishing

Vosti, S., J. Witcover, C.L. Carpentier, S.J.M. de Oliviera, and J.C. dos Santos. 2001. "Intensifying Small-Scale Agriculture in the Western Brazilian Amazon: Issues, Implications and Implementation." In D.R. Lee and C.B. Barrett, eds., *Tradeoffs or Synergies? Agricultural Intensification, Economic Development and the Environment.* Oxfordshire, UK: CABI Publishing.

Walker, R., and A.K.O. Homma. 1996. "Land Use and Land Cover Dynamics in the Brazilian Amazon." *Ecological Economics* 18(1): 76–80.

Walker, R., E. Moran, and L. Anselin. 2000. "Deforestation and Cattle Ranching in the Brazilian Amazon: External Capital and Household Processes." *World Development* 28(4): 683–699.

Walker, R., S. Perz, M. Caldas, and L.G.T. Silva. 2002. "Land Use and Land Cover Change in Forest Frontiers: The Role of Household Life Cycles." *International Regional Science Review* 25(2): 169–199.

Watson, R.T., I.R. Noble, B. Bolin, N.H. Ravindranath, D.J. Verardo, and D.J. Dokken. 2000. "Land Use, Land-Use Change, and Forestry: A Special Report of the Intergovernmental Panel on Climate Change." Cambridge, UK: Cambridge University Press.

White, D., F. Holmann, S. Fujisaka, K. Reategui, and C. Lascano. 2001. "Will Intensifying Pasture Management in Latin America Protect Forests—Or Is it the Other Way Around?" In A. Angelsen and D. Kaimowitz, eds., *Agricultural Technologies and Tropical Deforestation*. Oxfordshire, UK: CABI Publishing.

Wood, C.H. Forthcoming. "Introdução Conceitual e Metodológica ao Estudo da Pecuria, Uso da Terra e Desmatamento no Brasil, Peru, e Ecuador." In C. Wood, ed., *Reflexões sobre a Pecuária e o Desmatamento na Amazônia.* Brasília: Editora UNB.